UNIVERSITY OF NOVI SAD
Technical Faculty "Mihajlo Pupin"
Zrenjanin, Republic of Serbia

PROCEEDINGS

of the XIV International Conference on

Industrial Engineering and Environmental Protection IIZS 2024

Zrenjanin, Serbia, October 3-4, 2024.

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PhD Milan Nikolić, Dean of Technical Faculty “Mihajlo Pupin”, Zrenjanin

Technical preparation:

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INTRODUCTION

Department of mechanical engineering and Department of environmental protection of Technical Faculty "Mihajlo Pupin", Zrenjanin, has organized the XIV International Conference Industrial Engineering and Environmental Protection – IIZS 2024.

The topics of scientific conference «IIZS 2024», cover the fields of Industrial Engineering and Environmental protection: Mechanical Engineering, Energetics and process technique, Designing and maintenance, Oil and gas engineering, Health and environmental protection, Environmental management, Occupational safety and Engineering management.

The main goals of the conference are: fostering innovation and expanding knowledge for engineers in industry and environmental protection; supporting researchers in presenting their current research results; establishing new contacts with premier national and international institutions and universities; popularizing the Faculty and its leadership role in our society and immediate environment, to attract a high-quality young individuals to study at our Faculty; cooperating with other organizations, public companies, and industry; initiating the collection of ideas for solving specific practical problems; interconnecting and establishing business contacts; introducing professional and business organizations to the results of scientific and technical research; and presenting scientific knowledge and exchanging experiences in industrial engineering.

We would like to express our gratitude to the partners of the IX International Conference "IIZS 2024" – Aurel Vlaicu University of Arad, Faculty of Engineering, Arad, Romania; University St. Kliment Ohridski, Technical Faculty, Bitola, Macedonia; University Politehnica Timisoara, Faculty of Engineering, Hunedoara, Romania; University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, B&H, Republic of Srpska; and University of Giresun, Faculty of Engineering, Giresun, Turkey – for their support in organizing this event. We are also grateful to all the authors who have contributed their papers to the scientific meeting "IIZS 2024".

We would like to extend our special thanks to the Ministry of Education, Science and Technological Development, Republic of Serbia, and the management of Technical Faculty “Mihajlo Pupin”, University of Novi Sad, for supporting the organization of the Conference "IIZS 2024".

The IIZS Conference has become a traditional annual meeting for researchers from around the world. We are open to and grateful for any useful suggestions that could help make the next, XV International Conference on Industrial Engineering and Environmental Protection even better, both organizationally and programmatically.

Chairman of the Organizing Committee
Asst. Prof. Jasna Tolmač, PhD

Zrenjanin, October 3-4, 2024.

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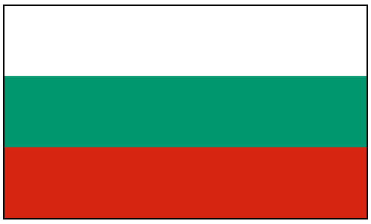

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Plenary Session

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EXAMINATION OF THE SAMPLE PROPERTIES MADE BY THE ADDITIVE TECHNOLOGY

Keynote paper

Mirko Karakašić[1]
[1]University of Slavonski Brod, Mechanical Engineering Faculty, Slavonski Brod, Croatia

Abstract: In the paper is presented an examination of the mechanical properties of the samples made of polymer materials Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). Specimens of the first and second series, were made with 100 % PLA filling and 100 % ABS filling. The third series of specimens was made with 100 % filling from PLA material and 20 % filling from ABS material. The specimens were made according to ISO 527 - 2: 1993 and tested in a tensile test. Samples with the highest proportion of PLA material had the highest average maximum force value compared to samples made of 100 % ABS filling. Samples made with different filling ratios of PLA and ABS materials gave worse results than expected. The reasons for the poor expected result should be sought in the additional optimization of printing parameters, as well as a larger number of specimens with varying proportions of PLA and ABS materials.
Key words: additive technology, 3D printing, tensile test

INTRODUCTION

Additive manufacturing (AM) is characterized by the creation of new products that are created, in contrast to classic machining where a new product is created by subtracting material, by adding material layer by layer [1]. The idea of printing objects using a 3D printers appeared in the seventies of the last century, while the first experiments began in the early eighties [2]. From then until today, new technologies and printers based on AM technology have been developed and improved.

There are several approaches according to which additive technologies (AT) are classified. Thus, according to [3, 4] ATs are grouped according to baseline technology, such as the use of laser technology, printer technology, extrusion technology, etc. According to [5] ATs are grouped according to the type of input raw material. The problem with this two - classification approach is that some processes get lumped together in what seems to be odd combinations. Example is Selective Laser Sintering (SLS) and Stereolithography (SLA) [1].

Today, one of the most widespread ATs is certainly Fused Deposition Modeling (FDM), which was developed and patented in 1989 by Steven Scott Crump with the company Stratasys [6]. This technology heats the initial material to its melting temperature through an extruder and a heating chamber. In this way, the incoming material changes from a solid state to a semi-melted state and is printed through a nozzle and placed layer by layer on the printer's work table, where the final product is obtained [2]. Due to the availability of affordable desktop printers and polymer materials with relatively satisfactory mechanical properties, FDM technology has today found its wide application in industry and hobbyist occupations.

One of the disadvantages of desktop printers is the insufficient accuracy of the product, especially if it concerns the production of products for the needs of industry. In the [7], the accuracy of the FDM desktop printer was analyzed in the production of multi-part printed products. There are frequent errors that manifest themselves through the dimensional accuracy of FDM technology, for example using ULTRAT and ABS filament materials [8]. Research in [9] analyzes the influence of printing parameters on increasing the accuracy of product dimensions. The influence of the quality of the material, i.e. its mechanical properties, is also extremely important. Papers [10, 11] deal with testing the mechanical properties of polymer materials used in FDM technology. In paper [11], the tensile mechanical properties of three different FDM 3D printed materials were investigated: PETG, ASA and PLA-Strongman.

[1]Corresponding author: mkarakasic@unisb.hr, ORCID: https://orcid.org/0000-0003-1498-2298

In order to improve the mechanical properties of products made of PLA and ABS materials, the mechanical properties of the mentioned materials were analyzed in this paper, by making samples according to the ISO 527 - 2: 1993 standard [12]. The samples were then tested to a tensile test. Three series of samples with a total of 30 samples were made. In the first series there are 10 samples with 100 % filling from PLA material, and in the second series there are 10 samples with 100 % filling from ABS material. The third series contains 10 samples made with 100 % filling from PLA material and 20 % filling from ABS material. When filling with ABS material, a mesh pattern filling was used. Therefore, the share of ABS material in the samples of the third series is 12 %, and the rest belongs to the share of PLA material.

MATERIAL AND METHODS

Structure of specimens

Examination of mechanical properties was performed on specimens made of polymer materials, Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). The specimens were grouped into 3 series, 10 specimens were made in each series (Table 1). The first and second series of specimens contain 100% ABS and 100 % PLA material proportion, and the filling percentage of the specimens is 100% PLA and 100% ABS (Table 1). In the third series of specimens, the filling percentage of ABS and PLA materials was varied with 20% ABS and 100% PLA. Depending on the percentage of filling, the proportion of ABS and PLA material is varied. Thus, the proportion of ABS material in the third series is 12 %, and the proportion of PLA material is 88 % (Table 1).

Table 1. *Structure of specimens*

No.	Material	Material proportion in the specimen (%)		Fill percentage (%)		Mass proportion (g)	
		PLA	ABS	PLA	ABS	PLA	ABS
1	PLA	100	0	100	0	1,9	0
2	ABS	0	100	0	100	0	1,6
3	PLA, ABS	88	12	100	20	1,05	0,14

Due to the simpler and faster printing of the specimens, the standard mesh filling was selected (Fig. 1).

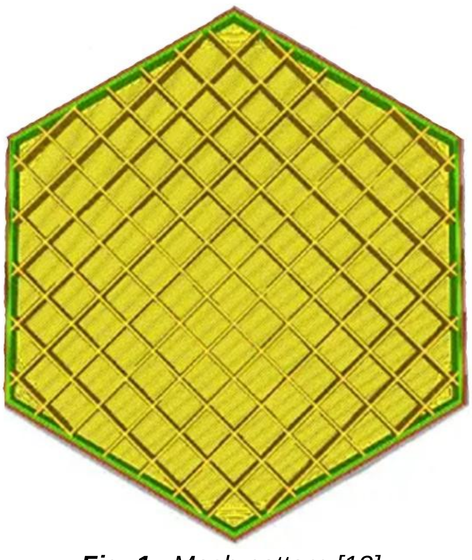

Fig. 1. *Mesh pattern [13]*

Modelling of test specimens, preparation for printing and printing on a 3D printer

The specimens were made according to the standard ISO 527 - 2: 1993 [12]. According to the mentioned standard, 1BA specimen type was selected. The dimensions of the modeled specimen in the CAD system for parametric modeling are shown in Fig. 2.

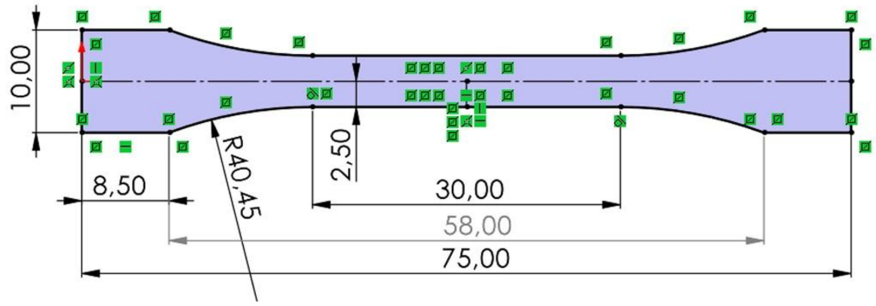

Fig. 2. *Test specimen*

Test specimens from series 1 are made of PLA material, and specimens from series 2 are made of ABS material. The samples were filled with 100 % polymer materials (Table 1). Therefore, the CAD models of the samples from series 1 and series 2 were modeled as a single body (Fig. 3). The height of the test specimens of series 1 and series 2 is 3,6 mm.

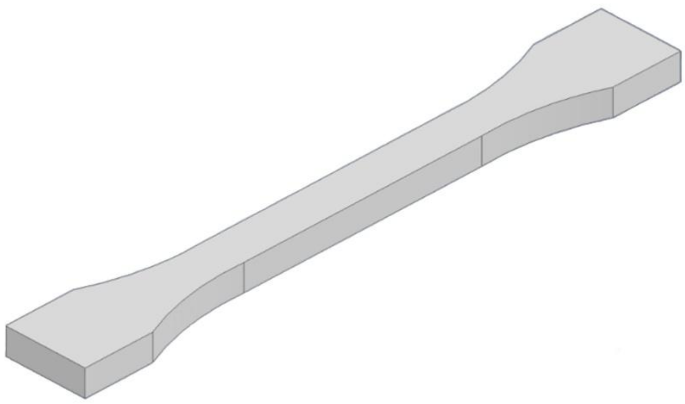

Fig. 3. *CAD model of test specimens from series 1 and series 2*

The samples from series 3 were modeled with 100 % PLA filling, but a mesh pattern was used for the ABS filling (Fig. 1). In series 3, the percentage of ABS filling was 20 %. The proportion of ABS material compared to the proportion of PLA material in series 3 is smaller and amounts to 12 % (Table 1). CAD models of specimens from series 3 are modeled from two bodies, i.e. as sandwich specimens (Fig. 4). The first body is filled with PLA material, and the second body is filled with ABS material. The first body consists of five lamellae (Fig. 4a). The second body consists of four lamellae (Fig. 4b). The thickness of each lamella of the first and second body is 0,4 mm, which corresponds to the thickness of each printing layer (Fig. 5).

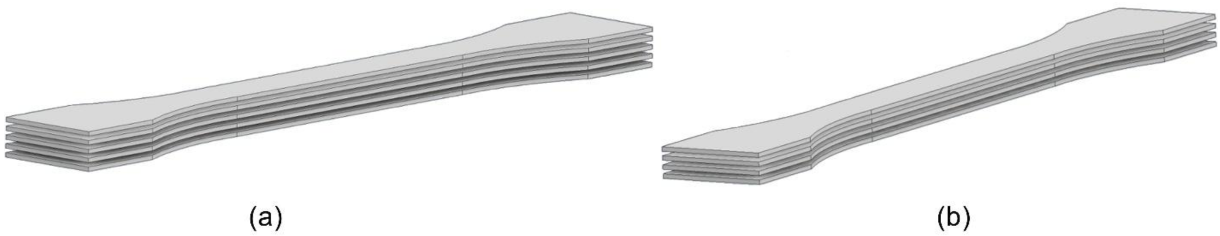

Fig. 4. *CAD models of test specimens from series 3*

Fig. 5. *Lamella thickness of PLA and ABS material of test specimen from series 3*

The preparation of the CAD models for printing was made in the UltiMaker Cura software [14]. The samples are placed in a horizontal position on the working surface of the printer. In order for the PLA and ABS materials from which the specimens were printed, to be better distinguished in the UltiMaker Cura program, PLA is designated as green, and ABS material is designated as blue (Fig. 6a). In the case of test samples from series 3, the lamellae of the two bodies were combined in the UltiMaker Cura program into one body. Lamellas prepared for printing with PLA material are marked in green, and lamellas prepared for printing with ABS material are marked in blue (Fig. 6b).

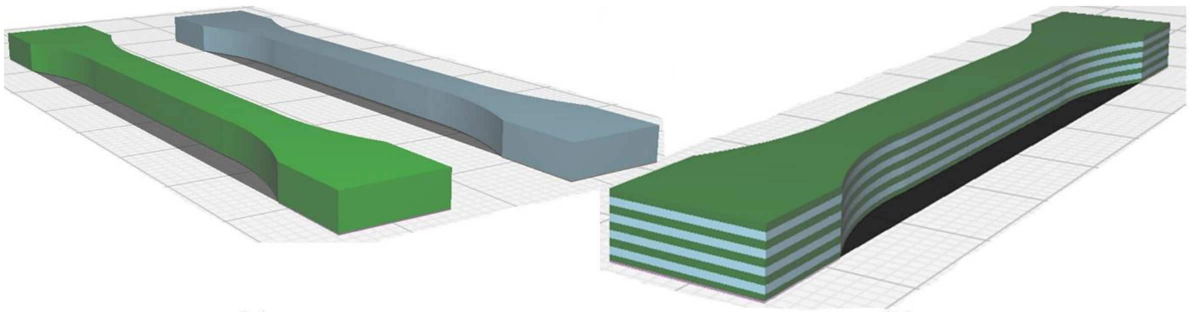

Fig. 6. *Assignment of polymeric materials to the lamellae of test specimens from series 3*

The test samples were printed at room temperature, using a Wanhao Duplicator D12, D12/230 printer. The basic technical characteristics of the Wanhao Duplicator D12, D12/230 printer are listed in [15].
For the purposes of printing the specimens, the following printing parameters were defined: the printing velocity is 60 mm/s, the printing temperature of both materials is 220 °C and the working surface is heated to 45 °C. A total of 3 specimen series were printed, and 10 specimens were printed in each series. The printout of the samples is shown in Fig. 7.

DETERMINATION OF SPECIMENS MECHANICAL PROPERTIES

The specimens were tested on a Shimadzu AGS-X tensile tester machine (Fig. 8). The samples were tested using a tensile test. The maximum tensile force of the tester machine is 10 kN. The specimens were continuously loaded until failure occurred. The test speed was 10 mm/min. During the measurement, the following quantities were analyzed: maximum force before cracking, maximum stress, maximum deformation, displacement and elongation. The results of the specimens mechanical properties testing are shown in Table 2 for specimens from series 1, in Table 3 for specimens from series 2 and in Table 4 for specimens from series 3. Diagrams of stress dependence on deformations for samples from series 1 are shown in Fig. 9, for sample from series 2 in Fig. 10 and for samples from series 3 in Fig. 11.

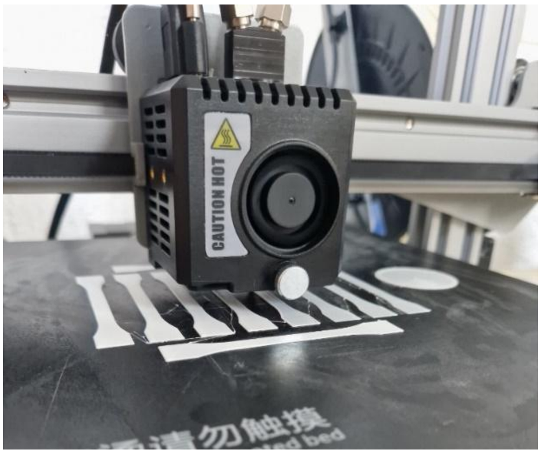

Fig. 7. *Printing of test samples on the Wanhao Duplicator D12, D12/230 printer*

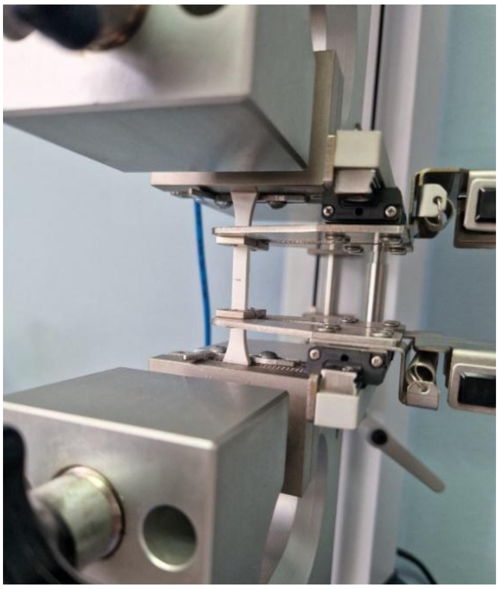

Fig. 8. *Specimen placed in the jaws of the tensile tester machine*

Table 2. *Specimen test results from series 1*

No.	Sample series	Maximum force (N)	Maximum stress (MPa)	Maximum deformation (%)	Displacement (mm)	Elongation (mm)
1.	1	674,156	33,7078	2,52000	1,56790	0,63000
2.	1	374,282	18,7141	1,26800	1,09453	0,31700
3.	1	749,620	37,4810	2,60400	1,73947	0,65100
4.	1	736,864	36,8432	2,96800	1,71940	0,74200
5.	1	673,997	33,6998	2,48000	1,59287	0,62000
6.	1	747,299	37,3650	2,52000	1,61443	0,63000
7.	1	795,911	39,7956	2,10800	1,58087	0,52700
8.	1	656,552	32,8276	2,50400	1,56283	0,62600
9.	1	570,895	28,5447	2,39600	1,34787	0,59900
10.	1	660,871	33,0435	2,64400	1,56447	0,66100
	Average value	664,045	33,2022	2,40120	1,53846	0,60030
	Maximum value	795,911	39,7956	2,96800	1,73947	0,74200
	Minimum value	374,282	21,0815	1,26800	1,09453	0,31700

Table 3. *Specimen test results from series 2*

No.	Sample series	Maximum force (N)	Maximum stress (MPa)	Maximum deformation (%)	Displacement (mm)	Elongation (mm)
1.	2	442,615	22,1307	7,28400	2,54630	1,82100
2.	2	520,832	26,0416	5,93600	2,20980	1,48400
3.	2	179,984	8,99919	6,62400	2,34247	1,65600
4.	2	569,139	28,4569	2,56400	2,29287	0,64100
5.	2	411,105	20,5553	3,18400	2,30947	0,79600
6.	2	471,300	23,5650	5,42400	2,69330	1,35600
7.	2	314,045	15,7023	9,10000	2,99613	2,27500
8.	2	83,4545	4,17272	5,13200	2,15897	1,28300
9.	2	349,385	17,4693	4,11200	2,30453	1,02800
10.	2	130,061	6,50303	16,1800	4,98977	4,04500
	Average value	347,192	17,3596	6,55400	2,68436	1,63850
	Maximum value	569,139	28,4569	16,1800	4,98977	4,04500
	Minimum value	83,4545	4,17272	2,56400	2,15897	0,64100

Table 4. *Specimen test results from series 3*

No.	Sample series	Maximum force (N)	Maximum stress (MPa)	Maximum deformation (%)	Displacement (mm)	Elongation (mm)
1.	3	185,491	9,27456	1,74800	1,23633	0,43700
2.	3	104,639	5,23194	2,56400	1,76937	0,64100
3.	3	143,668	7,18339	0,81600	0,92423	0,20400
4.	3	196,905	9,84526	2,80400	1,74620	0,70100
5.	3	97,5974	4,87987	0,65200	1,22620	0,16300
6.	3	195,429	9,77143	1,74800	1,27767	0,43700
7.	3	144,407	7,22035	2,21200	1,63117	0,55300
8.	3	151,264	7,56319	1,80400	1,62937	0,45100
9.	3	152,381	7,61906	1,55600	1,03113	0,38900
10.	3	25,4440	1,27220	1,85600	1,45890	0,46400
	Average value	139,723	6,98613	1,77600	1,39306	0,44400
	Maximum value	196,905	9,84526	2,80400	1,76937	0,70100
	Minimum value	25,4440	1,27220	0,65200	0,92423	0,16300

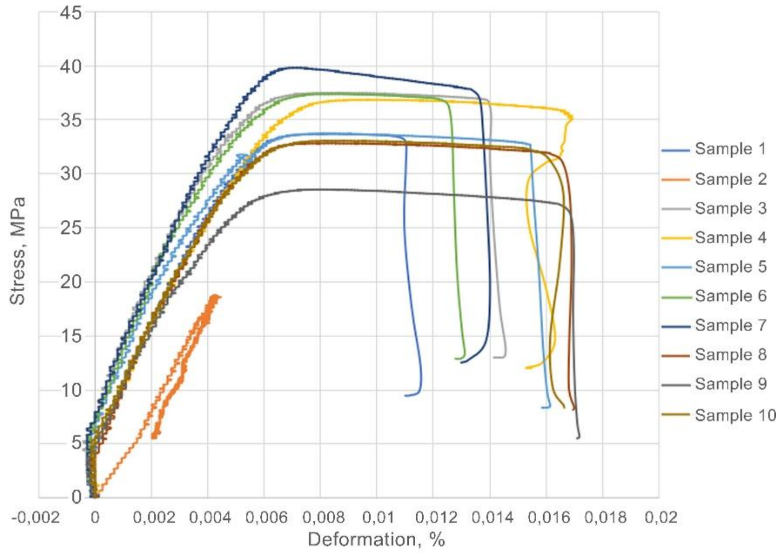

Fig. 9. *Diagram of stress dependence on deformations for samples from series 1*

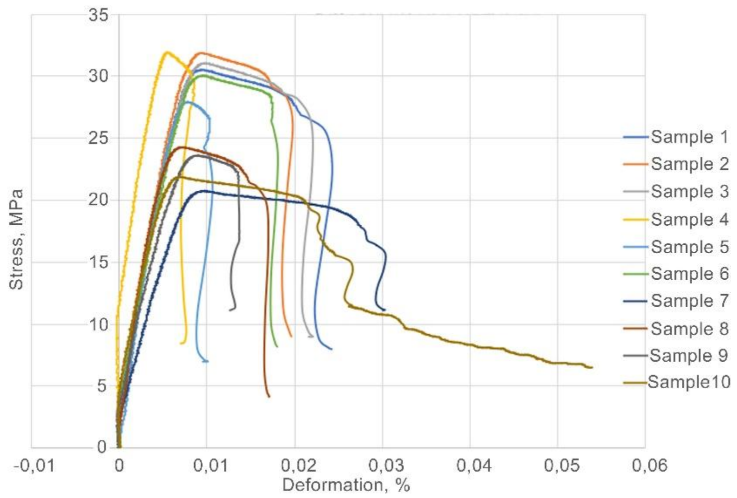

Fig. 10. *Diagram of stress dependence on deformations for samples from series 2*

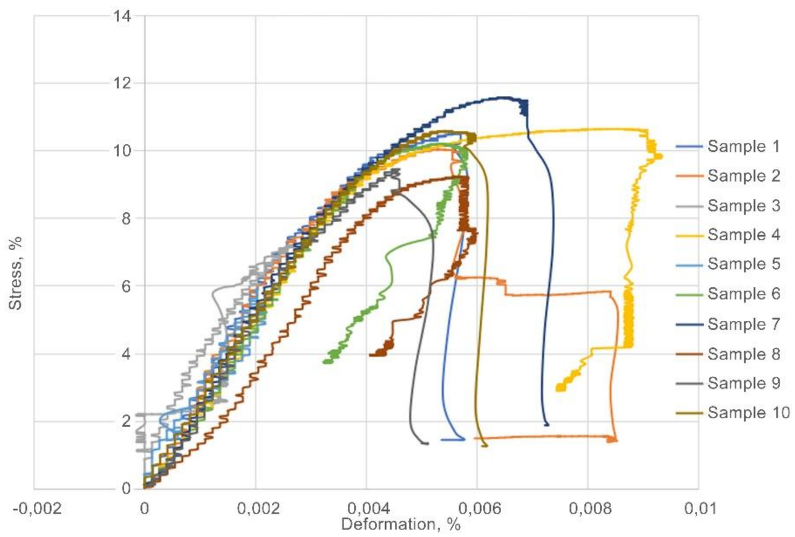

Fig. 11. *Diagram of stress dependence on deformations for samples from series 3*

The fracture locations of tested samples from series 1 are shown in Fig. 12, samples from series 2 in Fig. 13, and samples from series 3 in Fig. 14.

Fig. 12. *Fracture locations of samples from series 1*

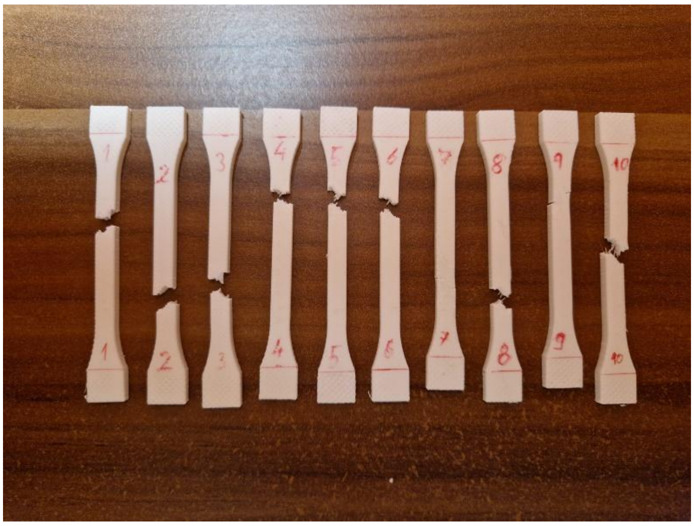

Fig. 13. *Fracture locations of samples from series 2*

Fig. 14. *Fracture locations of samples from series 3*

CONCLUSION

The mechanical properties of polymer materials play an important role in the application of FDM 3D printing technology. By assembling different polymer materials into a unique structure during the printing process, it should be possible to improve the mechanical properties of the printed models.

In this paper, the mechanical properties of the samples were tested, using a tensile test, on samples with 100 % filling from PLA material and samples made with 100 % filling from ABS material. The tested samples were also made with a filling of 100 % PLA material and a filling of 20 % ABS material. In the part of the samples where a proportion of 20 % of the ABS material filling was used, a standard mesh filling type of sample was used.
The samples with 100 % PLA material had the best mechanical properties. Test samples filled with 100 % ABS material showed worse mechanical properties compared to samples filled with PLA material. Samples that combined different proportions of PLA and ABS material showed the worst mechanical properties.
From the obtained results, it can be concluded that samples with different proportions of PLA and ABS materials should be further tested by additionally varying their mutual proportions. Then see if the obtained results will give better mechanical properties, considering the impact of printing parameters.
It would also be good to conduct similar research on metal samples using FDM 3D printing technology, varying the different filling structures and printing orientation.

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EVALUATING MICROPOLLUTANTS IN THE DANUBE RIVER: ASSESSING CONCENTRATIONS AND ENVIRONMENTAL IMPACT

Keynote paper

Marija Perović[1]
[1]Jaroslav Černi Water Institute, Belgrade, Serbia

Abstract: Freshwater pollution poses a significant global challenge, largely driven by the continuous release of synthetic organic substances into the environment. This persistent contamination underscores the urgent need for a thorough understanding of the chemical status of Earth's surface waters. Even trace amounts (ng/L; µg/L) of these substances, known as micropollutants, can accumulate in aquatic ecosystems, posing risks to both biodiversity and human health. This research examines key water quality parameters of the Danube River in Serbia, focusing on the prevalence of micropollutants within a river basin that spans 92% of the country's land area and 10% of the entire Danube basin. It also provides an overview of existing regulatory frameworks that set limit values for these contaminants. By reviewing official data on hazardous substances and other pollutants concentration, the study provides valuable insights into water quality challenges and offers guidance for future management strategies aimed at addressing micropollutants.
Key words: Danube, micropollutants, hazardous substances

INTRODUCTION

The entire life cycle of a product from production and processing to use and disposal can lead to the release of hazardous substances. These include household and industrial chemicals, pollutants from transportation (such as hydrocarbons and heavy metals), as well as pesticides widely used in agriculture and along roads and railways [1]. Micropollutants (MPs) are found in trace amounts across various environmental compartments and organisms. They include a wide range of contaminants, some of which are classified as priority substances (PSs) under environmental regulations due to their persistence, toxicity, and potential to bioaccumulate, posing significant risks to human health and the environment. Key groups of MPs include pharmaceuticals, personal care products, pesticides, trace metals, persistent organic pollutants, micro- and nanoplastics, artificial sweeteners, and other compounds that pose potential threats to ecological systems [2]. Urban wastewater treatment plants are significant point sources of hazardous substances, as conventional treatment methods, such as coagulation, sedimentation, sand filtration, chlorination, biological degradation, and UV irradiation, often fail to remove MPs, including Per- and Polyfluoroalkyl Substances (PFAS) [3,4]. Agricultural activities are a major source of MPs, primarily due to the extensive use of pesticides, which contaminate surface waters through runoff, leaching, and erosion, and reach groundwater through permeable soils and water percolation. The most studied PSs worldwide, are pesticides, including atrazine, simazine, chlorpyrifos, terbutryn, diuron, and alachlor [5]. Although soil can absorb and retain metals, emissions from agriculture, such as cadmium from phosphate fertilizers, zinc from animal feed, and copper used in feed, treatments, and disinfection, remain significant environmental concerns. PFAS comprise a broad range of over 4,700 synthetic compounds, attracting increasing attention due to their ubiquity in both the environment and human populations worldwide. Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonate (PFOS), are among the most widely used, frequently detected, and extensively studied PFAS in the environment [6]. They are used in cosmetics, textiles for stain and water repellence, adhesives, fire-fighting foams, paper products. Additionally, PFAS are found in semiconductors, lubricants, coating additives, cookware and food packaging, surfactants, agricultural applications, pesticides, and as erosion inhibitors in aviation [7-9]. Their presence in surface and groundwater highlights the connection between human activity and the hydrological cycle [10]. Although many hazardous substances have been banned or phased out, surface and groundwater contamination persist due to their past use and ongoing

[1] Corresponding author, marija.perovic@jcerni.rs, ORCID: https://orcid.org/0000-0003-2045-001X

illegal applications. This is evidenced by the continued detection of notable concentrations of these substances and their metabolites in the environment [11,12].

Legislative Framework for Pollutants and Hazardous Substances in water

Since its inception in 2000, the Water Framework Directive (WFD) has been the cornerstone of water protection in Europe, alongside the Environmental Quality Standards Directive (EQSD) and the Groundwater Directive. The WFD aims to protect inland surface waters, transitional waters, coastal waters, and groundwater by reducing discharges and emissions of priority substances (PS) and phasing out or minimizing those of priority hazardous substances (PHSs) through targeted regulations and benchmarks. The WFD identifies surface water pollutants of significant EU-wide concern as PS, including PHS listed in Annex X, with environmental standards set by the EQSD. Article 2 of the WFD defines hazardous substances as those that are toxic, persistent, and prone to bioaccumulation, or that raise similar concerns. Article 4 outlines the environmental objectives, requiring Member States to implement measures to reduce pollution from PS and to phase out emissions, discharges, and losses of PHS. The WFD requires EU Member States to closely monitor potential pollutants through a Watch List (WL) for surface waters [13]. The monitoring of PSs and contaminants of emerging concern is governed by Directive 2013/39/EU and the updated WL under Decision (EU) 2022/1307/EU. The WFD requires that for international river basins extending beyond EU borders, a single river basin management plan should be developed. Under the WFD, pollution from hazardous substances is a critical water quality issue that must be addressed in the Danube River Basin (DRB). This obligation also extends to non-EU Member States, which have committed to achieving similar objectives under the framework of the International Commission for the Protection of the Danube River (ICPDR). In 2000, ICPDR countries, including non-EU states, agreed to implement this directive across the entire Danube basin. The Federal Republic of Yugoslavia ratified the Convention on the Protection and Sustainable Use of the Danube River in 2003 and enacted the corresponding law. In the same year, Serbia, as part of the State Union of Serbia and Montenegro, joined the ICPDR.

In the Republic of Serbia within the Water Law ("Official Gazette of the Republic of Serbia", No. 30/2010, 93/2012, 101/2016, 95/2018, and 95/2018 - amended law) the Priority substances are those identified as posing significant risks to the aquatic environment or to other areas through it, as determined by specific regulations. This category includes "priority hazardous substances," which are selected priority substances that present an increased risk to human health or the environment. In Serbia the list of priority and priority hazardous substances and its Average annual concentrations (AAC) and Maximum allowable concentrations (MAC) are defined in Regulation on limit values of priority and priority hazardous substances that pollute the surface waters and deadlines for their achievement ("Official Gazette of the Republic of Serbia", No. 24/2014). This list is in accordance with Annex X of the WFD. In addition to the aforementioned, the Regulation on Limit Values of Pollutants in Surface and Groundwater and Sediment, and Deadlines for Their Achievement ("Official Gazette of the RS", No. 50/2012) defines the limit values of pollutants in surface and groundwater, as well as in sediment, along with the deadlines for achieving these values.

Around 90% of Serbia's renewable water resources come from outside its borders, emphasizing the crucial need for international cooperation [14]. Serbia, spanning 88,499 km^2, is predominantly within the Danube Basin, which covers 92% of its land and 10% of the total basin area [14]. Municipal sources are the primary contributors to pollution in Serbia, while emissions from industry are considered the primary source of hazardous substances in Serbia [14,15]. Agricultural pollution mainly stems from livestock farming, with minor contributions from mineral fertilizers used on non-irrigated lands [14].

This research aims to assess the presence and concentration of micropollutants, in the Serbian section of the Danube River using official data from the National Surface Water Quality Monitoring Program of the Serbian Environmental Protection Agency (SEPA). The scope includes identifying which priority substances and pollutants are detectable in the Danube section in Serbia.

MATERIAL AND METHODS

In this study, selected water quality data for the Danube River along its course through Serbia were analyzed, sourced from the National Surface Water Quality Monitoring Program of the Serbian Environmental Protection Agency (SEPA). From the SEPAs results of the examination of physical-chemical, chemical, and microbiological parameters for assessing the status of surface water the selected physical-chemical and chemical parameters of surface water, priority and priority hazardous substances and other pollutants were analyzed. Basic descriptive statistics for selected water quality parameters over a seven-year period (2016–2022), with monthly sampling frequency, was done. A total of 576 samples collected from Bezdan, Bogojevo, Novi Sad, Zemun, Smederevo, Banatska Palanka, and Tekija were all analyzed (Fig. 1).

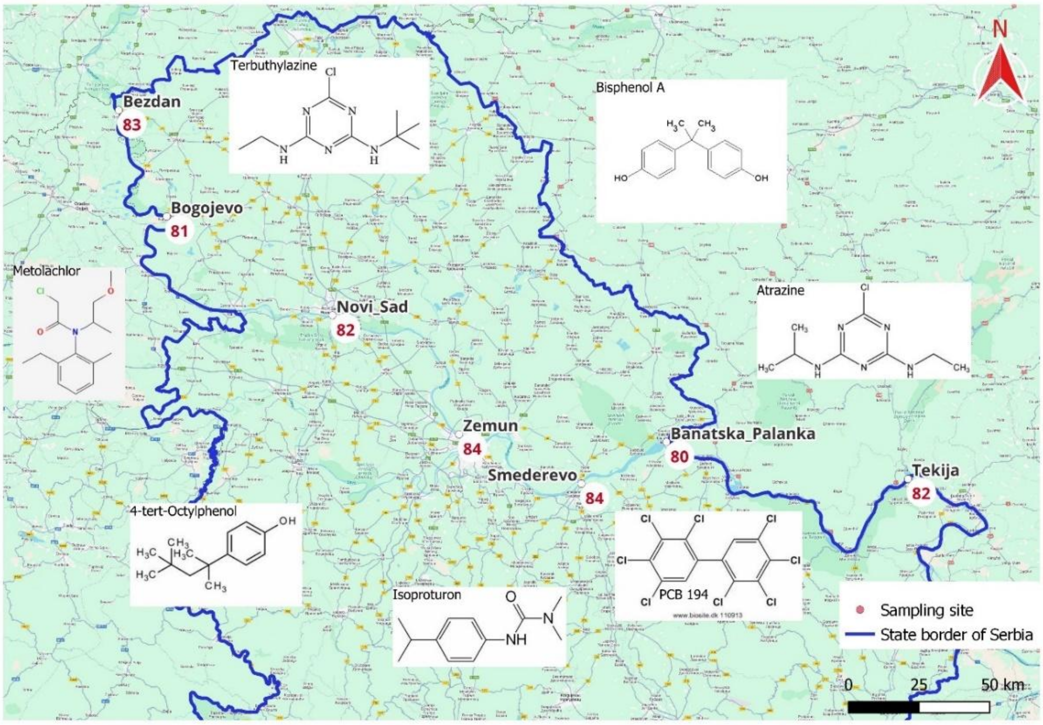

Fig. 1. *Sampling Locations with Marked Number of Samples*

RESULTS AND DISCUSSION

Table 1 presents the basic descriptive statistics for key water quality parameters specific to the Serbian section of the Danube River, providing an overall summary for all sampling locations combined. The range of electrical conductivity of water is from 291.0 µS/cm to 600.0 µS/cm, while median values (50th percentile) for NH_4^+, NO_3^- and Cl are 0.08 mgN/l, 1.01 mgN/l and 19.95 mg/respectively. The range of quantified boron is moderate, from below limit of quantification <10 µg/l to 253.5 µg/l. Seventy-five percent of the analyzed samples exhibit a chemical oxygen demand of up to 4.40 mg/l, indicating a moderate organic load in analysed water.

Although the measured range of total organic carbon (TOC) is quite broad, 75% of the samples show quantified concentrations of up to 4.80 mg/l. Additionally, the Biochemical Oxygen Demand (BPK5), which reflects the oxygen consumption by bacteria during the decomposition of organic matter in the water, averages 2.12 mg/l, with values ranging from a minimum of 0.60 mg/l to a maximum of 5.60 mg/l. This indicates that organic pollution is present but remains at manageable levels.

Table 2 provides basic descriptive statistics for selected metals, including cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn), copper (Cu), chromium (Cr), and metalloid arsenic (As). The largest concentration ranges are observed for Cu, Zn, and Ni. Total Cd was found at a mean concentration of 0.05 µg/l, with values ranging from less than 0.02 µg/l to 1.00 µg/l, indicating minimal contamination in most samples. Total Ni exhibited a mean concentration of 7.52 µg/l, with a notable range from less than 0.5 µg/l to 412.20 µg/l, suggesting sporadic pollution sources. Total Pb had a mean concentration of 1.39 µg/l, ranging from less than 0.5 µg/l to 30.10 µg/l, indicating generally low levels but highlighting potential localized pollution. Total Cr concentrations ranged from less than 0.5 µg/l to 58.00 µg/l, suggesting predominantly low levels; Zn and Cu exhibited significant concentration ranges, from less than 10 µg/l to 671.70 µg/l and from less than 1 µg/l to 834.30 µg/l, respectively, indicating influences from anthropogenic sources. As (total) was found with a mean concentration of 5.99 µg/l, ranging from 0.50 µg/l to 361.10 µg/l. The higher concentrations of arsenic raise health concerns and underscore the need for more detailed ongoing surveillance. While most metals are present at low concentrations, the significant variability, particularly in nickel, zinc, copper, and arsenic levels, emphasizes the necessity for continuous monitoring and more detailed data assessments to identify potential pollution sources and protect water quality.

Table 3 lists priority and priority hazardous substances detected above the limit of quantification (LOQ) in over 30% of samples, along with their applicable limit values as defined in the Regulation on Limit Values of Priority and Priority Hazardous Substances Polluting Surface Waters and Deadlines for Their Achievement ('Official Gazette of RS,' No. 24/2014). It should be noted that not all substances have prescribed limit values. Among these, the compounds identified include industrial chemicals such as organic derivatives of phenol (para-tert-octylphenol), PCB 194, and bisphenol A and pesticides (atrazine, terbuthylazine, metolachlor, and isoproturon) (Table 3). The same Regulation prescribes an AAC of $6.5x10^{-4}$ µg/L and a MAC of 36 µg/L for PFOS and its derivatives, but these compounds are not part of the regular monitoring in Serbia. Table 4 presents priority substances, metals cadmium (Cd), lead (Pb), and nickel (Ni) along with their limit values as regulated by the Regulation on Limit Values of Priority and Hazardous Substances Polluting Surface Waters and Deadlines for Their Achievement ("Official Gazette of RS," No. 24/2014). Table 5 outlines the prescribed limit values for polluting substances in surface waters, specifically chromium (Cr), copper (Cu), zinc (Zn), and metalloid arsenic (As). These limit values are established by the Regulation on limit values of pollutants in surface and groundwater and sediment and on deadlines for their achievement ("Official Gazette of the RS," No. 50/2012). Priority substances quantified in more than 30% of the measurements above the LOQ, which are part of both operational and surveillance monitoring (excluding metals), were selected for presentation and further discussion.

Organic derivatives of phenol, like Para-tert-Octylphenol (OP), are hazardous endocrine-disrupting compounds with significant environmental and health impacts. Primarily used in phenolic resin and lacquer production, OP exhibits weak estrogen-like activity and has been found in various environmental compartments, including water, phytoplankton, zooplankton, mussels, and fish tissues. Its concentration, influenced by diet and habitat, suggests bioaccumulation potential [16]. OP disrupts hormone regulation, affecting reproduction, growth, and behavior, and can mimic the sex hormone 17β-estradiol, leading to feminization in aquatic life and developmental issues in humans, including cancers of the sex organs [16]. The presence of alkylphenolic compounds along the Danube River highlights widespread wastewater contamination with varying impacts [17].

PCB 194, a synthetic organic compound classified as 2,2',3,3',4,4',5,5'-octachlorobiphenyl, belongs to the polychlorinated biphenyl (PCB) group. Despite being banned decades ago, PCBs persist in the environment due to their bioaccumulative properties and ongoing releases from historical industrial activities, spills, and thermal processes [18]. They can exist in vapor or particulate form and disrupt hormonal, reproductive, immune, and endocrine functions, leading to severe health issues, including cancer, birth defects, and cognitive impairments. Bisphenol A (BPA; 4,4′-dihydroxy-2,2-diphenylpropane) is a widely used chemical in the production of polycarbonate plastics, epoxy resins, and as a non-polymer additive in PVC. It can be found in products like shatterproof windows, eyewear, water bottles, and epoxy-coated metal food cans. While BPA is rapidly metabolized and excreted in urine, biomonitoring studies have detected unconjugated BPA, indicating ongoing internal exposure risks [19]. Human exposure primarily occurs through the consumption of food and bottled mineral water.

Atrazine, a chlorinated herbicide from the triazine class, is mainly used to control broadleaf weeds in crops like maize, soybean, and sugarcane, as well as in turf areas. As an endocrine disruptor, it can cause reproductive issues, behavioral changes, and impaired fetal growth, and is linked to birth defects and various cancers, including non-Hodgkin lymphoma and breast cancer [20]. In aquatic environments, atrazine degrades into metabolites such as deethylatrazine (DEA), deisopropylatrazine (DIA), and deethyl-deisopropylatrazine (DEIA). Given atrazine's half-life in water of 105 to over 200 days, its detection in the Danube suggests ongoing use, despite the ban on atrazine-containing herbicides in Serbia since 2007. This ban was implemented by the Plant Protection Administration of the Ministry of Agriculture, Forestry, and Water Management [21].

Terbuthylazine (TBA) has largely replaced atrazine in several EU countries and is now a widely used pesticide and one of the most frequently detected in continental and coastal waters with its metabolite desethylterbuthylazine (DET) being prevalent in EU aquifers [22]. DET is more water-soluble and binds less to organic matter, increasing the risk of groundwater contamination. Both TBA and DET are emerging chemicals of concern due to their persistence and toxicity to aquatic life, as well as their significant endocrine-disrupting effects on wildlife and humans. Metolachlor, a selective herbicide for annual grass weeds and certain broadleaf species, raises concerns due to evidence of bioaccumulation in edible fish and negative impacts on growth and development. Isoproturon, another selective herbicide, is used for controlling broadleaf weeds and grasses in crops. It has low acute toxicity, but related chemicals like monolinuron and linuron can cause developmental malformations. Data on environmental levels of isoproturon are limited, but exposure to the general population appears minimal, with health effects mainly studied in occupational settings.

The selected parameters represent micropollutants, detected above the limit of quantification in more than 30% of cases, providing insights into which substances are present in the Danube River. It is important to emphasize that these substances have not been analyzed in terms of whether the quantified average annual concentration or maximum concentrations exceed the prescribed limit values, as the presented data processing (overall summary for all sampling locations combined) does not correspond to that type of interpretation. The study aimed to identify which substances are present above the quantification limit, indicating their actual occurrence.

Table 1. *Basic Descriptive Statistics of selected parameters for the section of the Danube River flowing through Serbia (based on SEPA data, 2016–2022)*

		Flow	Susp.*	pH	Ec**	NH_4	NO_3	Cl	B	COD $KMnO_4$	BPK_5	TOC
Unit		m^3/s	mg/l	/	µS/cm	mgN/l	mgN/l	mg/l	µg/l	mg/l	mg/l	mg/l
No of samples		342	570	568	576	576	576	576	372	575	571	500
Mean		2932	20.4	8.09	402.9	0.10	1.16	20.60	31.00	3.90	2.12	4.11
Std. dev.		1371	20.3	0.21	54.4	0.07	0.55	5.16	23.17	1.07	0.75	1.14
Min.		1020	<4	7.08	291.0	<0.02	0.14	5.40	<10	1.29	0.60	1.30
Max.		9610	178.0	8.80	600.0	0.35	3.24	41.98	253.50	12.06	5.60	11.00
Percentile	25	1975	7.0	7.96	359.0	0.04	0.80	16.80	19.43	3.20	1.60	3.40
	50	2700	15.0	8.09	393.5	0.08	1.01	19.95	26.40	3.70	2.10	4.00
	75	3420	27.0	8.20	442.0	0.14	1.40	23.38	37.08	4.40	2.50	4.80

Susp. - suspended solids*
*Ec** - electrical conductivity*

Table 2 *Basic Descriptive Statistics of selected metals (and metalloid As) for the section of the Danube River flowing through Serbia (based on SEPA data,2016–2022)*

		Cd	Cd diss	Ni	Ni diss	Pb	Pb diss	Cr	Cr diss	Zn	Zn diss	Cu	Cu diss	As	As diss
Unit		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
No of samples		399	438	399	438	399	440	398	436	398	407	399	437	398	433
Mean		0.05	0.03	7.52	3.63	1.39	0.43	1.76	0.74	52.69	30.97	15.22	7.63	5.99	3.02
St.dev.		0.08	0.09	23.23	5.87	1.86	0.65	3.93	1.95	79.27	54.10	46.43	14.78	32.27	17.44
Min.		<0.02	<0.02	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<10	<10	<1	<1	0.50	<0.5
Max.		1.00	1.76	412.20	74.40	30.10	9.30	58.00	36.80	671.70	423.00	834.30	148.60	361.10	287.80
Percentile	25	<0.02	<0.02	1.90	1.20	0.60	<0.5	0.70	<0.5	15.40	<10	4.70	2.30	1.50	1.20
	50	0.03	0.02	2.90	1.90	1.10	<0.5	1.00	<0.5	26.10	14.00	6.80	3.80	1.80	1.50
	75	0.06	0.03	6.45	3.60	1.60	<0.5	1.58	0.70	51.15	26.25	12.35	6.70	2.30	2.00

Diss – dissolved

Table 3 *Statistical metrics for analysing priority and priority hazardous substances and other pollutants quantified above quantification limit (LOQ) in more than 30% of samples in Danube River in Serbia (based on SEPA data,2016–2022)*

Parameter	**Unit**	**No of samples**	**No of measurements above LOQ**	**Percentage of Measurements Above LOQ of Total Measurements**	**Maximum quantified concentration**	**Priority Hazardous Substances (PHS)***	**Prescribed AAC (µg/l) ***	**Prescribed MAC (µg/l) ***
Para-tert-Octylphenol	µg/l	434	139	32	0.162	No	0.1	/
Atrazine	µg/l	434	220	51	0.161	No	0.6	2
Desethylterbuthylazine	µg/l	434	252	58	0.045	Not Covered by Regulation*	Not Covered by Regulation*	Not Covered by Regulation*
Terbuthylazine	µg/l	434	360	83	1.672	Not Covered by Regulation*	Not Covered by Regulation*	Not Covered by Regulation*
Metolachlor	µg/l	432	354	82	0.71	Not Covered by Regulation*	Not Covered by Regulation*	Not Covered by Regulation*
Isoproturon	µg/l	434	223	51	0.02	No	0.3	1
PCB-194	µg/l	98	89	91	117.6	Not Covered by Regulation*	Not Covered by Regulation*	Not Covered by Regulation*
Bisphenol A	µg/l	297	117	39	0.165	Not Covered by Regulation*	Not Covered by Regulation*	Not Covered by Regulation*

** Regulation on limit values of priority and priority hazardous substances that pollute the surface waters and deadlines for their achievement ("Official Gazette of RS," No. 24/2014)*

Table 4 *Prescribed limit values According to Regulation on limit values of priority and priority hazardous substances that pollute the surface waters and deadlines for their achievement "Official Gazette of RS," No. 24/2014 ("Official Gazette of RS," No. 24/2014)*

Parameter	Unit	Priority Hazardous Substances (PHS)	Prescribed Average Annual Concentration (AAC) (µg/l)	Prescribed Maximum Allowable Concentration (MAC) (µg/l)
Cd and its compounds (depending on water hardness* class)	µg/l	Yes	<0,08 (class 1) 0,08 (class 2) 0,09 (class 3) 0,15 (class 4) 0,25 (class 5)	<0,45 (class 1) 0,45 (class 2) 0,6 (class 3) 0,9 (class 4) 1,5 (class 5)
Pb and its compounds**	µg/l	No	1.2	14
Ni and its compounds	µg/l	No	4	34

**For cadmium and its compounds, the limit value varies depending on the hardness of water, which is categorized into five classes (Class 1: <40 mg $CaCO_3$/L, Class 2: 40 to <50 mg $CaCO_3$/L, Class 3: 50 to <100 mg $CaCO_3$/L, Class 4: 100 to <200 mg $CaCO_3$/L, and Class 5: ≥200 mg $CaCO_3$/L)*

*** These values for the environmental quality standard indicate the concentrations of substances that are bioavailable.*

Table 5 *Prescribed limit values of polluting substances in surface waters according to Regulation on limit values of pollutants in surface and groundwater and sediment and on deadlines for their achievement ("Official Gazette of the RS," No. 50/2012)*

Parameter	**Unit**	**Limit Values [1]**				
		Class I[2]	Class II[3]	Class IIII[4]	Class IV[5]	Class V[6]
Cr (total)	µg/l	25 (or NL)	50	100	250	>250
Cu	µg/l	5 (T=10) 22 (T=50) 40 (T=100) 112 (T=300)	5 (T=10) 22 (T=50) 40 (T=100) 112 (T=300)	500	1000	>1000
Zn	µg/l	30 (T=10) 200 (T=50) 300 (T=100) 500 (T=500)	300 (T=10) 700 (T=50) 1000 (T=100) 2000 (T=500)	2000	5000	>5000
As	µg/l	<5 or NL	10	50	100	>100

(1) Unless otherwise specified, the values are expressed as total concentrations in the sampled specimen

(2) The description of this class corresponds to an excellent ecological status according to the classification provided in the regulation that stipulates the parameters for ecological and chemical status for surface waters. Surface waters belonging to this class ensure, based on the limit values of quality elements, conditions for the functioning of ecosystems, the life and protection of fish (salmonids and cyprinids), and can be used for the following purposes: drinking water supply with prior treatment through filtration and disinfection, bathing and recreation, irrigation, and industrial use (process and cooling water).

(3) The description of this class corresponds to a good ecological status according to the classification provided in the regulation that stipulates the parameters for ecological and chemical status for surface waters. Surface waters belonging to this class ensure, based on the limit values of quality elements, conditions for the functioning of ecosystems, the life and protection of fish (cyprinids), and can be used for the same purposes and under the same conditions as surface waters belonging to Class I.

(4) The description of this class corresponds to a moderate ecological status according to the classification provided in the regulation that stipulates the parameters for ecological and chemical status for surface waters. Surface waters belonging to this class ensure, based on the limit values of quality elements, conditions for the life and protection of cyprinids and can be used for the following purposes: drinking water supply with prior treatment through coagulation, flocculation, filtration, and disinfection, bathing and recreation, irrigation, and industrial use (process and cooling water).

(5) The description of this class corresponds to a poor ecological status according to the classification provided in the regulation that stipulates the parameters for ecological and chemical status for surface waters. Surface waters belonging to this class can be used for the following purposes based on the limit values of quality elements: drinking water supply with the application of a combination of previously mentioned treatments and enhanced treatment methods, irrigation, and industrial use (process and cooling water).

(6) The description of this class corresponds to a bad ecological status according to the classification provided in the regulation that stipulates the parameters for ecological and chemical status for surface waters. Surface waters belonging to this class cannot be used for any purpose.

T - water hardness (mg/L CaCO3)

NL – natural level (According to the Regulation on the limit values of polluting substances in surface and groundwater and sediment and deadlines for their achievement ("Official Gazette of the Republic of Serbia," No. 50/2012), is the concentration of a polluting substance that corresponds to a state of groundwater bodies whose undisturbed conditions are not subject to changes resulting from anthropogenic effects, or where such changes are very minor).

CONCLUSION

Potential pollution sources for aquatic environments include industrial activities, mines, tailings, waste disposal sites, landfills, wastewater and agricultural pesticide use. Despite the recognized significance of these pollutants in water management issues within Serbia, systematic data collection regarding these sources and their contributions to water quality is lacking [15]. Thus, it is crucial to intensify research efforts and improve monitoring practices to accurately assess the pressures exerted by these sources on water bodies. This study analyzed the quality of 576 water samples collected from various locations along the Danube River in Serbia, including Bezdan, Bogojevo, Novi Sad, Zemun, Smederevo, Banatska Palanka, and Tekija, in the period 2016-2022 (overall summary for all sampling locations combined). While metals such as Cd, Pb, Ni, Zn, Cu, Cr, and metalloid As are part of Serbia's official monitoring, the emphasis was placed on the frequency of detection of additional pollutants and hazardous substances. Results revealed that industrial chemicals, including para-tert-octylphenol, PCB 194, and bisphenol A, along with pesticides such as atrazine, terbuthylazine, metolachlor, and isoproturon, were detected above the limit of quantification in over 30% of the samples analyzed. Currently, there is insufficient data on pesticide usage and a lack of a comprehensive database detailing the quantities of chemicals applied in agriculture [15]. To better understand trends in pollutant concentrations and potential sources, a detailed analysis based on sampling locations is necessary, along with a spatial comparison of pollutant distributions across Serbia. The investigation of correlations between seasonal water level fluctuations and pollution concentration parameters is recommended to further elucidate the dynamics of these pollutants and their sources in the Danube River Basin.

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FREE VIBRATION ANALYSYS OF A BEAM RESTING ON WINKLER ELASTIC FOUNDATION THROUGH THE SUMUDU TRANSFORM METHOD

Research paper

Svetlana Lilkova-Markova[1*], Dimitar Lolov[2]
[1,2]University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria

Abstract: In the article are determined the free vibration characteristics of a beam lying on a Winkler elastic foundation. This well-known problem is solved by employing the Sumudu transform method to convert the fourth-order partial differential equation for the beam's natural vibrations into an algebraic equation. The solution assumes that the beam's free vibrations are harmonic. The obtained results are compared with those obtained using the finite element method.
Key words: Sumudu transform method, Free vibration, Winkler elastic foundation, vibration characteristics

INTRODUCTION

The structural dynamics is a science that develops methods for studying structures under dynamic loads. Elastic systems with a continuously distributed mass have infinitely many degrees of freedom. The different types of vibrations of such systems are shown in [1].
In [2], the free oscillations of a Euler-Bernoulli beam supported at its ends with different types of supports - linear elastic supports, dampers, torsion spring, torsion damper - were studied. The circular frequencies of the oscillations were determined and the graphs of the eigenforms were drawn.
[3] shows the application of Sumudu's method for solving ordinary differential equations. In [4] all the theorems in applying Sumudu's method are considered. In [5] a comparison is made between Sumudu and Laplace transforms in solving differential equations.
In [6] the free vibrations of Euler-Bernoulli beams are studied. The method of Sumudu transformations has been applied to different types of boundary conditions at both ends of the beam.

PROBLEM FORMULATION

The differential equation describing the transverse vibrations of a beam resting on the Winkler elastic foundation (Fig.1) is as follows:

$$EI\frac{\partial^4 w}{\partial x^4}+m\frac{\partial^2 w}{\partial t^2}+kw=0 \qquad (1)$$

Where EI is rigidity of the beam, m is the mass of the beam per unit length of the beam, k is the rigidity of the Winkler elastic foundation, x is the longitudinal coordinate along the beam axis. $w(x,t)$ is the transverse displacement of the beam. To solve this differential equation, the method of separation of variables is applied.
The functions $w(x,t)$ is sought in the following form:

$$w(x,t)=W(x)\sin\omega_n t \qquad (2)$$

where $W(x)$ is function of x; ω_n is the circular frequency of the beam.
After some mathematical transformations and taking into account of (2), the expression (1) takes the form:

[1] Corresponding author, lilkovasvetlana@gmail.com, ORCID: https://orcid.org/0000-0003-0582-8176
[2] dlolov@yahoo.com, ORCID: https://orcid.org/0000-0002-8138-0265

$$\left[EI\,W^{IV}(x) - m\omega_n^2 W(x) + kW(x)\right]\sin\omega_n t = 0 \tag{3}$$

$$W^{IV}(x) - \gamma^4 W(x) = 0 \tag{4}$$

$$\gamma_n^4 = \frac{m\omega_n^2 - k}{EI} \tag{5}$$

For the solution of the differential equation (4), the Sumudu transform method is employed. The method is very well described in [6].
The Sumudu transform equation is:

$$\frac{1}{u}\int_0^\infty \left[W^{IV}(x) - \gamma_n^4 W(x)\right] e^{-x/u}\,dx = 0 \tag{6}$$

Where u is the Sumudu parameter.
The equation (6) is transformed to the following equation:

$$\frac{W(u)}{u^4} - \frac{W(0)}{u^4} - \frac{W^I(0)}{u^3} - \frac{W^{II}(0)}{u^2} - \frac{W^{III}(0)}{u} - \gamma_n^4 W(u) = 0 \tag{7}$$

$$W(u) = \frac{1}{u}\int_0^\infty W(x) e^{-x/u}\,dx = S\,W(x) \tag{8}$$

$$W(u) = \frac{u^4}{1-\gamma^4 u^4}\left[\frac{W(0)}{u^4} + \frac{W^I(0)}{u^3} + \frac{W^{II}(0)}{u^2} + \frac{W^{III}(0)}{u}\right] \tag{9}$$

$$W(x) = S^{-1}\,W(u) \tag{10}$$

Where S is the transform operator of Sumudu.
The solution of equation (4) has the following form:

$$W(x) = W(0)\frac{\cosh\gamma_n x + \cos\gamma_n x}{2} + W^I(0)\frac{\sinh\gamma_n x + \sin\gamma_n x}{2\gamma_n} + W^{II}(0)\frac{\cosh\gamma_n x - \cos\gamma_n x}{2\gamma_n^2} + W^{III}(0)\frac{\sinh\gamma_n x - \sin\gamma_n x}{2\gamma_n^3} \tag{11}$$

RESULTS AND DISCUSSION

The free vibration characteristics of a beam resting on the Winkler elastic foundation are obtained through the Sumudu transform method. The beam is shown in Fig.1. The characteristics of the beam are: modulus of elasticity of the material of the beam $E = 3.10^7\ kN/m^2$, dimensions of the cross section of the beam 0.6/0.4 m., the length of the beam $l = 6m$. Rigidity of the Winkler elastic foundation is $k = 2000kN/m$.

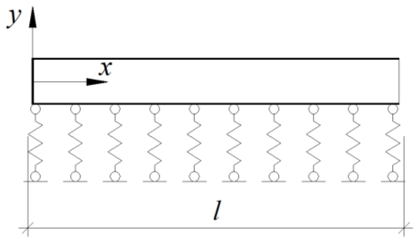

Fig. 1. *Static scheme of the beam*

The boundary conditions at the both ends of the beam, shown in Fig.1, are as follows:

$$W^{II}(0)=W^{II}(l)=0 \tag{12}$$

$$W^{III}(0)=W^{III}(l)=0 \tag{13}$$

Formulas (12) and (13) express that at the both ends of the beam, shown in Fig.1, the bending moment and the shear force are equal to zero.
From here, one obtains:

$$W^{II}(x)=W(0)\frac{\gamma_n^2(\cosh\gamma_n x-\cos\gamma_n x)}{2}+W^I(0)\frac{\gamma_n(\sinh\gamma_n x-\sin\gamma_n x)}{2} \tag{14}$$

$$W^{III}(x)=W(0)\frac{\gamma_n^3(\sinh\gamma_n x+\sin\gamma_n x)}{2}+W^I(0)\frac{\gamma_n^2(\cosh\gamma_n x-\cos\gamma_n x)}{2} \tag{15}$$

$$W^{II}(l)=W(0)\frac{\gamma_n^2(\cosh\gamma_n l-\cos\gamma_n l)}{2}+W^I(0)\frac{\gamma_n(\sinh\gamma_n l-\sin\gamma_n l)}{2}=0 \tag{16}$$

$$W^{III}(l)=W(0)\frac{\gamma_n^3(\sinh\gamma_n l+\sin\gamma_n l)}{2}+W^I(0)\frac{\gamma_n^2(\cosh\gamma_n l-\cos\gamma_n l)}{2}=0 \tag{17}$$

Equations (16) and (17) can be written in matrix form

$$\begin{vmatrix} \frac{\gamma_n^2(\cosh\gamma_n l-\cos\gamma_n l)}{2} & \frac{\gamma_n(\sinh\gamma_n l-\sin\gamma_n l)}{2} \\ \frac{\gamma_n^3(\sinh\gamma_n l+\sin\gamma_n l)}{2} & \frac{\gamma_n^2(\cosh\gamma_n l-\cos\gamma_n l)}{2} \end{vmatrix} \begin{Bmatrix} W(0) \\ W^I(0) \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \tag{18}$$

From (18) one could obtain the characteristic equation

$$\begin{vmatrix} \frac{\gamma_n(\cosh\gamma_n l-\cos\gamma_n l)}{2} & \frac{(\sinh\gamma_n l-\sin\gamma_n l)}{2} \\ \frac{\gamma_n(\sinh\gamma_n l+\sin\gamma_n l)}{2} & \frac{(\cosh\gamma_n l-\cos\gamma_n l)}{2} \end{vmatrix}=0 \tag{19}$$

The first three circular frequencies for the considered beam are: $\omega_1=239.69\,s^{-1}$; $\omega_2=602.69\,s^{-1}$; $\omega_3=1095{,}98\,s^{-1}$.
The first free eigenforms of the beam are shown in Fig.2.

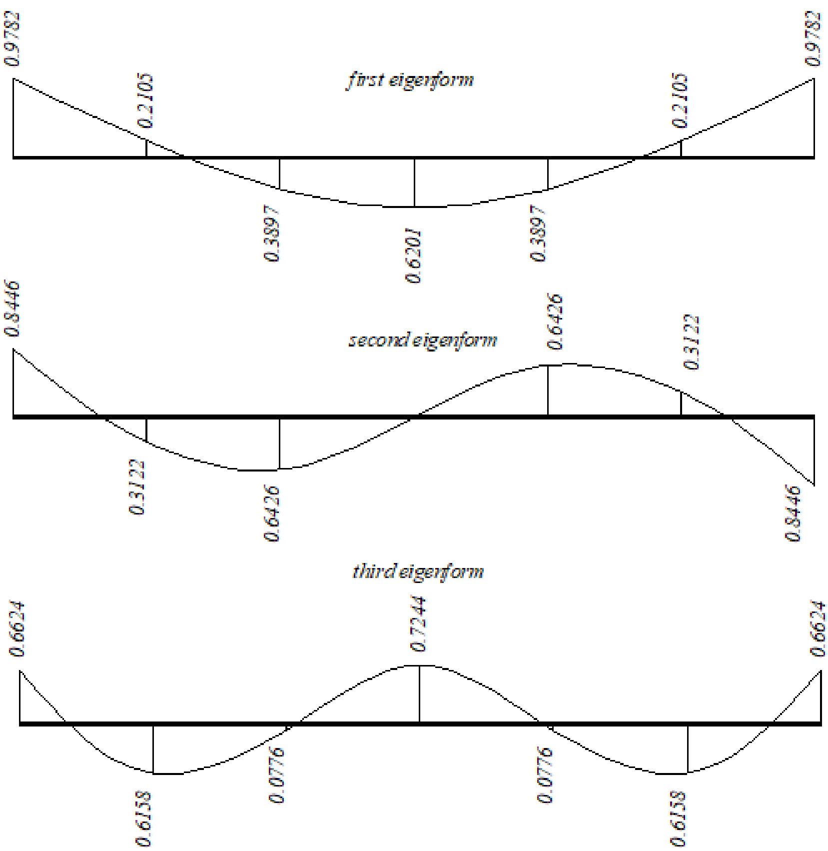

Fig. 2. *The first three eigenforms of the beam*

The obtained results coincide very well with those obtained using the dynamic analysis of the beam through the method of finite elements.

CONCLUSIONS

In conclusion, it can be said that the Sumudu transform method (STM) is reliable and easy to use in dynamic investigations of Euler-Bernoulli beams. It provides fast and accurate results. The major advantage of the method is the reduced computational time required to solve the governing differential equations, as they are transformed into algebraic polynomial equations, which are comparatively easier to solve. This main advantage makes it competitive with the widely used for dynamic investigations Finite Element Method (FEM). However, the STM is not widely used for dynamic analysis of Euler-Bernoulli beams.

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DEVELOPMENT OF A MODEL FOR ASSESSING VIBRATION RISK LEVELS IN HYDROPOWER PLANT TECHNICAL SYSTEMS

Research paper

Slobodan Juric[1], Slavica Prvulovic[2], Jasna Tolmac[3], Ljubisa Josimovic[4], Uros Sarenac[5], Milos Josimovic[6]
[1]High school "CEPS-Center for Business Studies" Kiseljak, Bosnia and Herzegovina
[2,3,5,6]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Djure Djakovica bb, Zrenjanin, Serbia
[4]College of Textile Engineering, Vilema Pusmana 17, 16000 Leskovac, Serbia

Abstract: This study focuses on the level of vibrations in technical systems, risk models, and the reduction of both vibrations and associated risks. The research subject includes hydropower plant facilities, which are strategically significant for the power industry, hold substantial investment value, and consequently are crucial for the state. Vibration diagnostics methods will help predict potential issues, thereby reducing risk levels and maintenance costs, which is very important, and increase the efficiency of the technical system. Vibration issues are addressed through measurement, calculation, and frequency analysis of time functions. Measurement allows for experimental determination of all necessary quantities to be compared with calculation results. Often, it is simpler to measure vibrations than the parameters required for specific calculations. For these reasons, and due to other advantages of measurement (simplicity, monitoring, and analysis of system status, etc.), vibration measurement is a common experimental task for determining risk levels.
Keywords: Risk models, hydropower plants, bearings, vibration

INTRODUCTION

The rapid technical-technological progress driven by the development of new technologies, materials, and information systems leads to changes in the content and nature of technical system maintenance. Risk-based maintenance methods do not replace "traditional" maintenance methods but essentially represent their important and useful complement. Additionally, vibration-based risk management is primarily directed at preventive maintenance based on condition, specifically conducting technical inspections of energy facilities to decide what, where, when, and how to inspect [1, 2].
The goal of risk-based vibration diagnostics is to prevent failures. To achieve this goal, it is necessary to identify the components of a facility whose failure can lead to significant financial losses and even worker injuries. Risk is a quantitative and qualitative description of danger, i.e., a measure of danger or the level of danger. Since the failure of a component of a technical system is essentially a statistical process (probability of occurrence), risk is an appropriate measure to guide maintenance decision-making. In the analysis, it is important to consider that a specific part can fail in various ways, i.e., maintenance costs associated with their failure must be evaluated with the conditional probability of a specific type of failure, which should be considered when determining risk [3, 4].
Risk-based maintenance methods do not replace existing methods but fundamentally serve as their important and useful supplement. Risk-based maintenance management is primarily focused on preventive maintenance and preventive maintenance based on condition, which is based on designed technical inspections of the observed part of the technical system. Based on monitoring the operational capability of technical system components and their mutual functioning (including statistical methods and parameters), a model of their dependence is formed. Adjusting risk parameters and machine condition diagnostics is necessary for a mathematical program that will represent the analyzed components as a

[1] ORCID: https://orcid.org/0009-0000-8041-4454
[2]Corresponding author, prvulovicslavica@yahoo.com, ORCID: https://orcid.org/0000-0001-6353-7145
[3]jasna.tolmac@tfzr.rs, ORCID: https://orcid.org/0000-0003-3860-2034
[4] ORCID: https://orcid.org/0000-0001-6580-6353
[5] uros.sarenac@tfzr.rs, ORCID: https://orcid.org/0009-0007-6619-6076
[6] ORCID: https://orcid.org/0009-0008-9517-2513

dynamic system [5, 6]. In vibration diagnostics, examinations are conducted under operating conditions without stopping the operation (on-line method). Like most diagnostic methods, this method requires considerable experience and relatively complex measuring equipment [7, 8].

MATERIAL AND METHODS

Risk Management in Power Plants

The benefits of risk management are manifold, primarily allowing organizations to:

- Comply with all regulatory requirements for operating in the global market
- Ensure effective decision-making processes
- Improve operations
- Ensure business continuity
- Reduce the likelihood of undesirable events (production interruptions, recalls, loss of operating licenses, fines, loss of market reputation)

Risk-based approaches are an important concept in quality management, providing product protection. They reduce, subjectively categorize risk, provide a list of priorities, facilitate decision-making, and improve transparency. Training employees in both industry and regulation in risk quality management ensures better knowledge and decision-making ability, building confidence in the process outcomes [9, 10].

Decision-making in power plants is ranked as high-risk decision-making because it impacts the energy system, considering that the agreed energy must be delivered to the system, and the operation of the technical system must be planned long-term.

The main elements of risk management in the field of quality are: responsibilities, preparation for analysis, risk assessment (risk identification, risk analysis), risk control – risk consideration, response, risk reduction, risk acceptance [9].

Responsibilities

Quality risk management activities are undertaken by a dedicated team of experts formed by the competent management authority within the company. This team should include experts involved in risk identification, mechanical and electrical engineers, IT specialists, statisticians, administrative representatives, and many others. The team has a leader or team manager who oversees, coordinates, manages, and reports on the team's activities and results.

Preparation for Analysis

Quality risk management encompasses systematic processes aimed at coordinating, facilitating, and enhancing scientifically-based decision-making related to risk. Possible steps in initiating and planning the quality risk management process include: gathering all additional data on potential risks, appointing a leader and necessary resources, and determining the timeframe for the risk management process.

Risk Assessment

Risk assessment involves identifying hazards, analyzing, and evaluating risks associated with exposure to those hazards.

Risk Identification

Risk identification is performed at the beginning of a project, during project progress assessments, and on other occasions when significant decisions are made.

Potential risks in power plants may include: generator faults, turbine faults, bearing faults (L1, L2, L3), cooling system and lubrication system faults, shaft faults, inadequate quality control equipment, and other identified risks [2, 11].

Risk Analysis

Risk analysis is the evaluation of risks in accordance with the identified hazards. It is a qualitative or quantitative process that links the likelihood of occurrence and the consequences of those hazards.

The aim of risk analysis is to:

- Distinguish acceptable risks from those that are unacceptable
- Predict the extent of consequences and the magnitude of damage
- Provide measures that will help in resolving and managing risks

Steps in Risk Analysis

Risk analysis steps include: preparation for analysis, preliminary analyses, risk consideration, assessment of their consequences and the probability of those consequences occurring, presentation of possible event developments, and risk management strategies.

Basis for Risk Analysis

The basis for risk analysis is a process flow diagram (Figure 1), which must show: details of all activities in the process, process inputs, and process outputs.

A process flow diagram is a graphical representation of the process flow and serves as the foundation for risk analysis, facilitating the identification of potential sources, control measures in the process, and guiding the team's work.

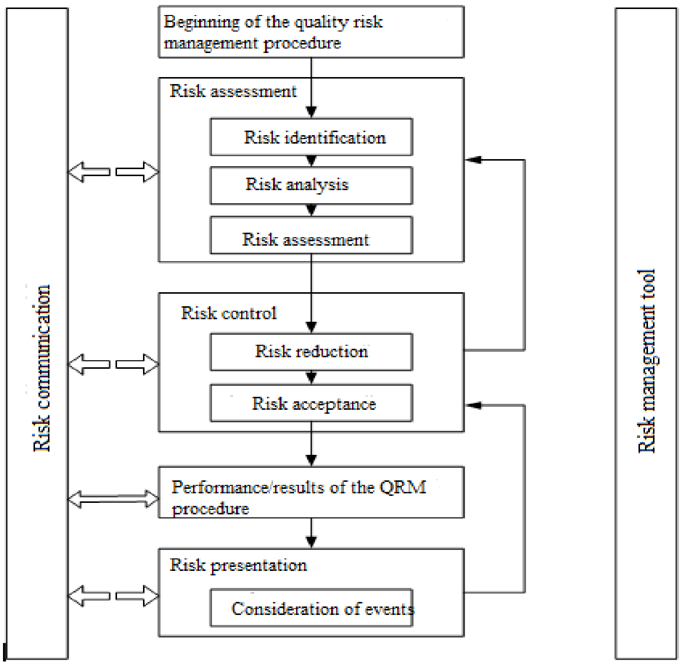

Fig.1. *Process Flow Diagram*

Regardless of the chosen technique, the preparation for risk analysis remains consistent. Since risk is determined by a combination of probability and consequence, a graphical representation of risk can be depicted as in Table 1 [12, 13].

Table 1. *Graphical Representation of Risk*

Consequences	**Probability**	**Insignificant 1**	**Minor 2**	**Moderate 3**	**Major 4**	**Catastrophic 5**
A (Almost certain)	V	V	E	E	E	
B (Likely)	S	S	V	E	E	
C (Possible)	N	S	S	E	E	
D (Unlikely)	N	N	S	V	E	

Where:
- E: Extreme risk; requires immediate action (take measures)
- V: High risk; requires attention from senior management
- S: Medium risk; management responsibility must be specified
- N: Low risk; managed by routine procedures

Risk Control

After assessing the risks, it is necessary to consider the response to the identified risk. Risk control involves making decisions to reduce and/or accept risks. The purpose of risk control is to reduce risk to an acceptable level [14, 15].

Risk Management Strategies:
- Avoid risk: Attempt to eliminate the source of threats
- Transfer risk: Attempt to transfer ownership and responsibilities for mitigating consequences to a third party
- Mitigate risk consequences: Attempt to reduce the intensity of threat exposure below an acceptable level. It is important to define what constitutes acceptable risk
- Accept risk: Acknowledge the existence of residual risk and choose measures to control it

It is recommended to first explore risk avoidance strategies (e.g., replacing a bearing or part of a bearing). Next, consider the possibilities of transferring risk to a third party, although these options are increasingly limited. The third choice is to mitigate the consequences of the risk, i.e., reducing the likelihood of fault occurrence.
The last resort is the strategy of risk acceptance when all other options are exhausted. In the case of risk acceptance, it is important to know what measures to take for specific control points.

Communication and Consultation

Communication involves the exchange of information about risk and risk management between decision-makers and others at all stages of the risk management process. This step is crucial for every decision made and the reasons why a specific activity is required in the risk management process. The risk management process outcome for a specific issue and its impact on quality must be documented by the risk analysis team in a "Risk Analysis Report" form.

Presentation of Risk Analysis Results

Risk management process activities should be implemented throughout the entire system management process. The results of the risk management process should be adopted as new knowledge and experiences. Once completed, the risk management process should continue in case of events that may affect the results or decisions of the completed analysis.

The frequency of risk analysis reviews depends on the risk level itself. A risk review may include reconsideration of risk acceptance decisions.

Experimental Research

By studying risk and vibration models, we can determine the threshold values within which the components of assemblies can operate safely and reliably during exploitation processes. Constructed threshold curves determine the frequency safety dependency as a function of the components' operational work with allowable risk – optimal operation of the analyzed assemblies.
Research results show that the systems studied, from the aspect of risk analysis and vibration of technical systems, keep pace with new technological changes, resulting in a relatively low failure rate of machines. This positively impacts the productivity of the entire production system.
Managing the condition change processes and maintenance of energy facilities based on risk involves optimizing the dynamics and scope of maintenance procedures according to certain criteria, typically the criteria of minimal costs and maximum readiness, as well as the "minimal risk" criterion. This is achieved through continuous monitoring of the facility's condition and performing maintenance processes throughout all life cycle phases. Risk-based maintenance methods are not replacements for "traditional" maintenance methods but essentially represent their important and useful complement.
For vibration measurements at HE "Jajce I," inductive sensors Telemecanique XS1 M12AB120, with a range of 0.2 to 2 mm and an output strength of 4 to 20 mA, positioned on the top of the main bearing, were used.
The equipment used for these investigations at HE "Jajce I" includes: a continuous vibration monitoring system on the turbine bearings implemented using the OneproD MVX measurement acquisition system supported by OneproD VIO (View) software [16].

RESULTS AND DISCUSSION

Vibrations are measured on bearings, bearing housings, or other parts onto which vibrations are transmitted. The direction of the measured vibrations must be the same as the direction of the load (radial for leading bearings and axial for thrust bearings). Measurement points vary depending on the type of device in accordance with relevant recommendations and standards (ISO 10816, ISO 7919, IEC 60994). Accelerometers capable of measuring frequencies over a wide range with uniform frequency response are used.
Analog signals monitored during measurements are digitized in real-time and stored in the form of binary files directly on the hard drive.
The measurement positions of dynamic quantities at HPP "Jajce I" are shown in Figure 2.
The figure depicts a schematic diagram of the measurement positions for dynamic quantities at the hydroelectric power plant (HPP) "Jajce I." Various points on the generator assembly are annotated to indicate the locations where different dynamic parameters are measured.
Measuring points: A_{GLX} and A_{GLZ} represent the measuring points for vibrations in the generator in the Xs and Z directions, respectively. S_{GLX} and S_{GLY} are for measuring vibrations in the Xs and I directions on the generator, A_{TLX} and A_{TLZ} indicate the measurement points for turbine vibrations in the Xs and Z directions, S_{TLX} and S_{TLY} correspond to the measurement of vibrations on the turbine in in the X and Y directions.

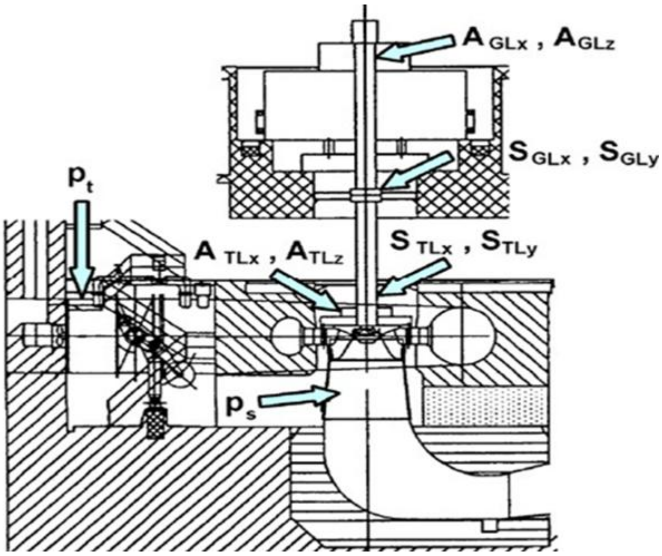

Fig. 2. *Measurement positions of dynamic quantities at HPP "Jajce I"*

Pressure Points: pt denotes the pressure measurement point at the top of the setup, possibly indicating the turbine inlet pressure, ps represents the pressure measurement at the bottom, indicating the suction or draft tube pressure.
The various acceleration (A) and strain/displacement (S) points are critical for assessing the dynamic behavior of both the generator and turbine. These measurements help in monitoring vibrations, structural integrity, and operational stability.
The schematic offers a comprehensive layout of measurement positions essential for monitoring the dynamic and hydraulic performance of the hydroelectric power plant "Jajce I." By systematically measuring accelerations, displacements, and pressures at these key points, operators can ensure the efficient and safe operation of the plant. This detailed monitoring is crucial for early detection of potential issues, thereby enhancing maintenance strategies and extending the lifespan of the equipment.

Display of norms for research results

The vibration measurements were conducted at the Jajce 1 Hydroelectric Power Plant, with an installed capacity of 60 MW and the following technical characteristics:

- Number of aggregates: 2, installed capacity of 60 MW
- Turbine type: Francis, rated power: 30 MW, rated speed: 300 rpm, runaway speed: 540 rpm
- Generator type: Three-phase synchronous, manufacturer: ASEA, apparent power: 36 MVA.

The International Standard ISO 10816-5 and norms VDI 2056 - Group G refer to condition assessment based on the overall level of absolute vibrations from hydro unit bearings.
The magnitude of vibrations is determined by the rate of change of amplitude. According to ISO 10816-5, there are two basic criteria: Criterion I: the magnitude of vibrations must remain below a certain limit, Criterion II: sudden changes in the magnitude of vibrations, even when specified limits are not exceeded, may indicate damage or irregularities.
Criterion III: Vibration magnitudes at nominal rotational speed in steady-state operation are normal within the four zones as shown in Table 2.

Table 2. *Limit values for operating zones at all main bearings*

Limit Zone	For thrust bearing Vrms velocity (mm/s)	For other bearings Vrms velocity (mm/s)
A/B	2.5	1.6
B/C	4.0	2.5
C/D	6.4	4.0

A - Vibrations of newly installed machines B - Vibrations in this zone are considered acceptable for continuous long-term operation C - Vibrations in this zone are considered unacceptable for long-term operation D - Vibrations in this zone are not permissible for operation
Vibration of the generator thrust bearing Arms (mm/s) on unit 1 is shown in Figure 3. Vibration of the turbine guide bearing Arms (mm/s) on unit 1 is shown in Figure 4.

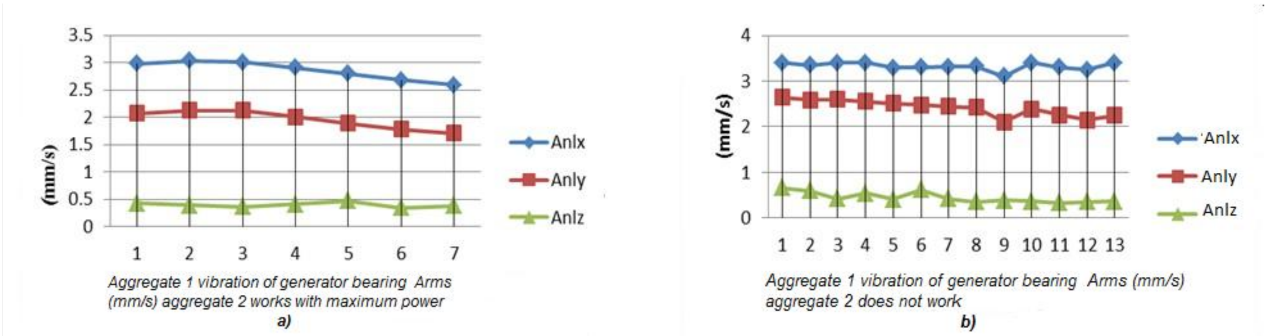

Fig. 3. *Aggregate 1 vibration of generator bearing Arms (mm/s) a) aggregate 2 works with maximum power; b) aggregate 2 does not work*

From fgure 3 according to table 2, vibration of the generator thrust bearing Arms (mm/s) (unit 2 is not operational) Anlx = 3.40 (mm/s), (according to ISO 10816-5 standard, zone B/C is 2.5 to 4.0) the machine condition is declared good.

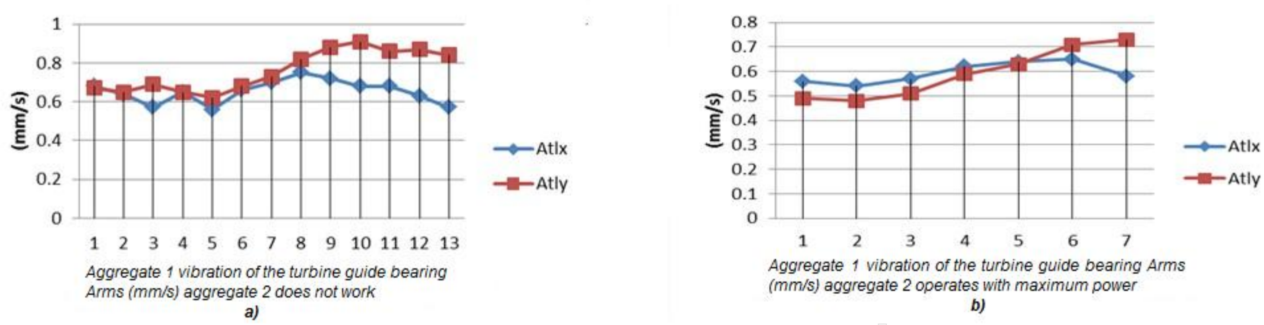

Fig.4. *Aggregate 1 vibration of the turbine guide bearing Arms (mm/s). a) aggregate 2 does not work; b) aggregate 2 operates with maximum power*

In the first scenario (Graph a), where Aggregate 2 is not operational, the vibration levels of Aggregate 1's turbine guide bearing Arms are depicted over 13 intervals. The vibration in the x-axis direction (Atlx) and the y-axis direction (Atly) shows a general upward trend, particularly noticeable after the 7th interval. Initially, both Atlx and Atly maintain relatively stable values, hovering around 0.5 to 0.7 mm/s. However, from interval 8 onwards, a significant increase is observed, with Atlx reaching approximately 0.7 mm/s and Atly slightly exceeding 0.9 mm/s by the 13th interval.
In the second scenario (Graph b), where Aggregate 2 operates at maximum power, the vibration data for Aggregate 1 is recorded over 7 intervals. Here, both Atlx and Atly start at lower values compared to the non-operational state of Aggregate 2, with initial measurements around 0.4 to 0.5 mm/s. Over the intervals, there is a gradual increase in vibration levels, though less pronounced than in Graph a. By the 7th interval, Atlx reaches approximately 0.6 mm/s, while Atly approaches 0.7 mm/s.

Comparing the two scenarios, it is evident that Aggregate 1 experiences higher vibration levels when Aggregate 2 is non-operational. The operational state of Aggregate 2 seems to mitigate the vibration levels of Aggregate 1, suggesting an interdependence between the two aggregates' operational states and their respective vibration behaviors. This could be indicative of load distribution dynamics, where the operational status of one aggregate influences the mechanical stress and vibration characteristics of the other.
Vibrations of the generator support bearing and turbine guide bearing vibration for aggregate 2, while aggregate 1 is not working, are given in Figure 5.

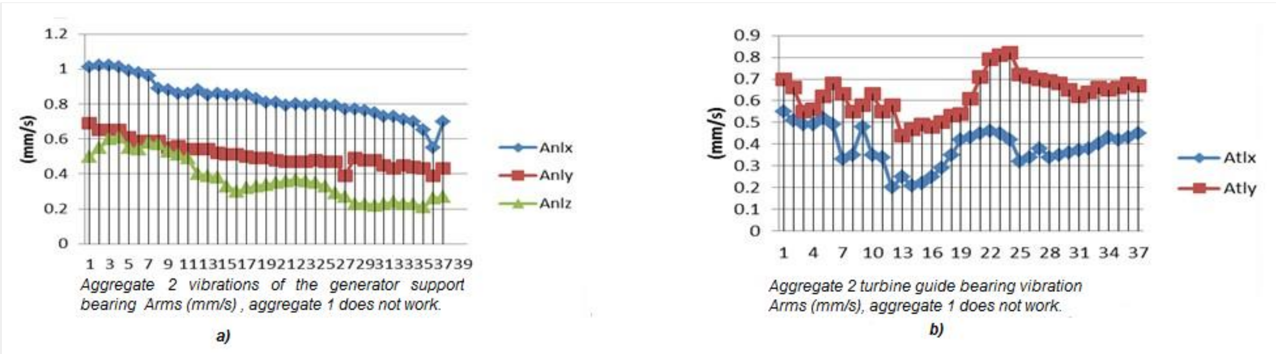

Fig.5. *Aggregate 2, aggregate 1 does not work. a) vibrations of the generator support bearing Arms (mm/s); b) turbine guide bearing vibration Arms (mm/s)*

The provided graph illustrates the vibration measurements of the generator support bearing arms in three axes: X (Anlx), Y (Anly), and Z (Anlz). The data is represented in millimeters per second (mm/s) and pertains to aggregate 2, while aggregate 1 is noted as not operational.
The X-axis (Anlx) shows the highest initial vibration levels compared to the Y and Z axes. Despite some variability, there is a noticeable downward trend over time, indicating a potential reduction in vibration or damping effect. The Y-axis (Anly) maintains relatively stable vibrations with slight fluctuations, suggesting consistent operational conditions along this axis. The Z-axis (Anlz) experiences the most significant reduction in vibration, indicating a possible stabilization or effective damping along this axis over time.The steady reduction in vibrations, especially in the X and Z axes, may indicate improvements in the operational efficiency or the effectiveness of the generator support bearing arms in mitigating vibrations.The stability in the Y-axis vibrations suggests that this axis is less affected by operational changes or that it has reached an equilibrium state.The graph provides valuable insights into the behavior of the generator support bearing arms under operational conditions. The decreasing trend in vibrations, particularly in the X and Z axes, could reflect improvements in the generator's performance or the damping system's effectiveness. The stable Y-axis vibrations further highlight the consistent performance in that direction. T these observations are critical for understanding and optimizing the generator's operational stability and longevity. From Figure 5 a, vibration of the generator thrust bearing (unit 1 is not operational) Arms (mm/s) Anlx = 1.02 (mm/s), (according to ISO 10816-5 standard, zone A/B is 1.6) the machine condition is declared good.Atlx and Atly vibrations exhibit a generally increasing trend towards the end of the measurement period.The vibration data for Unit 2 indicates varying levels of stability and performance over the measured intervals. The sharp increase in Atly vibrations around interval 24 suggests a significant event or change in operational conditions. The consistent increase in Atlx vibrations towards the end of the period may indicate a developing issue or changing load conditions on the turbine guide bearing.
Vibration of the generator lower guide bearing Arms (mm/s) on unit 1 is shown in Figure 6.

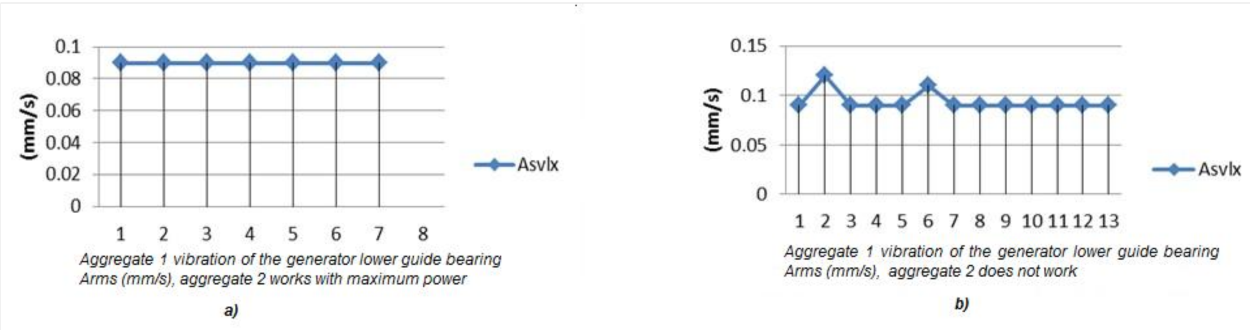

Fig. 6. *Aggregate 1 vibration of the generator lower guide bearing Arms (mm/s). a) Aggregate 2 works with maximum power; b) aggregate 2 does not work*

Analysis of the dynamic characteristics of HPP "Jajce I"

Based on the measured amplitude values for all measured bearings, diagrams are shown in Figure 6. The results confirm what was found during the measurements, that Unit 1 was in deteriorated mechanical condition regarding vibration levels compared to Unit 2. This is particularly evident in the case of the thrust bearing vibrations, where vibrations on Unit 1 are several times (3-4) stronger than on Unit 2 at the same operating conditions. Maximum RMS amplitudes on this unit can reach 3.40 mm/s, while on Unit 2 they are up to 1.02 mm/s. The assessment of all amplitudes is made according to ISO 10816-5 standard, with plotted limits of operating zones on the diagrams. The boundary area of uninterrupted continuous operation (zone B) according to the standard for the thrust bearing and this machine group is 4 mm/s. The differences on the turbine guide bearing between the units are significantly smaller, indicating that the source of increased vibrations comes from the generator direction. The levels of all vibrations on the "better" Unit 2 are in zone A according to the ISO standard, which is valid for good bearings. Unit 1 has bearing vibrations in zone B, which according to the ISO standard is still usable for continuous operation.
Vibration trends otherwise follow the machine's operating mode, i.e., its power and pressure fluctuations, so trends on the diagrams are sometimes similar to those for pressure pulsations.
A specific feature of Unit 1 is that vibrations are slightly lower when Unit 2 operates in parallel. Vibration of the lower guide bearing is measured only on Unit 1. Even here, their intensity is very low, so on Unit 2, which was much quieter, they were not measured.
By studying the risk and vibration models, we can identify the boundary values up to which component assemblies in exploitation processes can have correct and safe operation. Constructed boundary curves determine the dependence of frequency safety on the operation of components with permitted risk - optimal operation of analyzed assemblies.
The justification for this research lies in the analysis, which involves increasing the optimal value of operation of component assemblies of the hydroelectric power plant by approximately 15% compared to the originally existing state of operation.

CONCLUSION

In this study, developed a comprehensive model for assessing vibration risk levels in hydropower plant technical systems. The primary focus was on utilizing vibration diagnostics to predict potential issues and thereby reduce both risk levels and maintenance costs. This approach enhances the overall efficiency of the technical systems in hydropower plants.
Research highlighted the importance of vibration measurements and the subsequent analysis of these measurements to identify and mitigate risks. The findings underscore the utility of continuous monitoring and advanced diagnostics in maintaining optimal performance and extending the lifespan of hydropower plant equipment.
The implementation of risk-based maintenance strategies, which complement traditional methods, has proven effective in minimizing failures and improving decision-making processes. These

strategies focus on preventive maintenance based on condition monitoring, allowing for timely interventions that prevent significant financial losses and ensure the safety of workers.
Experimental research, particularly the case study at the "Jajce I" hydropower plant, demonstrated the practical application of these methods. The use of inductive sensors and advanced vibration monitoring systems provided valuable data that informed maintenance strategies and operational adjustments. The results showed that the systems under study exhibited a relatively low failure rate, positively impacting overall productivity.

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ARTIFICIAL INTELLIGENCE IN FUNCTION OF IMPROVING PRODUCT FUNCTIONALITIES

Review paper

Rade Dragović[1*], Milada Novaković[2], Zoran Bakić[3], Marija Matotek Anđelić[4], Igor Kostovski[5], Valentina Mladenović[6]
[1] Institute for standards and technology, Belgrade, Serbia
[2,4,6] Technical College of Applied Sciences, Zrenjanin, Serbia
[3] Ministry of Economy, Belgrade, Serbia
[5] University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: The paper aims to present the author's vision about the possibility of applying artificial intelligence in improving the functionality of products/services from series to series by monitoring the functionality of users, on the market and in all other environments where elements for the analysis of the improvement of individual product functionalities can be found. The paper gives a clear position on the constituent elements that should make up such a functional model with all the associated elements and connections with external entities, as well as a description of the product/service improvement cycle using artificial intelligence. Artificial intelligence is not a supporting part of the model, but used as a support for deciding whether and to what extent certain proposed existing functionality will be improved or new functionality will be added to the product/service. Artificial intelligence certainly opens a new stage of the industrial revolution because it's a big step forward in production with its technological capacity.
Key words: artificial intelligence, product, service, production, industry, improvement, product functionality, product life cycle.

INTRODUCTION

In a modern environment, artificial intelligence (AI) plays an important role in social development. AI has attracted a lot of attention in recent years. The availability of large amounts of data and information is considered to be one of the factors behind the increased use of artificial intelligence in many fields. Digital connection (machines, products, services, communication devices, etc.) together with the increasing amount of data generated in digitized systems offer completely new possibilities of using data for new applications, thereby increasing business efficiency. It can be said that AI technology enables efficient and comprehensive use of all data sources [1]. A product/service (in the following text - product) can be defined as the result of human labor that satisfies the needs of consumers, any item or service that is produced and offered on the market with the aim and purpose of satisfying the needs and wants of consumers. The user chooses a product that meets his expectations precisely through the performance and quality of the product. Product features such as: quality, brand, style, packaging, color, etc., influence the placement and sale of the product on the market [2].
Product improvement is a modification of its performance or a new brand of product that a company develops for a specific market. New products can be defined as any products that are introduced to the market and which differ in their characteristics from other products, with the fact that consumers also perceive such a product as a new product. A new product that replaces the old one, giving it improved performance. The process of creating a "new" product by entering a new market or increasing the benefits of existing customers. Product improvement can be small or large, for example, a certain ingredient or detail can be added to a product, or a part can be added to change its taste, appearance, structure, all depending on the type of product. If something is improved or some innovation is introduced, the performance of the product is also improved [3].

[1] Corresponding author, rade.dragovic@instate.biz, ORCID: https://orcid.org/0000-0002-0215-4076
[2] milada.novakovic@vts-zr.edu.rs, ORCID: https://orcid.org/0009-0009-6306-1488
[3] zoran.bakic@privreda.gov.rs, ORCID: https://orcid.org/0009-0001-9136-6002
[4] matotek@vts-zr.edu.rs, ORCID: https://orcid.org/0009-0007-0878-3133
[5] igor.kostovski@tfzr.rs, ORCID: https://orcid.org/0000-0003-3938-9538
[6] valentina.mladenovic@vts-zr.edu.rs, ORCID: https://orcid.org/0000-0001-6642-340X

The life cycle of a product can be defined as the process through which the product goes from its initial presentation on the market to the end of its existence, its final decline or cessation of its production. The product life cycle actually shows the process of product "aging" through stages. Every product goes through its life cycle. The life cycle consists of several stages: product development stage, product introduction stage, product growth stage (demand), product maturity stage and product decline or death stage [4]. The first phase of any product's life cycle begins with product development. In this phase, the idea for the product is developed, including market research, design and prototyping of the product. After that, the product is launched on the market with a marketing campaign. Product sales growth begins when customers become aware of the product and its performance. During the growth phase, the demand for the product in the market increases as well as the profit. In the maturity stage of the product, market saturation occurs, sales decline/slow down. Declining sales lead to declining profits. The decline phase indicates the end of the product/end of product life cycle period. As sales decline, so does profit. The company decides whether to cancel/shut down the product or to look for ways to revitalize it, such as rebranding (rebranding represents a certain change that will create a new image for the company) and enable it to be more recognizable on the market (this change refers to the logo, name, visual identity, slogan, vision, mission, as well as the target group). Extending the life cycle of a product means investing in improving the performance of the product; it also means changing the design, changing the way of promotion (updating, adapting to the currently current way of promotion), distributing the product to new markets, etc. [5].
Product functionality is a term that is inseparable from business software that includes and supports all standard business functions with the possibility of adapting the solution to the specific needs of a given company. It is necessary to comply with high standards in business, the maximum contribution to the improvement of the quality of products and services with the highest possible level of functionality.

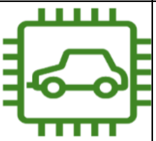
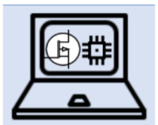
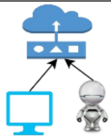
INDUSTRY 5.0

Industry 5.0 represents a new era of production with advanced technologies and human intelligence. It represents a significant shift compared to Industry 4.0. It can be said to enable improved customization by using advanced technologies referring to: Internet of Things (IoT), Artificial Intelligence (AI), and Robotics. It includes hyper-customization, better efficiency by optimizing processes while reducing waste. A human-centered design focus indicates manufacturing with the customized and unique needs of individual customers. Production of a wider range of products in smaller quantities to meet the demands of today's consumers. Industry 5.0 facilitates a more sustainable approach to production with the use of renewable energy sources, reducing the ecological footprint. It promotes the circular economy (CE) and focuses on reducing the impact of production on the environment [6] and is inclined towards the examination and analysis of the production of smart fabrics, then personalized products, co-designing, satisfied users [7]. Smart power technology is popular and has greatly strengthened the development of smart manufacturing. The main benefits of a smart manufacturing industry are: Improved productivity; Innovation and better quality products; Energy efficiency [8].
Based on the expectation that Industry 5.0 has (to evolve to its maximum), industry researchers have considered and defined it in various ways. The First Definition: Industry 5.0 is the first human-led industrial evolution based on the 6Rs (Recognize, Rethink, Realize, Reduce, Reuse and Recycle) [9].
Association/relationship is emphasized of humans and machines/robots to increase efficiency by harnessing human power and creativity [10]. Using enterprise social networks to enable good communication between human and cyber-physical production systems (CPPS) components, then, collaborate with human resources to enable personalized enterprise production through social networks [11].

INDUSTRY 6.0

Industry 6.0 can be defined as a change based on quantum discoveries, advanced biotechnologies, neural integration, decentralized autonomous systems and a strong focus on sustainable production [12]. Industry 6.0 is the sixth transformative phase of the architecture, engineering and construction sector, built on Industry 5.0 [13]. Industry 6.0 can be defined as a combination of Industry 4.0 and Industry 5.0. Industry 6.0 is characterized by innovations that set trends, people, robots to help in the home or for some special tasks, etc. [14]. The development of technology from Industry 1.0 to Industry 6.0 can be presented tabularly [15] according to the following table.

***Table 1.** Industrial revolutions*

Industrial Revolution	Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0	Industry 5.0	Industry 6.0
Technological Advancement						
Power Generation / Features	Mehanical work, Vapor power	Using electricity assembly line production, Mass production	Electronics Device, Automation	Robots, Computers, Internet of Things	Human-Robot interaction	Humanized Robot, AR/VR, Quantum computing, IoT and big data

Industry 6.0 is defined as "Ubiquitous, customer-centric, virtualized manufacturing." It is considered that the first step towards Industry 6.0 is actually the realization of Industry 4.0. which could not be implemented. Key elements in Industry 5.0 and Industry 6.0 approaches. - greater service orientation and Service Dominant Logic (SDL). The SDL approach will be linked to the 4R sustainability strategy (Replan, Reduce, Reuse, Recycle). We are also move towards zero waste, zero emission. The road to Industry 6.0 is long and demanding road because there are many unresolved issues related to sustainability (environmental, social and economic) -these challenges require changes to move towards the vision of Industry 6.0 [16].
It is considered that Industry 6.0 is characterized by virtualized production, directed towards users. Key factors such as: resource consumption, production dynamics, innovation, environmental impact, of course social impact, as well as market dynamics and economic impact are considered. It can be said that the new environment of Industry 6.0 presents a unique set of challenges and opportunities. A forward-looking perspective allows to anticipate new challenges such as lack of resources, climate change, etc. Identify innovative solutions to promote sustainable development so that sustainability remains at the forefront of the transition to Industry 6.0 [17].
In Industry 6.0, the primary focus is on the automation of mass production with the help of robots, foreseen by Industry 4.0, which could not be implemented. The next step would probably be domestic robotics integrated into everyday life, e.g. cleaning robots or robots for some specialized tasks. Alternative energy sources will gradually play a major role, replacing fossil fuels, working on renewable energy sources. Also, a new level of personalization in the product creation process is now available. The participation of customers in decision-making and designing (personal) products is being pushed more and more, personalization is being improved (customer-tailored product creation). With such developments, it is possible to assess and monitor the impact of products on the environment during use. In realizing the circular economy ambitions, the ability to provide wearable sensors and intelligent textiles provide a new level of information for manufacturers and functionality for consumers, although the industry must be aware of the need for ecological solutions for eWaste and the need for a greater possibility of reuse, recycling and remanufacturing in this sector [18].

Industry 6.0 represents the management of production resources, improvement of operations and safety, minimization of waste in production, fulfillment of quality requirements and supply of customers. In the case of extending the smart manufacturing of Industry 5.0, AI can be trained to construct the most efficient designs as well as to establish structural constraints based on the user's physical profiles for empirical purposes mentioned by user. This could lead to a higher order of smart manufacturing when user doesn't have to go into product specifications to get output information [14].

ARTIFICIAL INTELLIGENCE INTEGRATION IN THE SERVICE OF PRODUCTION

System for improving product functionalities must initially have some basic prerequisites in order to be formed. The basis is the fulfillment of the requirements of the ISO 9001 - Quality management systems - Requirements standard due to the establishment of a process approach as well as the need to establish Deming's PDCA cycle [19]. It is recommended to implement the requirements of the ISO/IEC 20000-1 standard - Information technology - Service management. To successfully establish a functionality monitoring model in a real environment, it is necessary to implement a Customer satisfaction monitoring system through the implementation of the requirements of the ISO 10001 standard - Quality management - Customer satisfaction - Guidelines for codes of conduct for organizations. The author's recommendation is that along with the implementation of the requirements of the ISO 10001 standard, the following standards should also be implemented:

- ISO 10004 - Quality management - Customer satisfaction - Guidelines for monitoring and measuring,
- ISO 10008 - Quality management - Customer satisfaction - Guidance for business-to-consumer electronic commerce transactions,
- ISO 10009 - Quality management - Guidance for quality tools and their application,
- ISO 10012 - Measurement management systems - Requirements for measurement processes and measuring equipment,
- ISO 10013 - Quality management systems - Guidance for documented information,
- ISO 10014 - Quality management systems - Managing an organization for quality results - Guidance for realizing financial and economic benefits,
- ISO 10015 - Quality management - Guidelines for competence management and people development,
- ISO 10018 - Quality management - Guidance for people engagement,
- ISO 10019 - Guidelines for the selection of quality management system consultants and use of their services.

The authors emphasize special attention to the details of implementation ISO 10004 standard - Quality management - Customer satisfaction - Guidelines for monitoring and measuring. This standard gives guidelines for defining and implementing processes to monitor and measure customer satisfaction. This document is intended for use by any organization regardless of its type or size, or the products and services it provides. The focus of this document is on customers external to the organization.

The model shown in the picture is designed so that a product (service) with initial functionalities (f_1, f_2, f_3, ..., f_n) is initially placed on the market. Through the Functionality live tracking system (FLTS), the functionality of the product is monitored in real time, and if this is not possible due to the nature of the product, then it is done in a time that is closer to real time. The obtained data are in addition to data from Market research system (MRS), Social research behavior system (SRBS) and other research systems which are specific to the reference product.

The author's recommendation is to implement the requirements of the current standards for the purposes of the mentioned research systems:

- ISO 20252 - Market, opinion and social research, including insights and data analytics - Vocabulary and service requirements. This standard establishes terms, definitions and service requirements for service providers conducting market, opinion and social research, including insights and data analytics (hereinafter referred to as "service providers").

- ISO 19731 - Digital analytics and web analyses for purposes of market, opinion and social research - Vocabulary and service requirements. Standard specifies the service requirements, for organizations and professionals that conduct digital analytics and web analyses for collecting, analysing and reporting of digital data for purposes of market, opinion and social research by various methods and techniques. It provides the criteria against which the quality of such services can be assessed and evaluated. Standard applies to digital and web analysis research activities such as:
  - understanding the usage of websites via the use of cookies, page impressions and other means, navigation across sites, time spent by visitors and their actions;
  - online metered panels, e.g. on-going measurement of web visitation via meters installed on panellists' desktop, mobile or tablet devices
  - tag-based solutions to measure online usage at universe level, which can be integrated with metered panel data to provide a hybrid measurement;
  - social media analytics which collect, aggregate and analyse online comments, and user-generated content such as blogs, forums and comments on news sites or other sites.
- ISO/TR 56004 Innovation Management Assessment – Guidance. This document will help the user understand why it is beneficial to carry out an Innovation Management Assessment (IMA), what to assess, how to carry out the IMA, and thus maximize the resulting benefits, which are universally applicable to:
  - organizations seeking sustained success in their innovation activities;
  - organizations performing IMAs;
  - users and other interested parties (e.g. customers, suppliers, partners, funding organizations, universities and public authorities) seeking confidence in an organization's ability to manage innovation effectively;
  - interested parties seeking to improve communication through a common understanding of Innovation Management (IM), via an assessment;
  - providers of training, assessment, or advice in IM;
  - developers of related standards;
  - academics interested in research related to IMA.

  The consequence of implementing the requirements of this standard should be the adoption of an Innovation Management strategy.

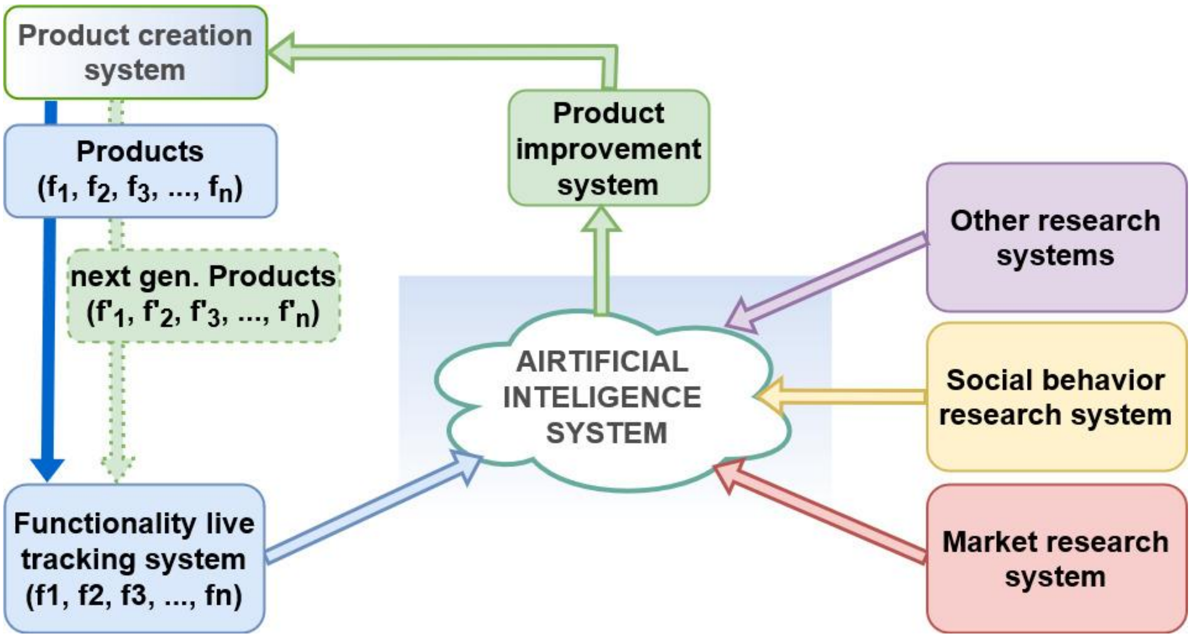


Fig. 1. *AI system for improvement of product functionality*

The aforementioned systematized data obtained from tracking and research systems are forwarded to the Artificial Intelligence System (AIS). The author's recommendation is that the AIS system is based on the requirements of the standard:

- ISO 42001 - Information technology - Artificial intelligence - Management system. Standard specifies requirements for establishing, implementing, maintaining, and continually improving an Artificial Intelligence Management System (AIMS) within organizations. It is designed for entities providing or utilizing AI-based products or services, ensuring responsible development and use of AI systems. ISO/IEC 42001 is the world's first AI management system standard, providing valuable guidance for this rapidly changing field of technology. It addresses the unique challenges AI poses, such as ethical considerations, transparency, and continuous learning. For organizations, it sets out a structured way to manage risks and opportunities associated with AI, balancing innovation with governance.

  An AI management system, as specified in ISO/IEC 42001, is a set of interrelated or interacting elements of an organization intended to establish policies and objectives, as well as processes to achieve those objectives, in relation with responsible development, provision or use of AI systems. ISO/IEC 42001 specifies the requirements and provides guidance for establishing, implementing, maintaining and continually improving an AI management system within the context of an organization.
- ISO/IEC 24668 - Information technology - Artificial intelligence - Process management framework for big data analytics. Standard provides a framework for developing processes to effectively leverage big data analytics across the organization irrespective of the industries or sectors. This document specifies process management for big data analytics with its various process categories taken into account along with their interconnectivities.

These process categories are organization stakeholder processes, competency development processes, data management processes, analytics development processes and technology integration processes. Standard describes processes to acquire, describe, store and process data at an organization level which provides big data analytics services.

The artificial intelligence system performs data processing and provides guidelines for the Product improvement system, which orders the Product creation system to generate next generation Products with new functionalities (f'_1, f'_2, f'_3, ..., f'_n). This cycle is not continuous, and by using the system in several generations of new products, the cycle is faster and generates products that are directly adapted to the requirements by the end-users.

CONCLUSION

The use of artificial intelligence is desirable and necessary in systems that want to improve their products and offer functionalities that will adapt to the requirements by the end-users through each next generation of products. A framework of standard requirements for the implementation of the artificial intelligence system, as well as supporting systems that should fill the artificial intelligence system with data, is given. Finding relevant data for the operation of artificial intelligence systems is described and clear guidelines for implementation are provided. An artificial intelligence system will be as successful as it is fed by databases that are accurate, precise, realistic and based on correctly identified end-user requirements. The establishment model can be used not only for one product but for several related products or products that are intended for a certain set of requirements according to the width of the implementation of the tracking or research system. The use of systems based on artificial intelligence irreversibly leads humanity into the next industrial revolution, which will manifest its undeniable effects in products and services that are adapted to the needs by the end-users.

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THE ROLE OF COOLANT IN THE ENERGY BALANCE OF INTERNAL COMBUSTION ENGINES

Research paper

Juraj Marković[1], Hrvoje Glavaš[2*], Tomislav Barić[1], Eleonora Desnica[4]
[1]Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, Osijek, Croatia
[2]University of Slavonski Brod, Mechanical Engineering Faculty, Slavonski Brod, Croatia
[3]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: Coolant in the energy balance of an internal combustion engine is a key fluid and often overlooked component that plays a crucial role in maintaining optimal performance and durability of an internal combustion engine due to its ability to absorb excess heat generated by fuel combustion. The aim of the paper is to present the energy balance of an internal combustion car with an emphasis on the role of the coolant. The paper presents the testing of the properties the coolant in real conditions. The results of measurements using the two most commonly used methods, Refractometer and Hydrometer with float, were compared with theoretical expectations.
Key words: coolant, antifreeze, distilled water, freezing point, energy balance, internal combustion engine

INTRODUCTION

Internal combustion engines produce a large amount of heat through the process of burning fuel. After the metal parts of the engine are exposed to excessive heat they begin to expand, thereby increasing the friction force between the cylinders and pistons. For this reason, it is necessary to use an adequate coolant that absorbs excess heat and transfers it to the engine's cooling system. The energy balance of internal combustion (IC) engines provides a detailed overview of how the thermal energy obtained by fuel combustion is processed and utilize through the engine, following path of energy through various engine components the visualization of the energy balance of a car with an IC engine can be made as shown in Fig. 1.

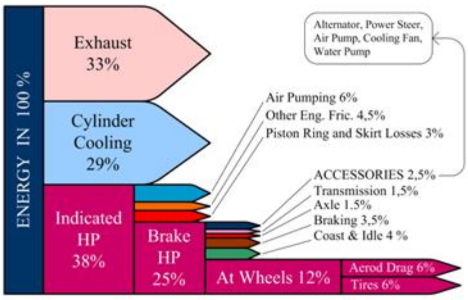

Fig. 1. *Energy balance of IC engine [1]*

Analyzing energy balance areas where thermal energy is used can be identified and improved to increase the overall efficiency of the engine. The energy balance of the engine is determined based on the values obtained by the experiment of driving the real engine for a certain time at a certain speed under stationary conditions. As can be seen from Fig. 1, a significant part of the energy is transferred to the refrigerant, which causes degradation over time and the need for regular replacement.

[1]Juraj Marković
[2]Corresponding author: hrvoje.glavas@ferit.hr, ORCID: https://orcid.org/0000-0002-3658-0364
[3]tomislav.baric@ferit.hr, ORCID: https://orcid.org/0000-0002-7852-3800
[4]eleonora.desnica@tfzr.rs , ORCID: https://orcid.org/0000-0002-4724-5764

In the early stages of the development of internal combustion engines, water was primarily used as a coolant as a medium with high heat capacity and good heat transfer properties. However, it turned out that water is not an ideal coolant due to a couple of disadvantages: relatively high freezing point (0 ℃), relatively low boiling point (100 ℃), corrosive impact to metals in the cooling system and when the water is at the freezing point the engine block, radiator and pump may burst [2].

At the end of the 19th and the beginning of the 20th century, a mixture of methanol and water was used as a coolant due to the characteristically low freezing point of methanol. Methanol in the role of antifreeze did not prove to be a permanent solution due to its high corrosivity, poor heat transfer properties and low boiling point, which led to the fact that cooling was not as effective as when only water was used as a coolant, especially during the summer months when the concentration of methanol in the mixture decreased significantly faster than the concentration of water due to its greater tendency to evaporate [3]. In order to reduce the impact of the corrosiveness of methanol on the cooling system, chromate, mercaptobenzothiazole, starch and sugar were added as corrosion inhibitors [4]. During the 1920s, denatured ethanol became an important antifreeze due to its easy availability, low cost, and relatively good freezing point reduction efficiency, but the real breakthrough in antifreeze technology for internal combustion engines occurred in 1927 when ethylene glycol appeared on the market. By using ethylene glycol as an antifreeze, the boiling point of the coolant was raised, by passing the problem of using high pressures to achieve a higher temperature of the coolant. The increase in the boiling point of the coolant has contributed to the fact that ethylene glycol is advertised as a "permanent antifreeze" due to its ability to be used in summer and winter months. Although ethylene glycol was the best solution, its unavailability and automakers' belief that ethyl glycol-based coolant leaked and adversely affected cylinder head gaskets and coolant pump gaskets limited its use [3, 4].

From 1950 to 1970, engine coolants intended for the English and European markets were produced in accordance with the British Standards Institution (BSI). The BSI standards were BS 3150 (ethylene glycol based antifreezes with ethanolamine and mercaptobenzothiazole as corrosion inhibitors) and BS 3151 (ethylene glycol based antifreezes with nitrite and benzoate corrosion inhibitors) which was intended for aluminum alloy engines and BS 3152 (antifreeze based on ethylene glycol with borate as a corrosion inhibitor) which was intended for engines made of cast iron [5]. Meanwhile, in the USA, glycol-based coolants were produced in which they used borates to raise the PH value of the liquid, and mercaptobenzothiazole, arsenite, nitrite, molybdate and phosphate were used as corrosion inhibitors [6]. Until the 1970s, there were three main approaches to corrosion inhibitor development established in the USA, Europe and Japan based on the conditions in those regions (eg water quality and weather conditions) [4].

By the 1990s, European and American coolant manufacturers decided to use hybrid organic acid technology (HOAT) with low silicate content in their products as a corrosion inhibitor [4]. In the 1990s, Japanese manufacturers began to use coolants based on ethylene-glycol hybrid technology of organic acid with phosphate, and from the early 2000s they began to use coolants based on ethylene-glycol hybrid technology of organic acid with low phosphate content [7]. Phosphate was added to avoid blackening of the aluminum surface caused by the formation of an aluminum oxide layer [8]. Due to the toxicity of ethylene glycol to the environment, in recent decades propylene glycol has also been used as a base for antifreeze in internal combustion engines. Antifreezes based on propylene glycol are used in systems where the toxicity of ethylene glycol is a problem, such as food freezing systems and solar collectors, and are already used in several European countries in the coolant in cars with an internal combustion engine.

Coolant as mixture of distilled water and antifreeze

Coolant is a mixture of distilled water and antifreeze. In addition to its primary role of absorbing excess heat and transferring it to the engine's cooling system, the coolant is

responsible for [9]: protection of metals from corrosion, prevention of cavitation in the liquid, neutral effect on engine sealing materials and prevention of galvanic reactions.
Mixtures of antifreeze and water, compared to pure substances or diluted aqueous solutions, behave unusually when freezing. Water, because it has a higher freezing point than ethylene glycol, begins to crystallize first, increasing the concentration of antifreeze in the mixture. By increasing the concentration of antifreeze in the mixture, the freezing point of the mixture decreases. While the freezing point of a solution of water and antifreeze base can be calculated relatively easily, this is not the case when corrosion inhibitors are also taken into account. Therefore, the exact freezing point of the coolant can be determined only by measurement.
Antifreeze consists of a base and various additives. Depending on the type of base material, antifreeze can raise the boiling point of the solution with which it is mixed. In antifreeze concentrates intended for cars with an internal combustion engine, the base makes up 94 % of the weight of the formulated product, while the rest of the concentrate mainly consists of corrosion inhibitors, oxidation inhibitors (phenols and amino acids), antifoaming agents (silicates and phenols), scale inhibitors (benzotriazole and amino acids)) and additives that give a characteristic color. When choosing liquids that form antifreeze concentrate, it is necessary to pay attention to some of the following factors [3]: heat capacity of liquid, liquid viscosity, metallurgy in the cooling system, non-metallic components in the cooling system, flammability of the liquid and liquid toxicity.
Antifreeze base is the key ingredient in the antifreeze concentrate. It represents the basic component by which most properties of the antifreeze concentrate are defined. In the past, the base of antifreeze concentrates consisted of monovalent alcohols such as ethanol and methanol. The reason for the cessation of their use is the low temperature of the boiling point can bee seen in Table 1. As the value of the boiling point of these alcohols is lower than the boiling point of water, they begin to evaporate before water, thereby increasing the risk of the formation of concentrated vapor that can be flammable [10]. Today, in practice, ethylene glycol and propylene glycol are used as the base of antifreeze concentrate.

Table 1. *Properties of common used alcohols [8]*

	t_1 (°C)	t_{vr} (°C)	ρ (°C)
Methanol	- 98	64.65	790
Ethanol	- 90	78.3	816

In Fig. 2 is a graph with which is possible to determine the freezing point of the coolant for different antifreeze base materials and percentages of antifreeze concentration [11]. Accordingly, the boiling point can be read from Table 2.

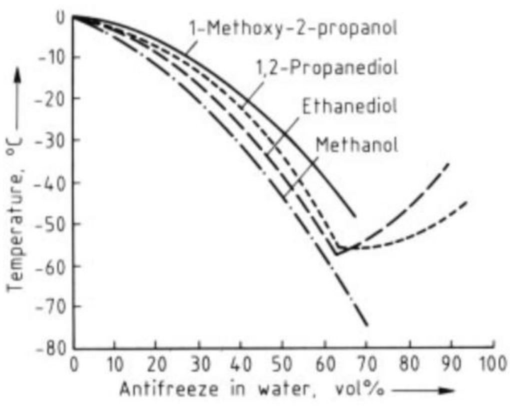

Fig. 2. *Freezing points for different mixtures of antifreeze and water [11]*

Ethylene glycol (IUPAC preferred name: ethane-1,2-diol [12]) ($C_3H_6O_2$) is a clear, odorless, slightly viscous liquid with a sweet taste. Glycol is a general term for alcohols with two hydroxyl groups on adjacent carbon atoms (1, 2-diol). The name ethylene glycol means "glycol obtained from ethylene". The high value of the boiling point of 198 ℃ and the low value of the freezing point of -13 ℃, with a relatively high heat capacity, make it an ideal material for the base of antifreeze concentrate, where it finds the greatest use [13]. The big disadvantage of ethylene glycol is that it is toxic to people and the environment. The toxicity is caused by the conversion of ethylene glycol into glycoaldehyde and then into glycolic acid, which leads to metabolic acidosis in the presence of alcohol dehydrogenase. Also, when mixed with water, it causes corrosion of metal parts of the cooling system.

Table 2. *Boiling points for mixtures of water and uninhibited antifreeze at atmospheric pressure [11]*

Antifreeze (%)	Methanol (°C)	Ethylene glycol (°C)	Propylene glycol (°C)
10	91.7	101.0	101.0
20	86.0	102.0	101.5
30	82.0	103.0	102.0
40	79.0	104.5	102.5
50	76.5	107.0	104.5
60	74.0	110.0	107.0

Propylene glycol (IUPAC preferred name: propane-1,2-diol [12]) ($C_3H_8O_2$) is a colorless, relatively viscous, odorless liquid with a slightly sweet taste. It belongs to the glycol family of organic compounds, just like ethylene glycol. The freezing point value of propylene glycol is -59 ℃ and the boiling point value is 187.6 ℃. With proper use and in the prescribed concentrations, propylene glycol is safe for human use and therefore can be found in the food industry as a food additive [14]. When using propylene glycol, you should pay attention to its color. When the coolant with propylene glycol takes on a reddish color, it means that the metal in the cooling system has corroded. Due to the lack of corrosion inhibitors, propylene glycol reacts with oxygen and metal ions to form organic acids such as formic, oxalic, and acetic acids that accelerate metal corrosion in the system, making it a more corrosive liquid than ethylene glycol.

Although propylene glycol has a lower freezing point and a slightly lower boiling point than ethylene glycol, it is not better as an antifreeze concentrate base because ethylene glycol has better thermal conductivity, higher corrosion resistance, and higher specific heat. Due to the aforementioned differences, ethylene glycol is more often used as a base for antifreeze concentrates, but newly emerging environmental protection trends could encourage the more frequent use of propylene glycol.

Considering that both the most common alcohols used as the base of antifreeze concentrate and the water with which they are mixed to form the coolant are highly corrosive materials, it is necessary to add corrosion inhibitors to them. Corrosion inhibitors are additives most often added to antifreeze concentrates to prevent or slow down the chemical reaction of metal corrosion. Corrosion causes the separation of oxide particles from the metal surfaces, which are retained and mostly deposited in refrigerators, thus impairing the necessary cooling effect [9]. They are classified into three types: Inorganic additive technology (IAT – inorganic additive technology), Organic acid technology (OAT – organic acid technology) and Hybrid organic acid technology (HOAT – hybrid organic acid technology).

Inorganic additive technology (IAT) involves the use of inorganic compounds as corrosion inhibitors such as silicates and phosphates. In principle, silicates and phosphates protect against corrosion in the same way, but they differ in their chemical nature and mechanism of action. Silicates are inorganic compounds containing silicon and oxygen. Phosphates are inorganic compounds containing phosphorus and oxygen. IAT corrosion inhibitors were of greatest benefit when rust in the cast iron engine block and other cast iron cooling system components was the primary item requiring protection.

Organic acid technology (OAT) uses only organic acids such as carboxylates and triazoles as corrosion inhibitors [15]. The technology of organic acids came to life during the 90s of the last century due to its long life, high efficiency and harmlessness towards the environment. Hersch, et al. [16] described the mechanisms by which organic acid inhibitors protect ferrous metals. Organic acid inhibitors prevent the adsorption of aggressive ions in the place where

the oxide layer is destroyed by creating a temporary protective layer. This mechanism can also explain the corrosion protection of aluminum. In particular, carboxylate inhibitors do not create a protective layer over the entire surface of the metal component, they are only adsorbed in places where corrosion occurs, and form protective layers [4].
Hybrid Organic Acid Technology (HOAT) combines the advantages of OAT and IAT technologies to provide a high level of corrosion protection and keep cooling systems functioning optimally. It consists of organic compounds such as amines, benzothiazoles, benzotriazoles and imidazoles in combination with inorganic compounds such as phosphates, silicates, nitrates and borates [3]. The principles of metal protection are the same as with OAT and IAT technologies.
Coolants are commercially available in two forms – as antifreeze concentrate and as a ready mixture. Antifreeze concentrates must be diluted with water before adding them to the car, as we already know in a ratio of 50:50. It is also of great importance that distilled water is used when diluting in order to avoid the accumulation of scale in the cooling system, regardless of the fact that in Europe from manufacturer's requirement that the coolant must be compatible with local hard water.
Different types of antifreeze are distinguished by the corrosion inhibitors used in them. It is possible to distinguish between three types of antifreeze: inorganic, organic and hybrid. In order to distinguish which type of antifreeze is in the package, it is necessary to pay attention to the marking of the manufacturer's standard on the package and the color of the antifreeze.
Since each group of vehicle manufacturers uses its own standards for antifreezes, we will in Table 3 observe the standards of the VW group and compare them with the standards and products of the world's largest chemical concern BASF and the manufacturer PENA [17 - 19].

***Table 3**. VW, BASF and PENA refrigerants [17 - 19]*

VW	BASF	PENA	Color	Description
G11	G48	NF	Green / blue	EG + Inorganic corrosion inhibitors (Si) or Si - OAT
G12			Red	EG + Si - OAT
G12+	G30	AL EXTRA	Pink/red	EG + Si - OAT
G12++	G40		Pink	EG + Si - OAT
G13		BIO GREEN	Purple	Glicerin + Si - OAT
G12evo	G65		Purple	EG + PSi - OAT

It is recommended to avoid mixing antifreezes of different types or different manufacturers, unless the manufacturer's specification states that the products are compatible for mixing, as in the case of G11 and G12+ antifreezes. The general rule is that antifreezes of a "higher" type can be put into antifreezes of a "lower" type, but not vice versa. For example, G12+ antifreeze can be added to G11, but G11 should not be added to G12+.

Analysis of the basic properties of the coolant

Coolant gradually degrades due to continuous heating and cooling cycles and interaction with metal parts of the engine. This process is inevitable and with it the coolant loses the properties obtained by adding antifreeze (lowered freezing point, higher boiling point, protection against corrosion, etc.) thereby jeopardizing the optimal efficiency and longevity of the engine. Therefore, periodic testing of the properties of the coolant in the cooling system is necessary in order to avoid the aforementioned negative consequences. Three tests are generally performed to check the properties of the coolant - visual test, pH value test and freezing point test. The visual test, as the name implies, observes the appearance of the coolant sampled from the expansion or overflow vessel. If the color of the sampled coolant is darker than the color of the used antifreeze concentrate and if there are pieces of rust or debris at the bottom, it can be established that the coolant has degraded significantly. Testing the pH value determines the acidity of the coolant. It is preferable that the reading values are in the interval between 8.5 and 10 on the pH scale because then the coolant is not acidic (< 7 on the pH scale) and does not pose a threat to cooling system components such as gaskets and rubber hoses. The freezing point test will be performed and explained in more detail in the next subsection. If the tests give unsatisfactory results, it is necessary to replace the coolant in the car.

DETERMINING THE FREEZING POINT OF THE COOLANT

A lowered freezing point is one of the key properties obtained by adding antifreeze to the coolant. It, like most of the other properties obtained by adding antifreeze, is lost through the gradual degradation of the coolant. This is a big problem because during the winter months, especially when the outside temperatures are lower than 0 ℃, there is a danger of the water in the cooling system freezing, which can cause system components to crack. That is why it is recommended to check the freezing point of the coolant in the cooling system before such temperatures occur. It can also be used to determine the concentration of antifreeze in the coolant, which, as is mentioned earlier, has a significant impact on the other properties of the coolant, and the boiling point of the coolant (a higher boiling point prevents the occurrence of cavitation and evaporation of the liquid). In the event that testing determines an unsatisfactory freezing point, it is not necessary to change the coolant in the system, but you can just add antifreeze concentrate until a satisfactory freezing point temperature is obtained. In the following experiment, the freezing point of nine coolant samples with different concentrations of distilled water and antifreeze was measured (10 : 90, 20 : 80, 30 : 70, 40 : 60, 50 : 50, 60 : 40, 70 : 30, 80 : 20 and 90 : 10) and a sample of pure antifreeze with a refractometer and a floating hydrometer (Fig. 3). All samples are in 100 ml plastic bottles, and all ratios shown refer to the volume fraction of distilled water and antifreeze contained in the coolant sample. The antifreeze used is G12+ standard antifreeze concentrate from the Croatian auto cosmetics manufacturer PENA called "AL EXTRA". After measuring the freezing point of all samples with both instruments, authors compared the obtained results with the values shown in the graph in Fig. 2 in order to distinguish which measurement method provides accurate results and better value for money, given that the price of these two instruments varies considerably.

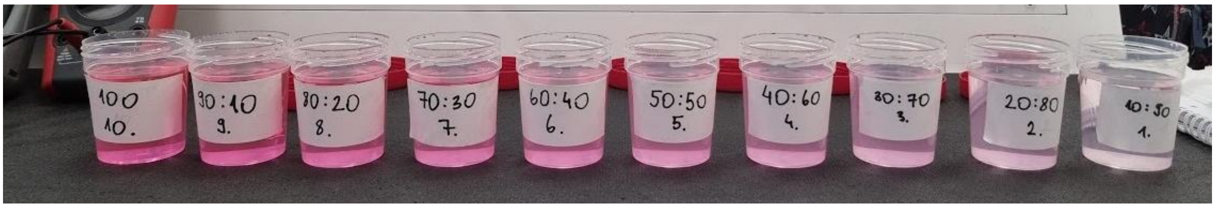

Fig. 3. *Coolant samples of 100 ml with different volume fractions of distilled water and antifreeze*

The first measurement is performed with a refractometer (Figure 4). A refractometer is a measuring instrument used to determine the refractive index of a material. Since the refractive index of solutions is proportional to their concentration, the refractometer enables us to determine the proportion of antifreeze in the coolant. It consists of a light filter, calibration screw, focus adjuster, main prism assembly, eyepiece and rubber handle.

Fig. 4. *Refractometer BAHCO 3046-REF*

When a beam of light passes through the sample, it is refracted at a certain angle, and further passing through the prism intensifies this refraction so that it is more noticeable. After the beam of light exits the prism, a point is formed on the scale that shows how much the light is refracted. In this way, something can be learned about the observed liquid, depending on the setting of the scale, as in this example, the freezing point of the cooling liquid. Before starting to measure the freezing point of the coolant, it is necessary to calibrate the refractometer.

First we open the light filter to be able to put two drops of distilled water on the prism, then we close the light filter and leave the sample for 30 seconds to adapt to the ambient temperature of the refractometer. Then we place the refractometer on the side where the light filter is located in front of the light source. During this time, we will observe the circular field through the eyepiece (the upper part of the field is blue, and the lower part of the field is white) in which there is a scale, and we will use the sharpness adjuster to increase the sharpness of the circular field in order to get a clearer image (Fig. 5).

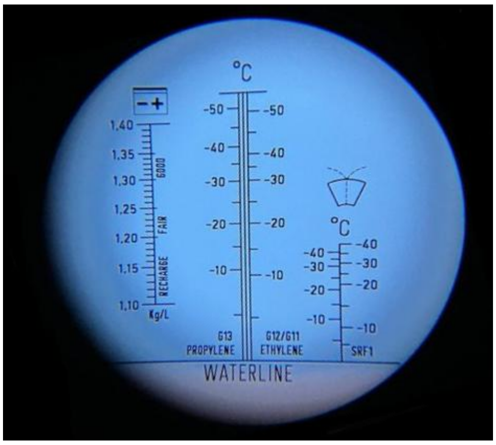

Fig. 5. *Calibrated scale visible in the eyepiece of the refractometer*

The calibration of the refractometer is completed when, by turning the calibration screw, we set the boundary between the two parts of the field on the line marked "WATERLINE". When we find that the refractometer is calibrated, we will wipe the prism with a soft cloth and put two drops of the coolant test sample on it. Then we put the refractometer again on the side where the light filter is located in front of the light source and through the eyepiece we observe the change of boundaries between the two parts of the field. The boundary between the two parts of the field will now be on the scale and will represent the freezing point of the coolant sample. We record the read value and repeat the process for the other samples.

The second measurement is performed with a float hydrometer (Fig. 6). A float hydrometer is a measuring instrument used to measure the relative density between a float and a coolant based on the principle of Archimedes' law. The coolant is extracted from the container with a pump, which creates the vacuum needed to suck the coolant into the glass housing of the hydrometer, which has a temperature scale with a float on the bottom. After the coolant reaches the glass case, the temperature scale with the float at the bottom floats on its surface partially submerged. By Archimedes' law, we know that the buoyancy acting on an immersed body is equal to the weight of the liquid displaced by the body. In the case of a float hydrometer, the buoyancy acting on the float is equal to the weight of liquid displaced by the float. Its action enables the float to float on the surface and sink to a depth corresponding to the density of the coolant. The higher the density of the liquid, the less the float sinks into it. As the specific density of ethylene glycol is higher than the specific density of water, we can conclude that coolants containing a higher volume fraction of antifreeze are denser than liquids containing a lower volume fraction of antifreeze. This would mean that the float will be more deeply immersed in coolants that contain a smaller volume fraction of antifreeze. According to this data, a temperature scale was designed at the bottom of which the float is located, enabling us to read the freezing point of the coolant depending on the depth at which the float is located.

Fig. 6. *Hydrometer with float*

The results of measurements with a refractometer and hydrometer with a float and the corresponding values from the graph in Fig. 2 are shown in Table 4 in which t_1 the values measured by the refractometer, t_2 the values measured by the hydrometer and t_3 the values from the graph in Fig. 2 are indicated.

Table 4. *Measurement results*

Ratio (antifreeze : $H_2$0)	t_1 (℃)	t_2 (℃)	t_3 (℃)
10 : 90	-3	-12	-3
20 : 80	-9	-17	-8
30 : 70	-12	-23	-10
40 : 60	-20	-27	-22
50 : 50	-30	-32	-34
60 : 40	-44	< -34	-51
70 : 30	< -50	< -34	< -60
80 : 20	< -50	< -34	< -60
90 : 10	< -50	< -34	< -60
100 : 0	< -50	< -34	< -60

CONCLUSION

The coolant is a mixture of distilled water and antifreeze, and due to the influence of corrosion inhibitors, their freezing point can be most accurately determined by measurement. Since antifreeze consists of a base and various additive, depending on the type of base material, antifreeze can raise the boiling point of the solution with which it is mixed. In antifreeze concentrates, the base makes up 94% of the weight of the formulated product. That is why it is important that the base of the antifreeze concentrate consists of a medium whose boiling point is higher than the boiling point of distilled water. Otherwise, they evaporate before the water, which can result in the formation of concentrated steam that can be flammable. Also, the coolant loses its properties through exploitation due to the addition of antifreeze (lower freezing point, higher boiling point, protection against corrosion, etc.). Therefore, in this work, the freezing point of the coolant was determined on samples with different proportions of antifreeze and distilled water. Antifreeze concentrate standard G12+ was selected. The test was carried out with a refractometer and a floating hydrometer, and the measurement results were compared with those from the relevant literature. It was found that when increasing the proportion of antifreeze in the coolant samples, the expected result was a lower freezing point of the coolant. The measurement results obtained using a refractometer were closer to the results from the relevant literature. This indicated that the measurement results obtained using a refractometer were more accurate than those obtained by measurements using a floating hydrometer.water is higher. This indicates the fact that the refrigerant loses its properties through exploitation.

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PRODUCT DEVELOPMENT OF AN INDUSTRIAL CONTROL SYSTEM FOR ROTOR WITH A FOCUS ON DESIGN FEATURES

Research paper

Jure Marijić[1], Ivan Grgić[1], Marko Vilić[1], Mirko Karakašić[1], Željko Ivandić[1]
[1]University of Slavonski Brod, Mechanical Engineering Faculty in Slavonski Brod, Slavonski Brod, Croatia

Abstract: The growing demand for electrical products means that the production of basic parts such as stators and rotors must be intensified in order to meet market demand. This increase in demand requires faster and more efficient production processes. The stamping process produces a large number of components that require detailed quality control due to their technical complexity. Given the high production volume, checking all components becomes a challenge, especially given the time constraints. Often, the time required for production does not match the time required for detailed quality control, which can lead to downtime or increase the number of defective products. Therefore, it is crucial to develop and implement a control system that can check quality within the specified time frame.
This paper presents an innovative solution that focuses on the design features of an advanced control system. The proposed system enables precise control of the internal diameter of the rotor, which is crucial for ensuring the correctness of the product. The system also enables automatic sorting of the rotors according to their correctness, which further improves the efficiency of the production process.
Key words: *Product development, design features, stamping, production*.

INTRODUCTION

Stamping, the process of processing metals or non-metals without separating the particles, is becoming increasingly important in the context of modern production requirements focussed on mass and serial production. This technique is an optimal choice due to its ability to automate machines and achieve a high level of productivity, [1].
The progressive tool can be seen in Fig. 1. performs several operations at different stages in each stroke as a key aspect of this process, allowing complex geometric shapes to be achieved, [2]. The material passes through a series of specialised cells that perform various operations and shape the material into the final product, [3]. In a progressive tool, the product is manufactured by moving the sheet metal through the processing stages in stages, achieving a specific shape at each stage until the product is completely finished, [4]. Progressive tool is particularly suitable for the continuous production of thin sheets with complex geometries, where the same sheets can be combined into stacks, further increasing the efficiency of the production process. These tools are extremely efficient in the production of large quantities of products, making them indispensable in the industry, [5].
The analysis of the available literature did not reveal any work on this topic, but the analysis of the products available on the market showed that there are various structural solutions, [6]. Since stamped products often have complex geometries and are defined by a narrow tolerance range, it is important to perform quality control. Control points such as outer and inner diameters as well as the product height are specified by the manufacturer, which often requires the development of special testing machines that meet the highest standards of precision and reliability. The following describes in particular the structural development of the system for testing the internal diameter of the rotor. The design solution is presented in two separate phases:

- Input system in the control system,
- Checking the internal diameter of the rotor.

The 3D modelling package SolidWorks was used to create the 3D model of the rotor, which is the starting point of the development, and to develop the control system as a whole, [7].

[1]Corresponding author, jmarijic@unisb.hr

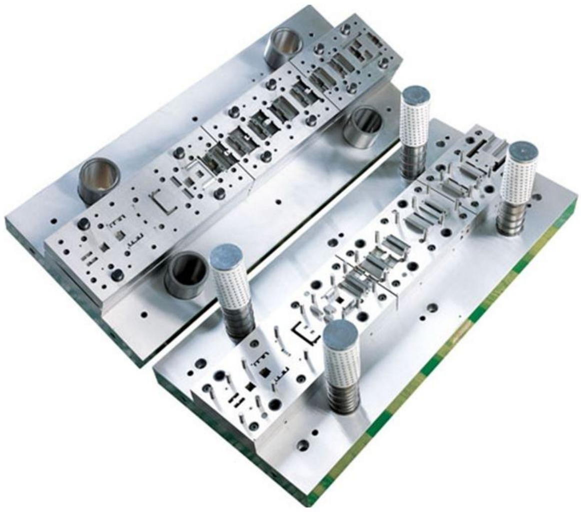

Fig. 1. *Progressive stamping tool*

MATERIAL AND METHODS

Conceptual solution of A control system

After defining the list of requirements and creating a morphological matrix and combining different solution principles for the execution of sub-functions of the control system for controlling the internal diameter of the rotor, two variants were selected. The optimal solution shown in Fig. 2. was determined by the evaluation procedure. It should be noted that all solutions fulfil the requirements specified in the requirements list.

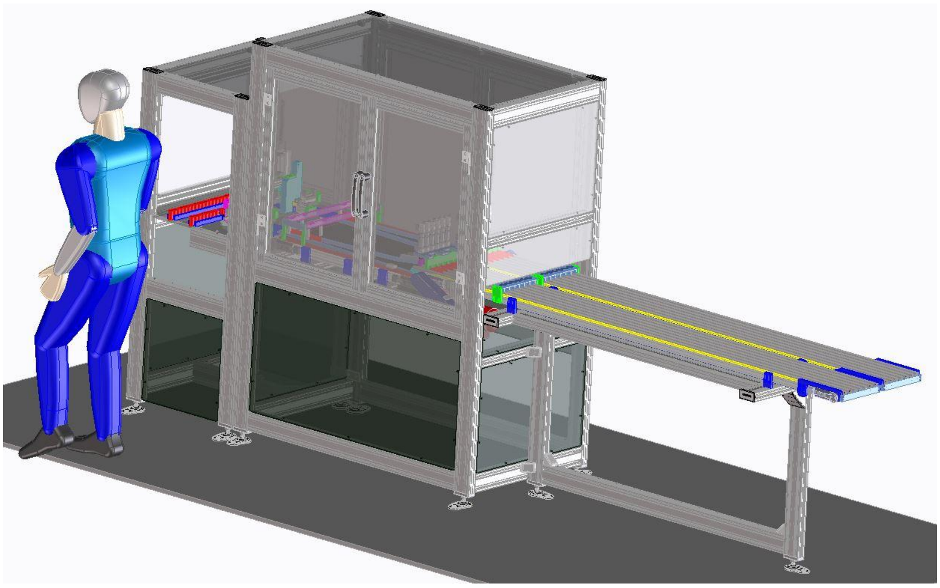

Fig. 2. *Conceptual design of a control system*

The principles of Design for Assembly and Design for Maintenance were followed in the development of the structural solution. By applying the guidelines of these approaches, the chosen project solution offers a defined function and functionality. The design includes standard profiles and connecting elements which minimises the machining requirements when creating the project solution, [8]. Guided by such an approach, a system was developed that enables function, ensures the availability and interchangeability of structural elements, guarantees the safety of employees, facilitates maintenance and reduces the time required for assembly and disassembly, [9].

Fig. 3. shows the finished industrial control system from Experio d.o.o. In the continuation of the article, the development and design features of the two phases mentioned in the introductory part are presented.

Fig. 3. *Industrial control system from Experio d.o.o.*

Input Assembly of the Control System

It should be emphasised that the input assembly is divided into two units. Both units are defined by the customer's project requirements:

- 12 input lines in which the products are arranged horizontally,
- 2 output lines in which the products are arranged vertically.

The complete input assembly can be seen in Fig. 4., while Fig. 5. shows the design requirements in terms of product positioning. In the rest of the text, the individual solutions for the design requirements mentioned are described and presented, as well as their mutual connection and design solutions for individual problems arising from the combination of the requirements mentioned.

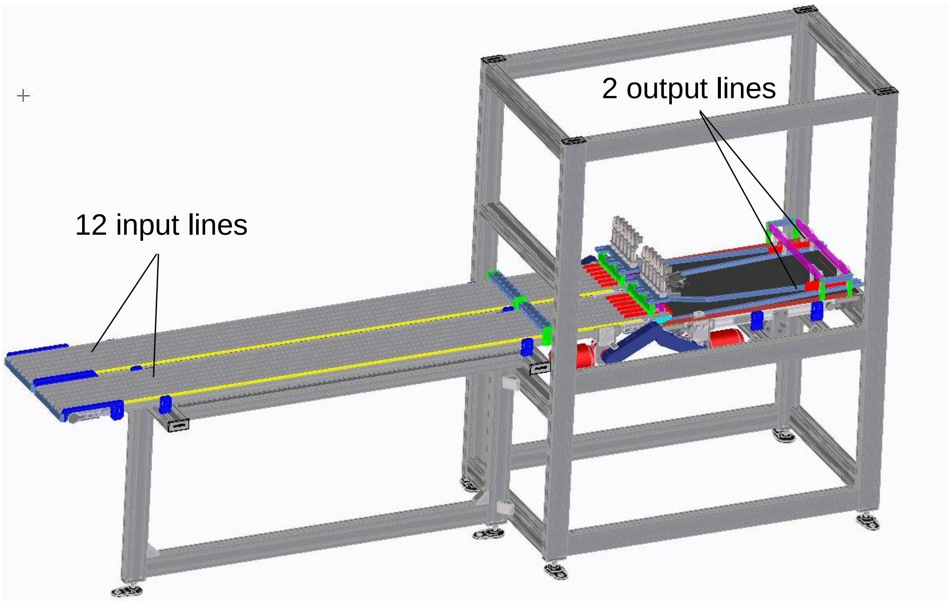

Fig. 4. *Input Assembly of the Control System as 3D model*

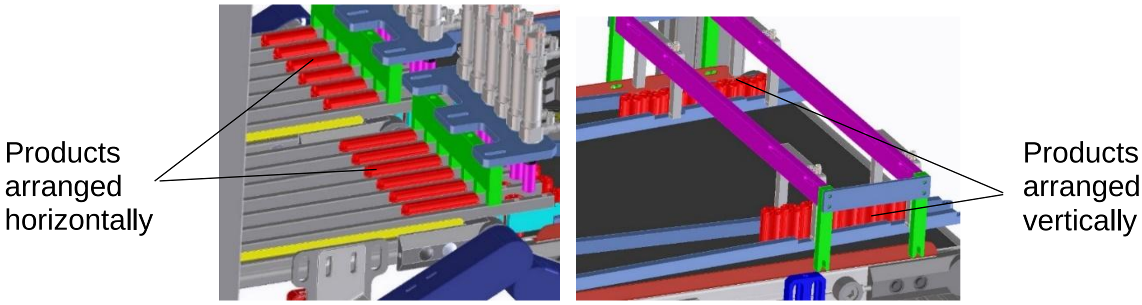

Fig. 5. *Design requirements for the input and output of the input assembly*

The solution for the above-mentioned design requirement with 12 input lines contains two equally sized evacuation lanes. This solution was chosen due to the optimal dimensions of the conveyor belts, which maximise the efficiency of product evacuation. The details of this solution are shown in Fig. 6.

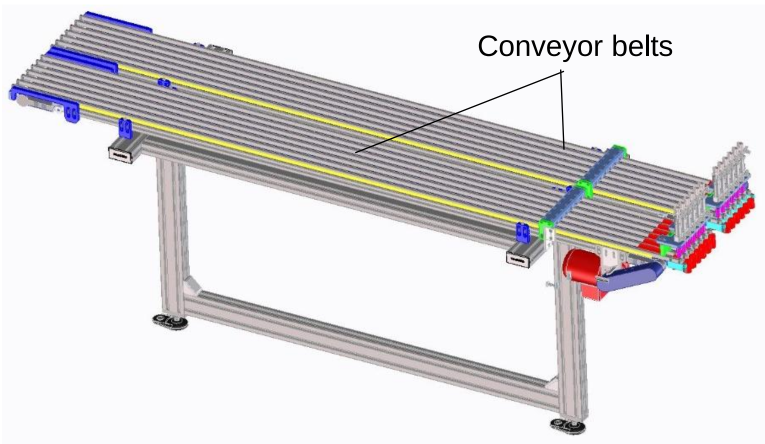

Fig. 6. *Two conveyor belts for 12 input lines*

Conveyor belts are based on the principle of rotating rollers over which the belt is pulled. The basic mechanism of torque transmission is based on the frictional force between the belt and the rollers. Friction enables torque to be transferred from the rollers to the belt, which fulfils the main function of transport. The torque required to start the system is generated by an electric motor. This torque is transmitted to the shaft inside the rollers via a belt. The shaft is slotted and connected to the rollers via a spring, which enables the rollers to rotate and thus the conveyor belt to move. The conveyor belt consists of two main parts:

- driven roller,
- free roller, [9].

The input system and the entire control system for the rotor are designed according to guidelines that enable easy assembly and disassembly. Due to the dimensions of the conveyor belts and the complexity of the entire input system, it is necessary to ensure the possibility of manipulation. The solution can be seen in Fig. 7.

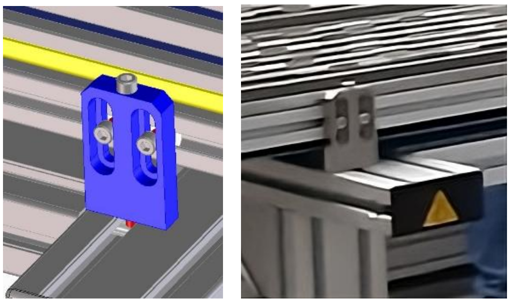

Fig. 7. *Part for the manipulation of conveyor belts*

As mentioned in the previous text, the input products must be placed horizontally, while the products at the output of the input assembly must be positioned vertically in order to control the internal radius. The design solution utilises the free fall of the product from one conveyor to another using pneumatic cylinders with a piston that act as stops or product guides to maintain the vertical position during the fall, [10]. An inductive sensor has been installed which, when activated, pulls out the piston and prevents the product from tipping as it falls. This can be seen in Fig. 8., both in the 3D model and in the explant. Here it becomes clear why the ability to manipulate the conveyor belts was necessary to connect the two systems as easily as possible.

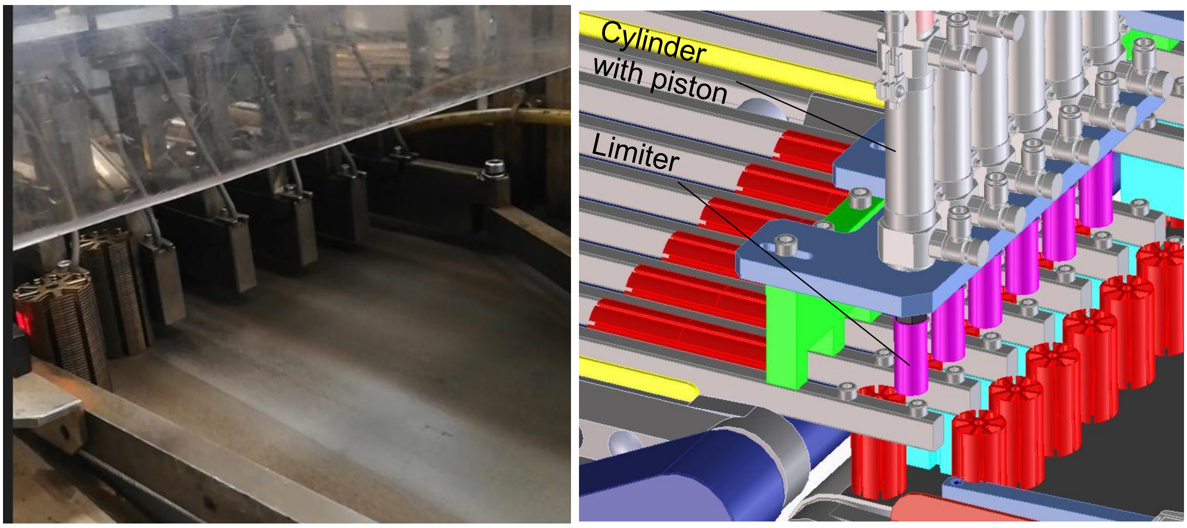

Fig. 8. *Method for product positioning*

As already mentioned, the design requirement for two output lines was solved by using a conveyor belt. Twelve lines are fed into two output lines via a product diverter and a vibration system, as shown in Figure 9. The vibration system uses frequency vibrations to prevent the rotor from sticking to the wall of the cutter, [11]. Inductive sensors are attached to the output lines to ensure product tracking through the system, [12].

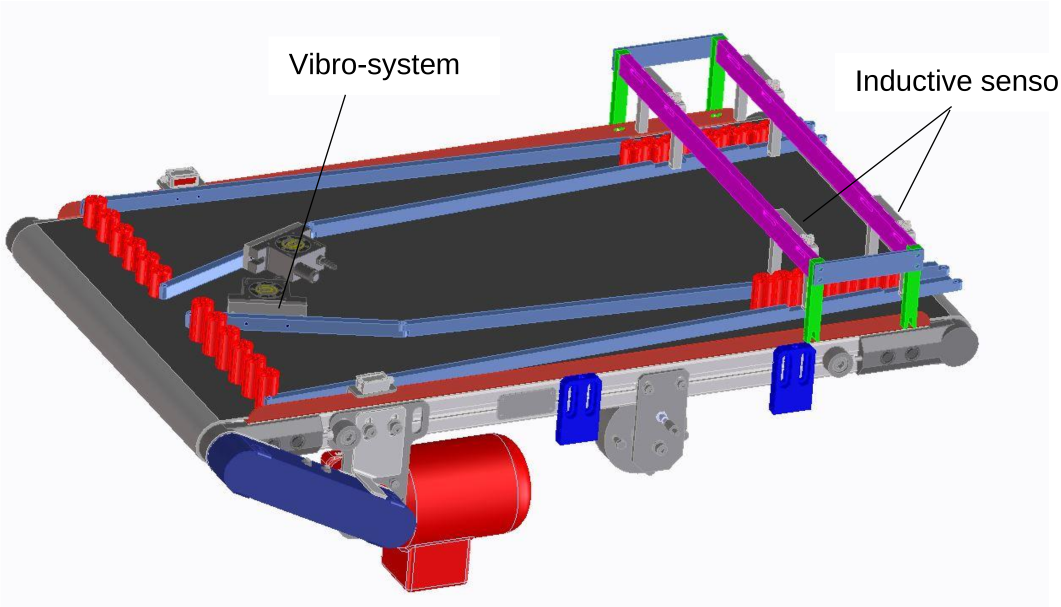

Fig. 9. *Product diverter and a vibration system*

Control of the inner diameter of the rotor

It is important to point out that the control system for checking the internal diameter is defined in two lines according to the design task in order to ensure the flow of the entire input control system. The two lines mentioned are structurally identical, so that only one is described in the following text. Fig. 10. shows the control system as a whole, while Fig. 11. and Fig. 12. show the functional principles. Fig. 13. shows the parts of the control system in use.

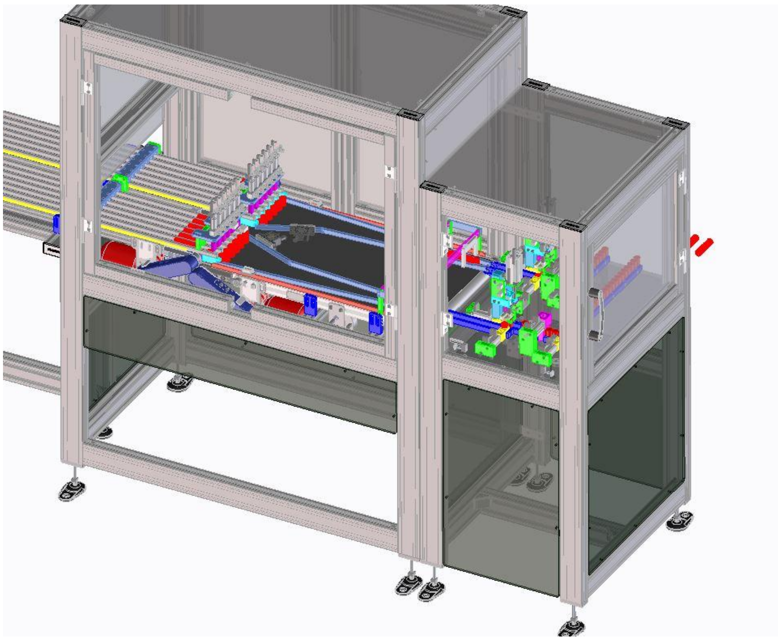

Fig. 10. *Control system as 3D model*

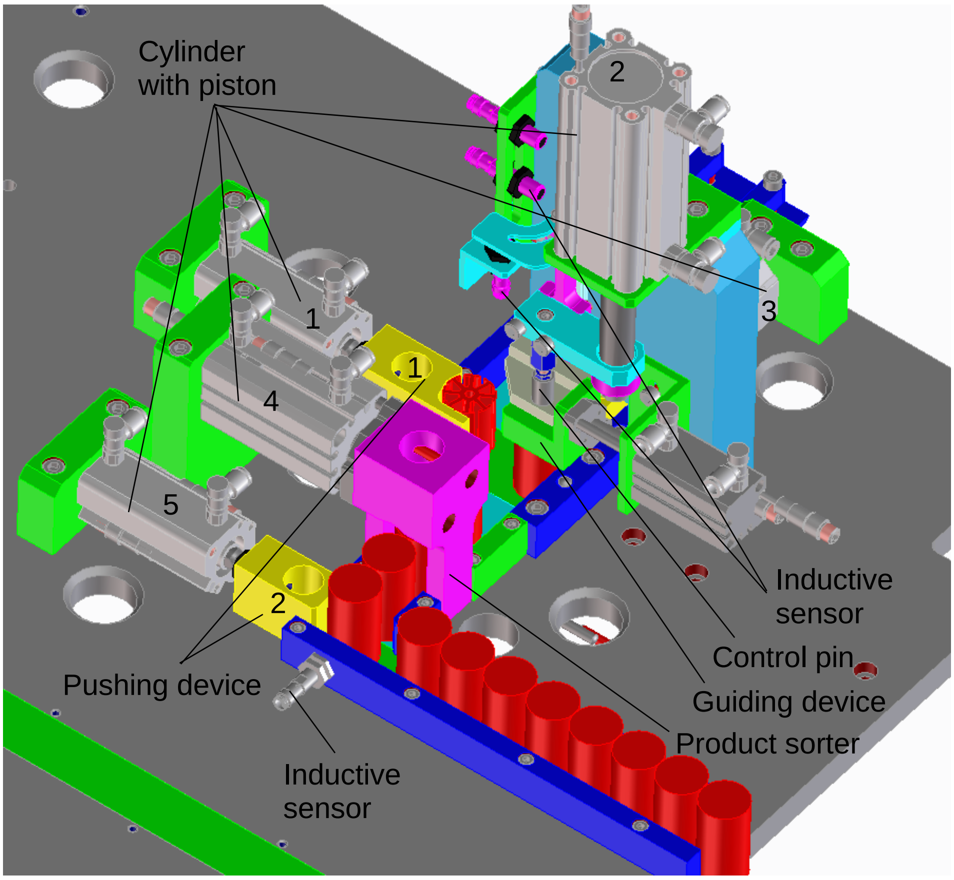

Fig. 11. *Work principles*

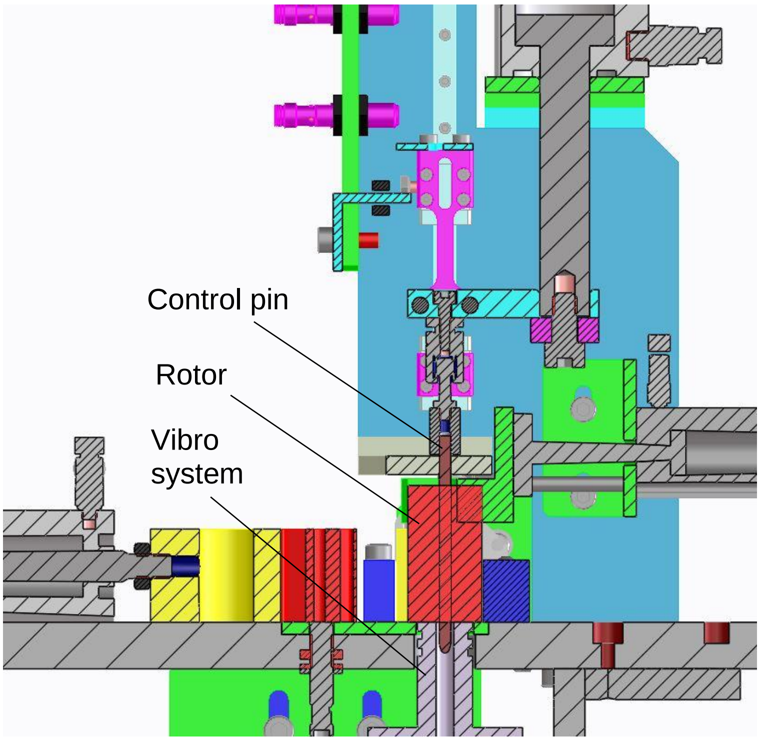

Fig. 12. *Cross-section of the control station*

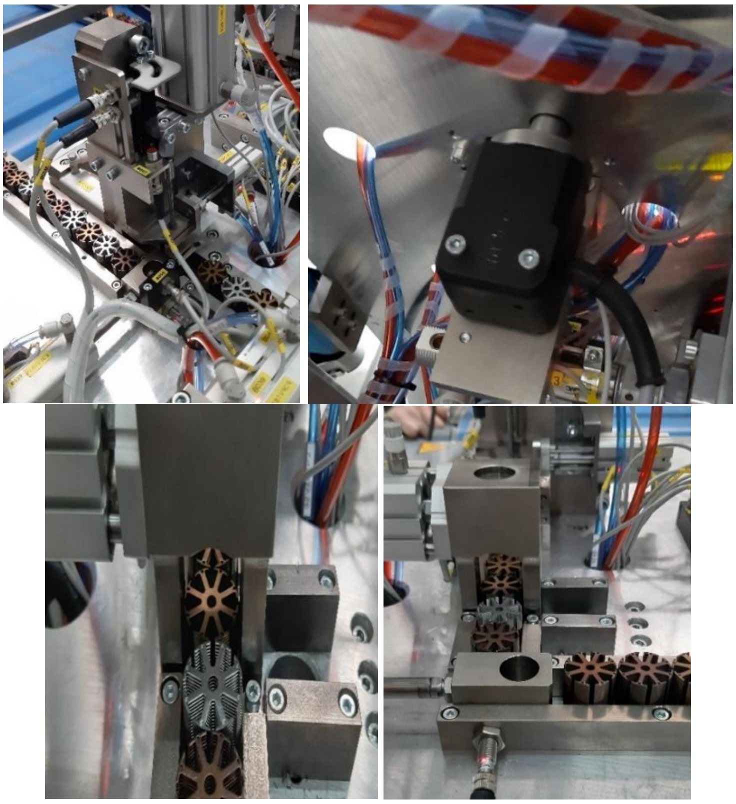

Fig. 13. *Control system in operation*

The control system for the inner diameter of the rotor is based on the free fall of a directional control pin through the specified diameter. The first task was to position the rotor in the control station. The movement of the rotor through the control system is achieved by cylinders with pistons and rams, which can be seen in Fig. 11. Inductive sensors make it possible to monitor the position within the control system and activate the necessary pushing and guiding device to perform the functions at hand. As can be seen in Fig. 11, the rotors entering the control system push each other towards the cylinder with the piston 1. By activating the said cylinder with the pusher 1., the rotor is positioned in the control station. The control pin then falls freely through the inner diameter of the rotor. The positioning of the control pin is defined by a cylinder with a piston 2. and inductive sensors as controls. Under the rotor in the control station is a vibration system that eliminates small disturbances in the positioning of the controlled diameter of the rotor in relation to the control pin. Fig. 12. shows the operating principle of the control with a control pin described above. After the control, the cylinder with the piston 3. is activated, which pushes the rotor further through the system. If the control pin does not pass through the rotor, the inductive sensors check the position of the pin, the cylinder with the piston 4. is activated and the product sorter pushes the rotor out of the control line. The flow chart described above ensures the quality control of every rotor that enters the system.

CONCLUSION

The modern growth in demand for electrical equipment has had a direct impact on the need to develop advanced control systems for rotors, products of the stamping process. The increased demand for the stamping of stators and rotors, the key parts of electrical devices, requires the development of sophisticated control systems to monitor the stamped products due to their complex geometry.
This paper presents the structural development of the control system for monitoring the internal diameter of the rotor. The control system is described in detail as a whole and divided into two basic functions. By applying product design methods, features have been developed that

improve assembly, facilitate the procurement of spare parts, reduce the need for technological processing and enable a modular structure.

The experience gained after a certain period of application has shown that the response has been positive and that the structural solution fulfils all functional requirements as well as the requirements for easy maintenance, assembly and disassembly. In the context of today's trends in mass production, where the quality and cost-effectiveness of products are paramount, it is necessary to continuously work on the development of tools and equipment to meet the growing demands of the market.

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THE ROLE OF CERIUM AND PRASEODYMIUM AS RARE-EARTH ELEMENTS IN FILLER METAL FOR BRAZING DIAMOND – AN OVERVIEW

Research paper

Zoran Karastojković[1], Jasmina Pekez[2], Radiša Perić[3]
[1]Society for Ethics and Evaluation in the Arts and Sciences, 11000 Belgrade, Serbia
[2]Technical Faculty, University of Novi Sad, 22000 Zrenjanin, Serbia
[3] "Perić&Perić"d.o.o., Dunavska 114-116, 12000 Požarevac, Serbia

Abstract: In brazing technology is not common practice the use of pure metals as a filler material, but rather in the form of an alloy. A versatility of alloys was developed for use in brazing or soldering, however as in welding. Rare-earth elements (REEs) have specific chemical and metallurgical properties and they are not commonly used in the making of a filler alloy. So, it would be expected that cerium, praseodymium and samarium, as part of group REEs, may be used for improving some specific properties of a filler brazing alloy. Providing brazing technologies includes a versatility of chemical and metallurgical properties and demands that should be fullfilled, such as fluidity, strength, corrosion resistance, etc. Most of these properties may be satisfied when added cerium, praseodymium or other REEs in small amounts in brazing filler metal (BFM). For economical reasons, the using of REEs is not profitable, because they are expensive, rather than for technological reasons, at first for deoxidation during melting and improving the wettability. For brazing diamonds such expensive filler metal could be used only if the bond strength is increasing.
Key words: brazing, cerium, praseodymium, doping, filler metals

INTRODUCTION

Brazing technologies are not present in industry or laboratory investigations as welding does. Besides this, brazing finds very specific applications from joining the gutter (made from zinc-coated steel sheet) up to the space shuttle (ceramics plates are brazed on the light metal structure).
The oldest brazing filler metals belong to precious metals, as gold and silver.
Later, brass was used in many applications, and now brazing is used for the joining structural components, as well in the tool industry for fastening a "hard metal" (almost carbides), including brazing of wolfram-carbide inserts on cutting or percussive tools. Now, the most known group of brazing alloys are based on silver with the addition of versatility elements, such as Cu, Zn, Ni, Mn, and others. Rare-earth elements (REEs) in the alloying of BFM are not yet common in industrial practice for joining the same or different materials. Here will be analyzed the influence of cerium and praseodymium in some BFM
Cerium and praseodymium, as other REEs, belong to the middle of the Periodic table, see Fig. 1, but the name of the whole group now is a misnomer, because their presence in nature are greater in comparison to Ti, Mo,W and others. In the time of discovering (18th century) REEs were rare, indeed. Generally, all of the REEs have low toxicity, which means they can be handled safely, [6].
In nature, REEs cannot be found at the elementary state but in compounds, so they're solvent extraction (as metallurgical) processes really is complex – some times is needed a hundred even thousend of cycles for producing the 99,9% purities, this fact acts on their high price. Instead of it, the uses of REEs are growing in electronics, mobile phones, fuel cels, for high-performance (permanent) magnets, for catalysts, ceramics, glass polishing, etc. Cerium is used in metallurgy to stabilize the structure, also could be used in welding, one of its minor application is brazing, [4].
Producing of brazing filler metal became a challenge, from many either technological or economical aspects. REEs could be used in a variety of BFM, here will be shown some results in brazing of diamonds.

[1]Corresponding author, zoran.karastojkovic@gmail.com
[2]pekezjasmina@gmail.com, ORCID:https://orcid.org/0000-0003-0454-5326
[3]pericradisa@gmail.com,

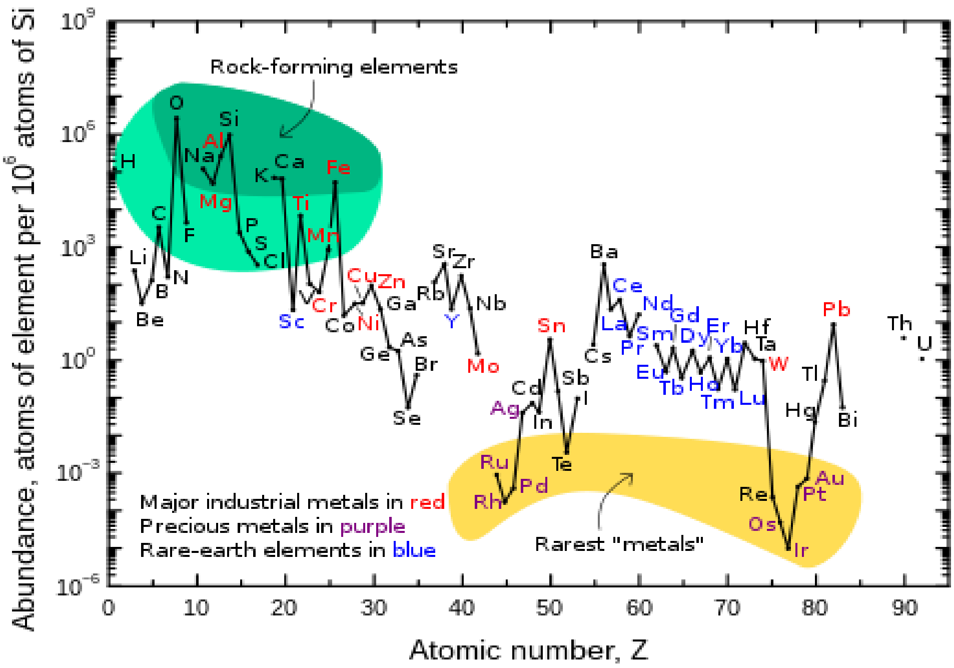


Fig. 1. *Distribution of REEs in Earth´s crust*

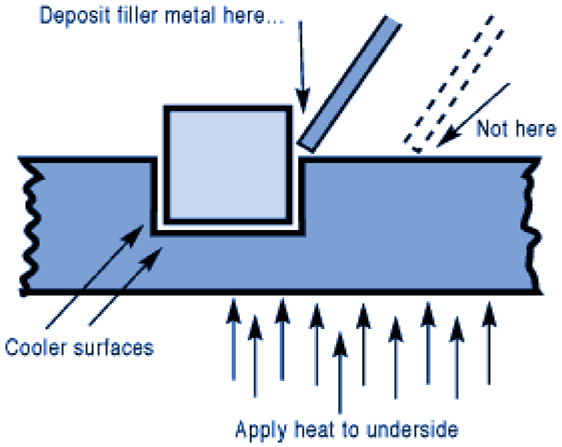
MATERIAL AND METHODS

Shortly about brazing filler metals

Brazing has a long history, above 4000 years, at the beggining was used for joining of noble metals at royal courts. According to the basic definition of brazing, this process is providing at temperaatures above 450^{0}C, without melting the parent metal. In brazing is obviously the usage of filler metal, which in molten state (slightly above its liquidus temperature) must fulfill the gap between close-fitting parts, known as capillary action - wetting. The protection atmosphere is desired, usually is provided by flux. The strength of brazed and cooled components are not as they welded. As a brazing filler metal in industry firstly were employed copper and copper alloys (with zinc or tin). There are number of alloys suitable for brazing on the basis of other non-ferrous metals, as aliminium, nickel, etc, but now in usage are dominant silver alloys. All of those brazing filler metals must fullfil certain demands, from which here will be discussed a few.

Heating-up for brazing

Design of brazing gap plays an important role, as well as the way of heating up BFM during brazing, when introducing the heat must be avoided directly on the filler metal, rather on the base metal, as well ilustrated in two examples in Fig. 1, see arrows. Filler metal must posses a good fluidity, so the direct heating up of solder, especially when flame is used, will be blowen-up the molten solder metal. Keep in mind that solders commonly are expensive, so blowing of melted BFM is not desired or cost effective process. Only when the base material is heated than the filler metal could be added, in Fig. 2a) it is represented as bar, with the exactly position for deposition.
If the filler metal is copper, as in Fig. 2b), than the heating up to the melting must be provided through the steel component.



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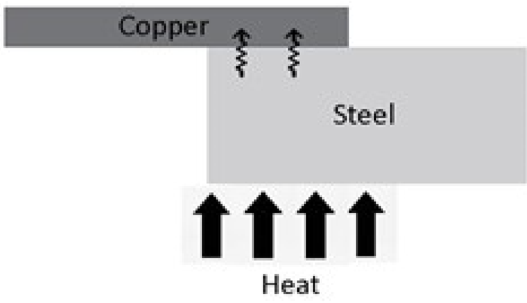
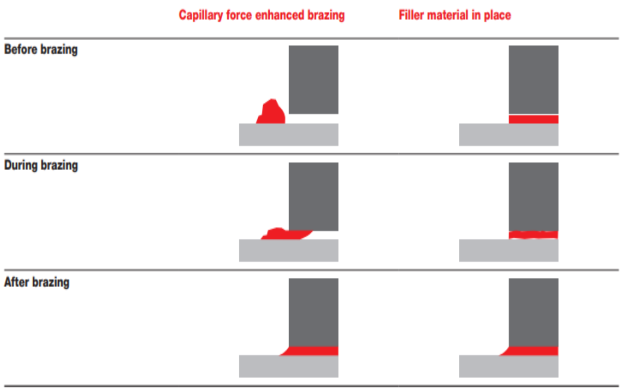


b)

Fig. 2. *Heating-up components for brazing*

Fluidity and wetting/capilary action

Fluidity is in close relation to the wetting properties, something similar to casting processes. Scheme for capillary actions are shown in Fig. 3a), and confirmation of successful brazing in reality is the best visible by applying the metallographic inspection, Fig. 3b).



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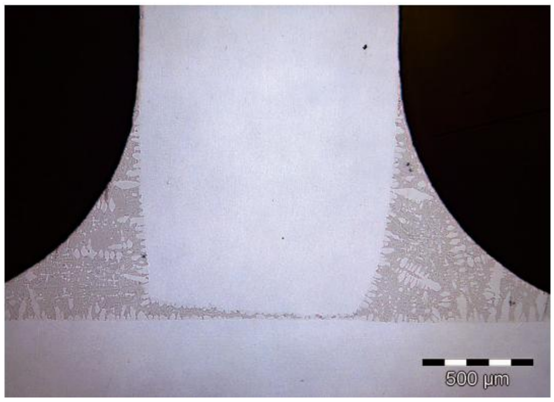


b)

Fig. 3. *Illustration of capillary actions a) and microstructure at one T-type joint after solidification b)*

Shortly about important properties of rees

In many science books, the REEs are described as chemicaly similar to one another, and they may be considered as one element. In fact, these elements posses:

- pretty high chemical activity (deoxidation/desulphurization in melts),
- silver, silvers-white or gray color,
- instead of their high luster they tarnish in air,
- high electrical conductivity,
- some of them have luminescent properties (when stimulated by electromagnetic radiation).

Almost of REEs melts at the middle range of temperatures: cerium posses the lowest melting temperature, 795^{0}C, praseodymium 931^{0}C, while lutetium melts at the highest temperature, 1663^{0}C. However, their alloys may be melted at ranges which are determined by metallurgical behavior, making eutectics, intermetallic compounds, versatility of phases, etc. Density of

REEs are in range of 4,47g/cm^3 for ytrium to 9,32 g/cm^3 for thulium. The REEs generally are trivalent, some of them are tetravalent (Ce,Pr,Tb), but a few can be divalent (Sm,Eu,Yt). All of REEs posses pretty high thermodinamic affinity, so they are able to produce wide range of phases or compounds with other elements from the nature, making: oxides, nitrides, carbides, sulphides, and/or halides.

Mechanical properties

Changes of moduli elasticity according to their atomic number is shown in Fig. 4.

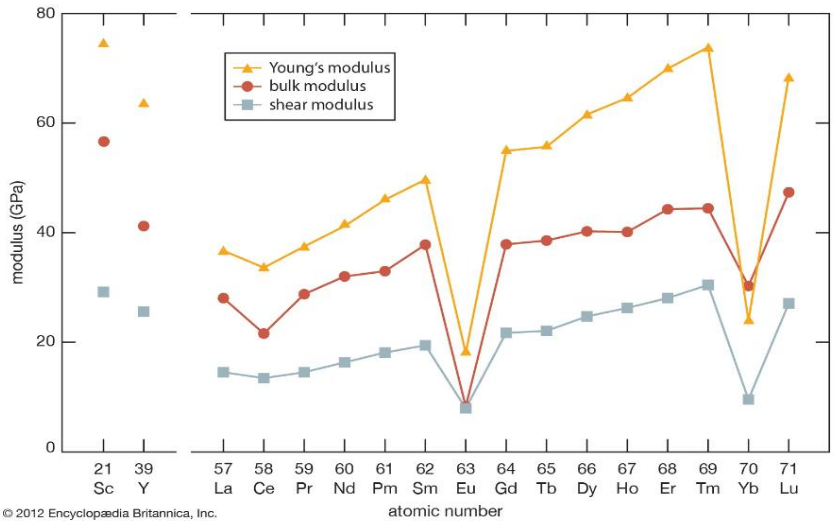


Fig. 4. *Elastic moduli of REEs according to their atomic number from Periodic table*

For comparison, the elastic moduli of REEs fall in the middle percentage of other metals. It is worthy to mention that REEs does not posses mechanical properties for example as like the most of steels, but they may increase these properties by treating a liquid metal (when an excess of oxygen is removed) and refining the solidified metal structure. The REEs are not weak metals but not especially strong (R_m=120-160MPa) and with moderate ductility (15-35%). In every case those and other properties markably depends from the purity of the REE metals.

Braze filler metal with some rees

Braze filler metal (BFM) ordinary contains various alloying elements for achieving versatile properties (physical, chemical and/or metallurgical), desirable for brazing process, including a postbrazing proces, as grain refining after solidification the melt, etc. The compatibility of the added element with base metal and with other alloying metals is necessary, indeed. For brazing diamonds in medical implatants usually is used golden BFM, as a qualitative biocompatible material.

The role of here refered metals into BFM may be described as in acting for: improving the wetting characteristics, deoxidizing role during melting, enhancing the corrosion resistance, contribute to higher strength, toughen the joint, increasing the service temperature of the brazed joint, but rarely REEs may suppress the brazing temperature at BFM, as for example cerium does. Those elements are making solid solutions with parent metal, but also may form nitrides, enhancing the strength of brazed joint. All REEs, generally, posses great chemical activity toward oxygen (and nitrogen from air), and from that may be successfuly used for deoxidation of melted BFM, [5,6]. Main oxides that can make cerium and praseodium are CeO_2, Pr_6O_{11}, but another types of oxide also may be found, [7]. REEs elements are multivalent, in the example of cerium it means oxides as Ce_2O_3 or Ce_3O_4. The most efficient glass polishing agent for optical lenses is considered to be CeO_2. Beside of here mentioned

metals, another kinds of REEs for example as Sm, Nd, Er, intensively are investigated for using as BFM, [5,6].
In particular uses, when the desired properties (as strength, corrosion resistance, etc.) are expected to be improved, than advanced group of brazing alloys may be used, some of them may be (micro) alloyed by using for example cerium, praseodium or samarium, until now. REEs generaly are expensive elements, it means that is not reasonable to use them for brazing of plane carbon steels or similar cheap alloys. Now, attempts were made for improving other the brazing characteristics in the brazing of diamonds or some structural alloys, [6,8,9]. Improving the brazing characteristics means, after all, leads to the greater abrasive strength of brazed diamond grits on the substrate.
Brazed diamond tools have shown some better characteristics than sintered or electroplated diamond tools. For diamond brazing tools as the main filler alloys are used Cu-Sn-Ti and Ni-Cr. The graphitization intensively is occured when the brazing temperature is above 900^0C, see Fig. 5a).

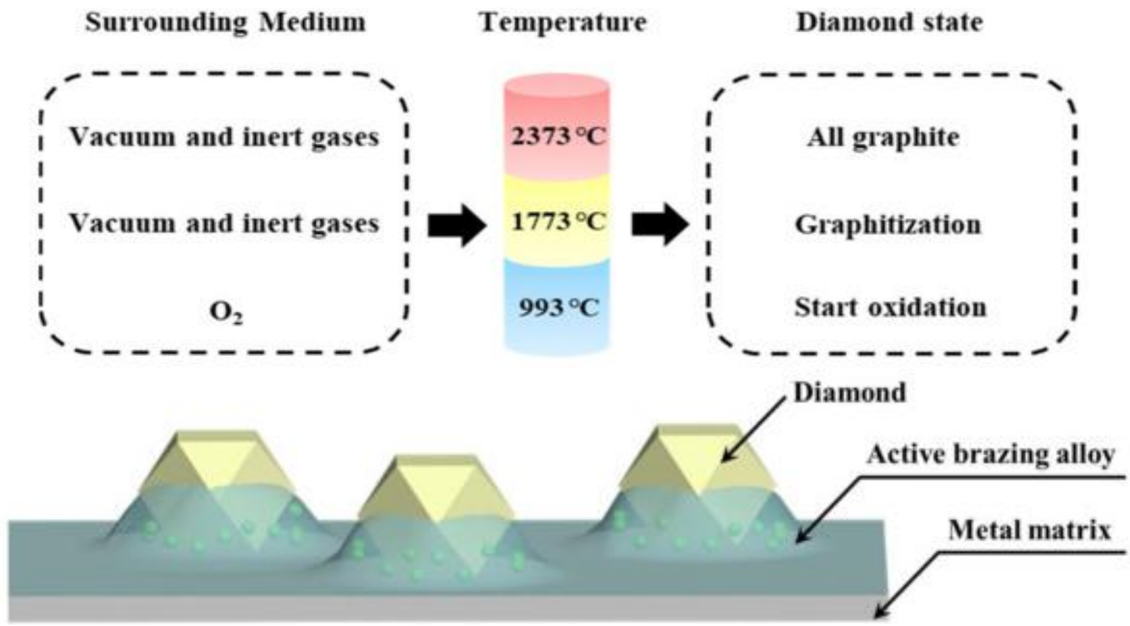


Fig. 5. *The influence of temperature and medium on diamond states a) and the role of BFM on wettability of diamond grits b)*

- **Brazing of diamonds by Cu-based alloy with cerium**

Cu-based filler metals, as a cheaper alloys, are applicable for brazing diamond. In using Cu-Sn alloys may be formed an intermettalic compound as like Cu_6Sn_5, which may have influense on increasing the strength but also on increasing the brittleness. In brazing alloy Cu-Sn could be added titanium [5], when the melting temperature and other mechanical properties usually are increased, so recently the alloys from Cu-Sn-Ti system recorded rising application for brazing diamond tools. But eventhough, this alloy needs further improving the brazing characteristics, one approach is to use a kind of another more alloying element in the BFM. In the case of Cu-based brazing alloy cerium and praseodium may influence on increasing the wettability, [5-8]. The transverse rupture strength (TRS) than depends from the contest of Ce, Fig. 6.

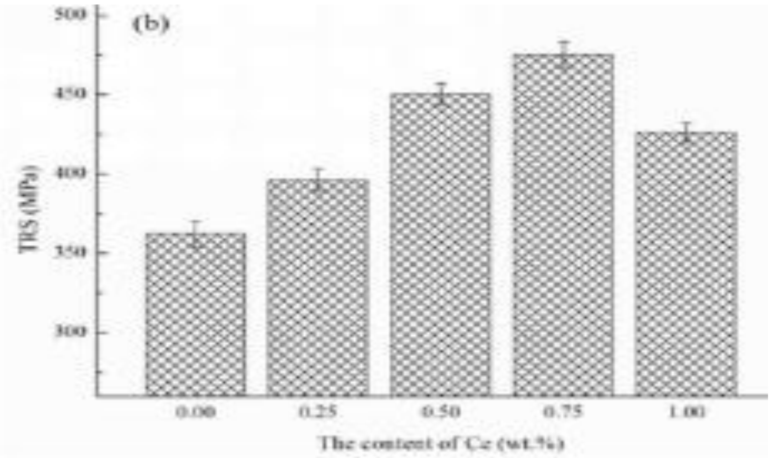


Fig. 6. *The influence of Ce content on TRS in Cu-Sn-Ti brazing alloy [7]*

The increasing of TRS is explanable by imroved wettability. Cu-Sn-Ti alloys do not have a high values of bonding strength to diamonds, it means that application of this alloy becomes limited. Adding of Ce, as a doping element, also promote the grain refinement of used brazing alloy. Doping of Ce into Cu-Sn-Ti usually is achieved by using a master alloy Cu-Ce. Also doping of Pr in Cu-Sn-Ti alloys leads to the excelent grain refinement, and to improving the bonding strength, while the grinding performance of such diamond tool is also improved, [6].

- **Brazing diamonds with Ni-Cr alloy**

For diamond brazing Ag–Cu-based alloys were used over a years, but now is tendency for applying Ni-Cr filler alloy as a cheaper alloy and from that fact has atracted more attention, [10]. Between BFM and diamond or steel substrate are possible many reactions, which must be carefuly monitored, some of them are scetched on Fig. 7. If carbides were formed they lead on increasing both hardness and strength of the bond.

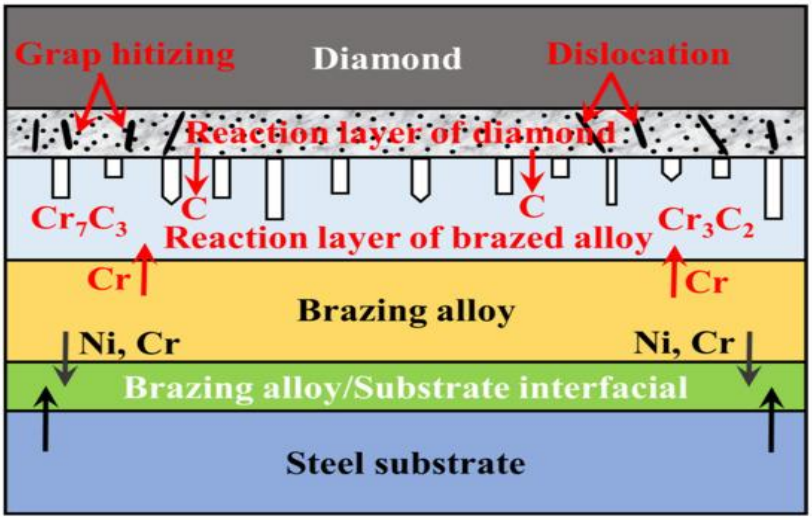
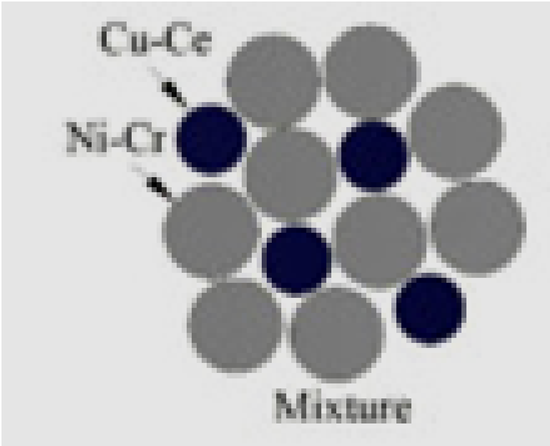


Fig. 7. *Reactions of BFM between diamonds and steel substrate when Ni-Cr alloy is used [13]*

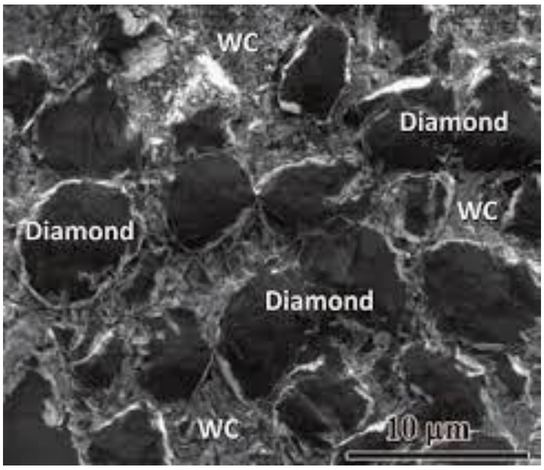
- **Brazing diamond with NiCr-x(CuCe) alloy**

Ni-Cr filler alloy has the advantages of: low cost, high temperature resistance and high wear resistance in comparison to previous Cu-Sn-Ti alloy. However, higher brazing temperatures (1080^{0}C for Ni-Cr) can cause thermal changes, when the graphitization (transform of diamond

into graphite) may took place, see Fig. 5, but Cu doping into Ni-Cr filler alloy can significantly inhibits the graphitization process which is the main influencing factor on the thermal damage of diamond, than on the tool performance, [10,11].
The most effective way for doping of Ce in BFM is through the Cu-Ce alloy. All of these factors can affect on the performance, for exploaration of diamond tools the wear resistance is the most important. The composite BFM may be produced by adding of Cu-Ce powder into Ni-Cr powder, as scetched in Fig. 7a), after they are milling for hours.



a)



b)

Fig. 6. *Scetch of two powders in mixture a) and diamond grains with brazed WC powder at one diamond drilling bit b) [10]*

In producing diamond tools may be added powder of hard WC powder, as could be seen from Fig. 6..

- **Brazing diamond with Ni-Cr doped by Pr**

Praseodimyium in addition to about 1% in Ni-Cr causes the formation of phases NiPr and Ni_5Pr. The purpose of Pr doping into Ni-Cr filer alloy is to contribute to improving the properties of this BFM, including reducing the thermal damage, interfacial bonding to diamond, refining the dendritic size, causing an increasing hardness and lowering melting point [16]. Those phases in the form of intermetallic compounds, as other oxides or carbides in controlling amounts, contribute to increasing all of the mentioned properties the strength of used BFM. is valuable.

CONCLUSIONS

REEs have reached an enormous impact on daily life, one minor application for brazing is shown here, briefly showing the influence of cerium and praseodymium brazing diamond, while other REEs also may be used for the same purpose. Alloys for brazing diamonds are pretty well established on copper and silver bases, but for achieving better properties first of all, in bond strength, many other BFM still are in progress. One approach is introducing the rare-earth element in small amounts into the brazing alloy.
Alloys on silver base, as from system Ag-Cu-Ti, are however expensive, and this factor limits the scope for their application. Alloys from systems Ag-Cu-Ti and Cu-Sn-Ti are prone to oxidation and show poor wear resistance. Ni-Cr system attracted more attention as a cheaper alloy, but here arise problems about the higher brazing temperature and possible graphitization. Doping of cerium and praseodymium has shown some advantages as: grain refinement, better wettability, reducing thermal damage, increased bond strength, wear resistance and/or reduced crack propagation.
Here discussed elements, however as other REEs, are expensive, so it could not be expected their usage for brazing of plain carbon steels, or similar cheap materials.

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MECHANICAL CENTRIFUGATION AND PYROLISIS AS A COMBINED PROCESS FOR EFFICIENT MANAGEMENT OF OIL REFINERY SLUDGE

Research paper

Srđan Kovačević[1*], Nikolina Tošić[2], David Mitrinović[3], Marko Muhadinović[4], Galina Ilinykin[5], Natalia Sliusar[6]
[1,2]University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
[3]Institute for the Development of Water Resources "Jaroslav Černi", Belgrade, Serbia
[4]Lafarge BFC Srbija, d.o.o.
[5,6] Perm National Research Polytechnic University, Environmental Protection Department, Perm, Russia

Abstract: This work presents a review of mechanical centrifugation and pyrolysis, two prominent techniques used for the efficient management of oil refinery sludge. The petrochemical industry produces large quantities of hazardous oily sludge, which demands complex and costly treatment methods due to its diverse composition. However, a major component of this sludge is crude oil, which holds significant recycling potential. As a result, various technologies, including combined processes, have been developed to recover crude oil from sludge. This study evaluates the effectiveness of combining mechanical centrifugation and pyrolysis, specifically focusing on their oil recovery capabilities. The primary objective is to explore the development of these recycling technologies while summarizing and comparing their mechanisms, advantages, and limitations.
Key words: Oil sludge, centrifugation, pyrolysis, recycling.

INTRODUCTION

The petroleum industry generates substantial amounts of oily sludge through various stages of oil production, including crude oil exploration, transportation, storage, and refining, [1]. Crude oil production generates approximately 0.1% to 0.5% of oily sludge annually. On average, the petroleum industry produces around 0.3% sludge from crude oil, amounting to an estimated 228.29 million tons per year globally as of 2020, [2].
The waste oil sludge generated includes drilling fluid, petroleum wastewater, sludge from petroleum effluent treatment plants, and bottom tank sludge, [3]. The quantity and characteristics of oily sludge are influenced by factors such as the type of crude oil, storage conditions, downstream processing methods, and the design of refining equipment.
Globally, various techniques are employed for the treatment and disposal of petroleum sludge, including thermal, mechanical, biological, and chemical methods. However, these approaches are generally not economically sustainable.
In addition to the costs associated with the removal, transportation, and landfilling of petroleum sludge, the sludge itself contains numerous toxic compounds. These contaminants include petroleum hydrocarbons, such as aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), with over 33% total petroleum hydrocarbons (TPH) and 550 mg/kg of PAHs present in the sludge. It also contains polychlorinated biphenyls (PCBs) and heavy metals like barium, lead, zinc, mercury, chromium, arsenic, and nickel, [4]. Also, oily sludge contains substantial amounts of oil emulsions, water, heavy metal ions, and other recyclable resources composed of hydrocarbons and refractory petroleum hydrocarbons, which are a renewable energy with high potential value, [5]. The resource utilization of oily sludge can not only effectively reduce the disposal volume and pollution degree of hazardous waste solids but can also reduce the use of nonrenewable resources, [1].

[1]Corresponding author, srdjankovacevic@uns.ac.rs, ORCID: https://orcid.org/0000-0002-5440-8752
[2]nikolina.tosic@uns.ac.rs, ORCID: https://orcid.org/0000-0003-1352-53
[3]david.mitrinovic@jcerni.rs, ORCID:https://orcid.org/0000-0003-1352-5351
[4]marko.muhadinovic@lafarge.com, ORCID: https://orcid.org/0009-0009-7570-3695
[5]galina.perm.59@yandex.ru,
[6]nslyusar@gmail.com, ORCID:https://orcid.org/0000-0003-0123-6907

In recent years, physical recovery and treatment technologies, such as mechanical centrifugation and pyrolysis, as well as combined physical and chemical processes, have been increasingly applied in engineering. These technologies not only enable the efficient recovery of crude oil from oily sludge but also significantly reduce its harmful impact on human health and the surrounding environment.

MATERIAL AND METHODS

Mechanical centrifugation

Mechanical methods for processing oily sludge primarily focus on pretreatment and the separation of oil derivatives (such as oil, fuel oil, paraffin, and bitumen) from water, thereby reducing the water content in the waste. Typically, waste separation involves heating and the addition of reagents (demulsifiers and coagulants), carried out in multiple stages using specially designed centrifuges and decanters, as illustrated in Fig. 1. Phase separation is achieved through the application of centrifugal forces.
Centrifugal separation is influenced by several factors, with the most critical being the viscosity of the oily sludge and sediment, particle size, and centrifugation speed. Additionally, the larger the separation zone during centrifugation, the easier and more efficient the separation process, [1].

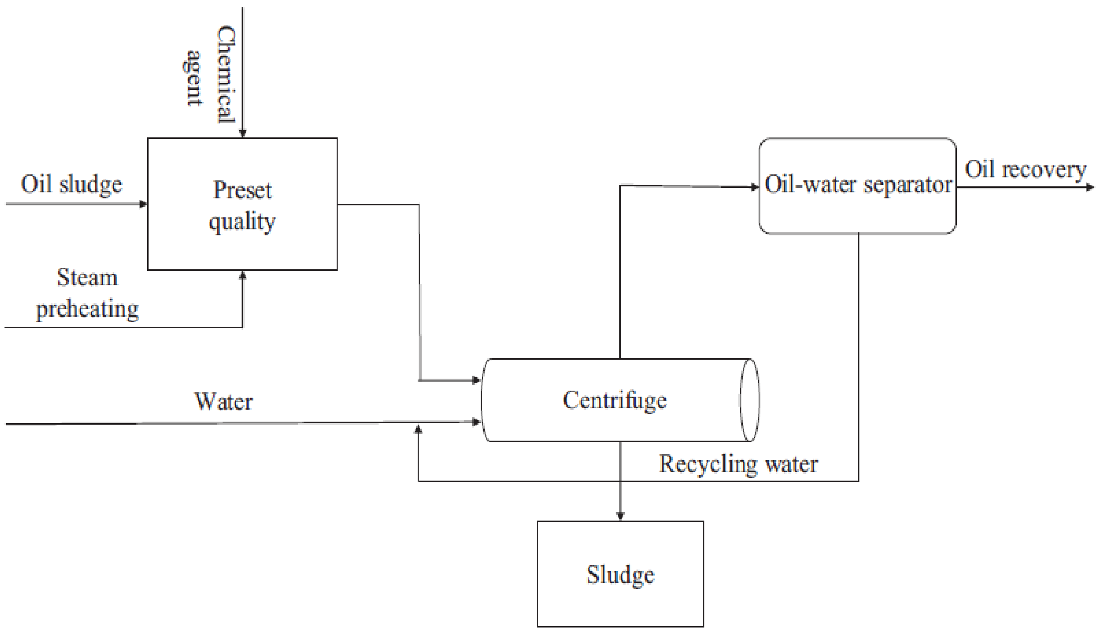

Fig. 1. *Flowchart of recovery of crude oil by mechanical centrifugation [1]*

To enhance centrifugation efficiency and reduce energy consumption, the viscosity of waste oily sludge must be lowered through pretreatment methods such as the addition of organic solvents, demulsifiers, surfactants, steam injection, or direct heating. After mechanical centrifugation, the oily sludge is separated into a solid phase (about 8%), wastewater (about 80%), and a liquid phase (about 12%) that is returned to the processing cycle. The wastewater is sent for further treatment, while the solid phase undergoes additional processing. Water is used during the treatment process and is recirculated, while steam is used to heat the raw input material.

Pyrolysis process

Pyrolysis technology involves heating oily sludge in an oxygen-free environment under slight positive pressure. This process separates oil and organic matter, breaking down the sludge into three components: pyrolysis residue, liquid, and gas. The resulting products, which vary based on the procedural conditions, include char, liquid fuels, and gases. This method is used to convert waste into usable resources, optimizing the recovery of valuable materials from the sludge, [7].
Liquid pyrolysis products contain organic acids, bases, phenols, asphaltenes and hydrocarbons. It can be used as a raw material to produce gasoline, kerosene, oil or liquid boiler fuel.
Pyrolytic oil can also be used as a fuel substitute for furnaces. There are options for applying solid residues (as a filler for rubber-bituminous mastics, paints, etc.).
Heavy metals and other pollutants in oily sludge can be enriched and fixed into a solid residue, which greatly reduces the degree of environmental pollution. The liquid product produced by the pyrolysis process has a good capacity reduction effect and is suitable for storage and transportation; the resulting oil can be directly used for diesel engines; the carbon-containing solid residue can also be reused as an adsorbent, flocculent, soil improver, and so on. However, pyrolysis can be limited by numerous factors, such as temperature, heating rate, characteristics of the sludge and chemical additives.

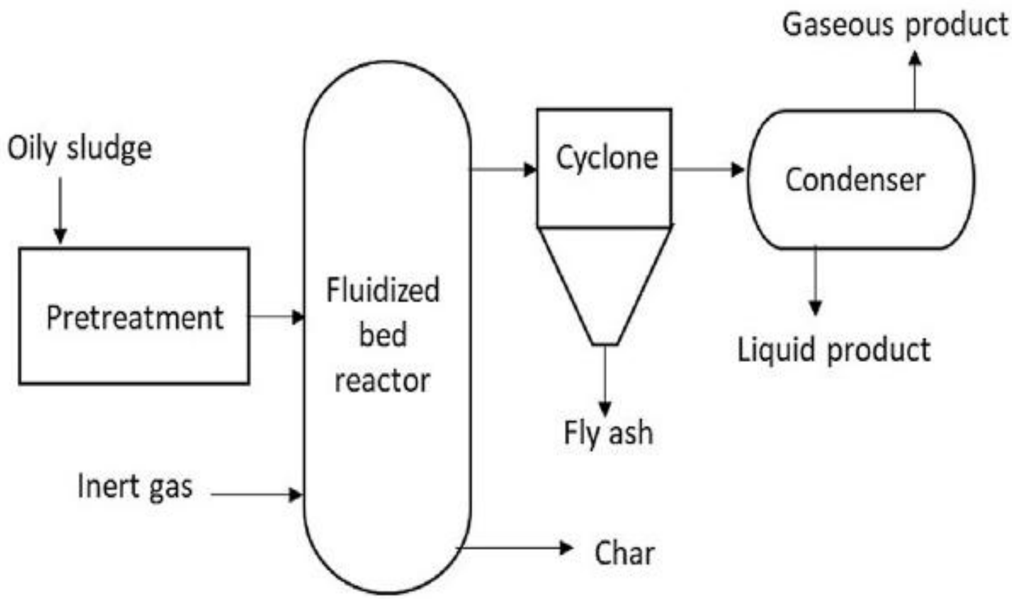

Fig. 2. *Fluidized bed system for oily sludge pyrolysis [8]*

Pyrolysis methods can be roughly categorized into three types, namely ordinary pyrolysis, catalytic pyrolysis, and microwave pyrolysis.

RESULTS AND DISCUSSION

Hazardous waste management option in oil refineries which include application of mechanical centrifugation as a pretreatment technology and pyrolysis as a final treatment has been analyzed. A theoretical scenario has been examined with the application of material flow analysis. The following picture shows the material flow analysis for the assumed scenario, depicting the percentage of oily sludge throughout the entire treatment system.
It is assumed that the efficiency of water phase separation during the mechanical centrifugation process is approximately 80% which depends on the material characteristics but it is in accordance with the literature data, while the remaining fraction comprises two

phases: the liquid fraction (approximately 12%), which can be returned to the processing of crude oil, and the solid fraction that requires final treatment (8%), [8,9]. The remaining solid fraction is further treated through the pyrolysis process.
The pyrolysis of oily sludge yields three main products: oil, gas, and char. When conducting the pyrolysis process, it is crucial to control both the quantity and quality of these products. Among these three products, char still contains a significant amount of organic matter, resulting in a higher char yield compared to ash content. Given the substantial presence of inorganic materials in oily sludge, char yields tend to be relatively high. Throughout the pyrolysis process, a majority of the organic components are released as gaseous products. Oil, distinguished by its high calorific value and ease of storage, is the most desirable product for recycling.
However, without the use of catalysts and additives, only a small quantity of oil is typically obtained at high temperatures, [10-12]
During the pyrolysis process, the assumption is that 70% of the material is converted into pyrolytic oil, 10% of the material transforms into a solid phase (coke) and 10% of input material is transformed to inert residue which requires adequate final disposal, and the remaining 10% is converted into the gaseous phase known as pyrolytic gas, respectively, [13].

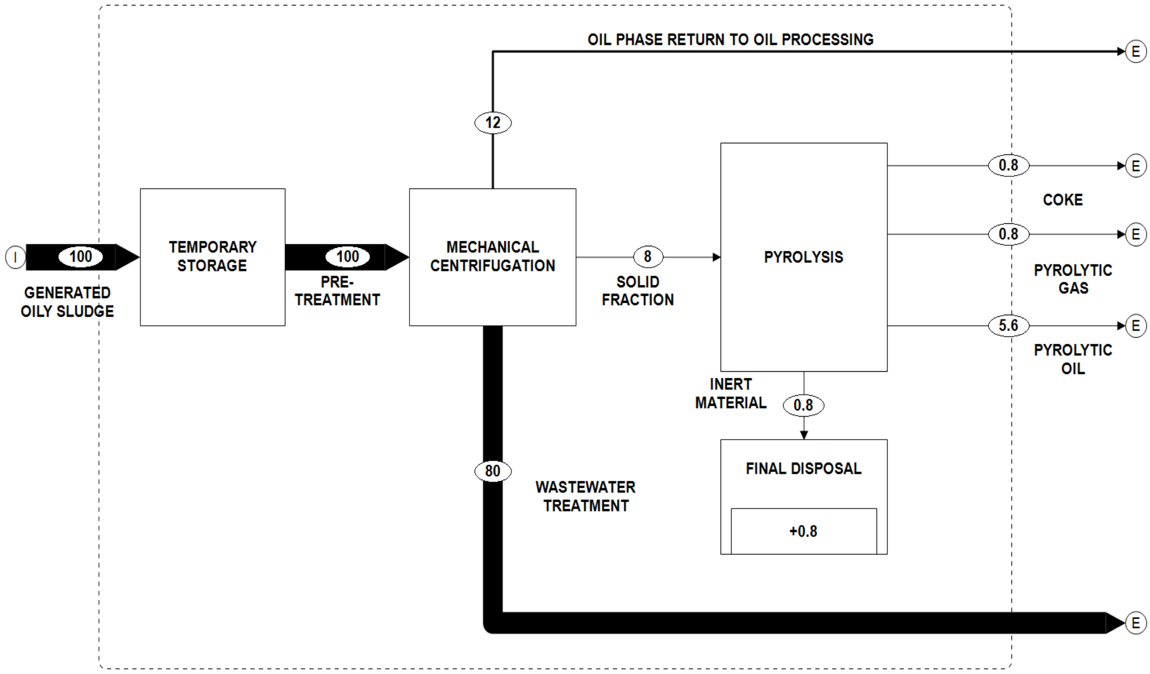

Fig. 3. *Material flow analysis of theoretical scenario*

By applying material flow analysis, it can be concluded that the management system for oily sludge, which involves pretreatment through centrifugation and final treatment through pyrolysis, is highly efficient. At the end of the process, only 0.8% of the initial mass of material require final disposal, achieving a system efficiency of nearly 99%.
There are certain limitations to the use of the analyzed technologies. Before the centrifugation process, the material being treated should ideally be in a minimally liquid form, with a maximum particle size of less than 50 mm before mixing. After mixing and passing through a vibrating screen, the maximum particle size should be 20 mm before entering the decanter centrifuge. Mechanical centrifuges can be used to treat oily sludges and sediments with suspended material concentrations of up to 15%. However, it is necessary to add additional water during the mixing and heating phase for effective separation. Heating the incoming oily sludge and sediment to a temperature of 60-70°C using steam is essential to

introduce the required reagents and achieve efficient phase separation. Some limitations for pyrolysis technology include: pyrolysis process requires an input moisture concentration below 50%, necessitating pretreatment, also applying pyrolysis leads to significant emissions of pollutants into the atmosphere which requires the use of expensive equipment for gas cleaning and finally secondary waste disposal needs to be addressed.
The advantages of using mechanical pretreatment through centrifugation include: Effective Separation: Centrifugation efficiently separates different phases of a mixture, allowing for the extraction of valuable components; Improved Efficiency: It enhances the overall efficiency of subsequent treatment processes by reducing the initial concentration of impurities and contaminants. Reduced Environmental Impact: By removing contaminants before further processing, it helps minimize environmental pollution and ensures compliance with regulatory standards. Cost Savings: Mechanical pretreatment can lower operating costs by reducing the burden on downstream equipment and processes. Enhanced Product Recovery: It aids in the recovery of valuable materials and energy from waste streams, maximizing resource utilization. Process Optimization: It contributes to the overall optimization of the treatment process, resulting in improved product quality and yield. Reduced Maintenance: Centrifuges are known for their robustness and durability, reducing the need for frequent maintenance and downtime. Versatility: Centrifugation can be applied to various industries and processes, making it a versatile option for waste treatment and material recovery.
The advantages of using pyrolysis include:

- Efficiency in Hydrocarbon Removal: Pyrolysis is effective in removing hydrocarbons, with removal rates ranging from 50% to 90%;
- Swift and Efficient Process: Pyrolysis is known for its speed and efficiency in breaking down complex materials;
- Utilization of Pyrolytic Gas: The pyrolytic gas generated can be utilized within the plant's processes, contributing to resource optimization;
- Low Operational Costs: Pyrolysis often involves lower operational costs compared to alternative methods;
- Reuse of Pyrolytic Oil: The obtained pyrolytic oil can be reused in oil processing, leading to cost savings and profit generation.

CONCLUSION

In the petroleum industry, the generation of oily sludge is inevitable, and this presents a global challenge in its treatment and management due to its hazardous nature.
The choice of the most suitable treatment method may be influenced by various factors, including the composition of the oily sludge, treatment capacity, costs, and the applicable disposal standards.
The management of oily sludge generated during the storage and handling of crude oil necessitates the implementation of suitable procedures to minimize its volume and extract valuable materials and energy from it. Efficient management strategies aim to mitigate the toxicity of oily waste and minimize potential negative environmental impact.
Management options for both oil recovery and reducing the volume of sludge for disposal encompass various techniques. The choice of the most suitable technology depends on the characteristics of the oily sludge, treatment capacity, operational and maintenance costs, and the geographical location. In some cases, an appropriate management decision may involve integrating different processes. In this case the management system for oily sludge, which involves pretreatment through centrifugation and final treatment through pyrolysis, is highly efficient with numerous advantages.
Utilizing a combination of mechanical centrifugation and pyrolysis can result in significantly higher efficiency compared to using each technology individually. Moreover, this approach helps mitigate the limitations and drawbacks associated with individual technologies, making it a viable management option for handling hazardous oily sludge generated in oil refineries.

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THE INFLUENCE OF THE LAYER HEIGHT ON THE HARDNESS OF THE TPU PLASTIC SPECIMEN MADE BY 3D PRINTING

Research paper

Dušan Jovanić[1], Eleonora Desnica[2], Dušan Malić[3]
[1,3]Technical College of Applied Sciences, Zrenjanin, Serbia
[2]Univesity of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: The paper presents a influence of a layer height of a 3D printed specimen by Fused filament fabrication of Thermoplastic polyurethane (TPU) on the hardness by Shore A and Shore D scale method. One of the disadvantages of 3D printing is that the parts have much weaker mechanical characteristics and need to be tested to determine the functionality of the working part. According to ISO 17296-3: Additive technologies- Main characteristics and corresponding test methods, hardness testing is provided for all groups of plastic parts.
Hardness testing of plastic materials is defined by the standard EN ISO 868: 2015- Plastics and ebonite- Determination of hardness by indentation using a durometer (Shore hardness) and was performed with an digital durometer- hardness tester and ISO 7619-1: Rubber, vulcanized or thermoplastic- Determination of indentation hardness- Part 1: Durometer method (Shore hardness).
Key words: Hardness testing, Additive production, Fused filament fabrication, Thermoplastic polyurethane (TPU).

INTRODUCTION

Additive manufacturing can be divided according to ISO 17296-2: Additive technologies- General principles- Part 2: Overview of process categories and filling, into: Vat photopolymerization- laser stereolithography (SLA) and full-layer illumination-based stereolithography (DLP-SLA, LCD-SLA); Material extrusion (FFF- Fused filament fabrication); Binder jetting; Material jetting; Powder bed fusion- procedures using laser (SLS, SLM, DMLS) and procedures using electron beam (EBM); Directed energy deposition (DED- Deposition of materials using directed energy) and Sheet lamination (LOM- Laminated object manufacturing, PSL), [1].
The process of material extrusion FFF- Fused filament fabrication or FDM- Fused Deposition Modeling the trade name of the company Stratasys, uses solid thermoplastic material- filament, which is pushed through a heated nozzle, the temperature of which depends on the type of polymer, and in a doughy-melted state it is applied to a heated or unheated build plate, after which it hardens and forms the desired piece layer by layer, [2].
The most important parameters that can be adjusted with a 3D printer for the process of extruding materials- FFF are: manufacturing speed, extrusion speed, the height of the applied layer in the shell and infill and the temperature of the nozzle and build plate.
The main limitations of Fused filament fabrication center around the anisotropic nature of parts. The layer-by-layer nature of FFF printing results in parts that are fundamentally weaker in one direction. How a part is orientated during the printing process has an impact on how strong it will be in each direction. Infill percentage also has an effect the strength of a part. Most printers produce parts and prototype with 20% infill saving significantlyon cost and time. Where as a bracket that will experience loading will need a higher infill percentage (up to 100% or fully dense). Higher levels of infill will result in a stronger part, but will increase build time and cost, [3].
Due to the lower quality of the processed surface and weaker mechanical characteristics of Thermoplastic Polyurethane (TPU) parts obtained by 3D printing, it is necessary to determine the mechanical characteristics: hardness, impact strength, tensile strength, bending strength,

[1] Corresponding author, dusan.jovanic@vts-zr.edu.rs, ORCID: https://orcid.org/0009-0001-6058-4074
[2] eleonora.desnica@vtfzr.rs, ORCID: https://orcid.org/0000-0002-4724-5764
[3] dusan.malic@vts-zr.edu.rs, ORCID: https://orcid.org/0009-0002-1846-4228

fatigue strength, compressive strength, creep, aging, friction coefficient, resistance to shear and crack propagation according to ISO 17296-3: Additive technologies- General principles- Part 3: Main characteristics and corresponding test methods, [4].
This standard also defines test categories for metal parts, plastic parts and ceramic parts and classifies them into three groups: group H (tests of functional parts that are highly safety-critical), group M (tests of functional parts that are not safety-critical) and group L (esting parts during construction or prototype parts). Hardness testing is provided for all these groups of plastic parts.
The goal of this work is to determine the hardness of the workpiece made of Thermoplastic polyurethane (TPU) depending on the height of the applied layer in the shell and infill.
The hypothesis of the research are that the highest hardness of the workpiece made of TPU plastic is achieved at the lowest layer height both in the casing and in the filling.

3D PRINTING THERMOPLASTIC POLYURETHANE

There are a large number of polymers with different mechanical, physical, chemical, electrical, thermal and other characteristics, which have a wide range of applications. Hardness is a complex material property influenced by a variety of factors. Thermoplastic polyurethane (TPU) is non-toxic and environmentally friendly material. TPU has excellent properties of high tension, strength, toughness, and aging resistance and has been widely used in medical and health, electronic appliances, industry, sports etc. The unique feature is higher elasticity. TPU filament is the most used 3D printing flexible material now. Thermoplastic polyurethane (TPU) also has the properties of high strength, good toughness, wear resistance, cold resistance, oil resistance, water resistance, aging resistance, and weather resistance that other plastic materials cannot match at the same time, it has a high waterproof moisture permeability, wind, cold, anti-bacterial, anti-mildew, warm, anti-UV and energy release, and many other excellent functions. According to molecular structure, TPU could divide into polyester and polyether types. The shore hardness of the filament could range from 60 A to 80 D. The characteristics of thermoplastic polyurethane (TPU) are given in Table 1, [5].

Table 1. *Characteristics of Thermoplastic polyurethane (TPU)*

The parameters	Values
Hardness Shore A (ISO 7619-1)	93A
Hardness Shore D (ISO 7619-1)	41 D
Density (EN ISO 1183-1-A)	1.24 g/cm³
Tensile strength (ISO 37)	55 MPa
Elongation at break (ISO 37)	600 %
Tear strength (ISO 34-1Bb)	95 N/mm
Abrasion loss (ISO 4649-A)	30 mm³

TPU filament is not easy to print. You need to search for the best temperature with nozzle and the speed should be much slower. Thermoplastic Polyurethane needs to be printed on a 3D printer equipped with direct extruder. Recommended printing parameters for 3D printing of Thermoplastic Polyurethane are: Print Temperature (210-240℃), Hot bed Temperature (50-60 ℃), Print Speed (15-50 mm/s) and Pumping Distance (0-2 mm), [6].

EXPERIMENTAL PART

In a series of experiments, a specimen was used as a working object. Dimensions of the sample are ϕ 40 x 6 mm. The 3D model of the specimen (Fig. 1) was realized in the software package SOLIDWORKS 2016 and then it was formed into a suitable STL file with the maximum resolution allowed by the software.

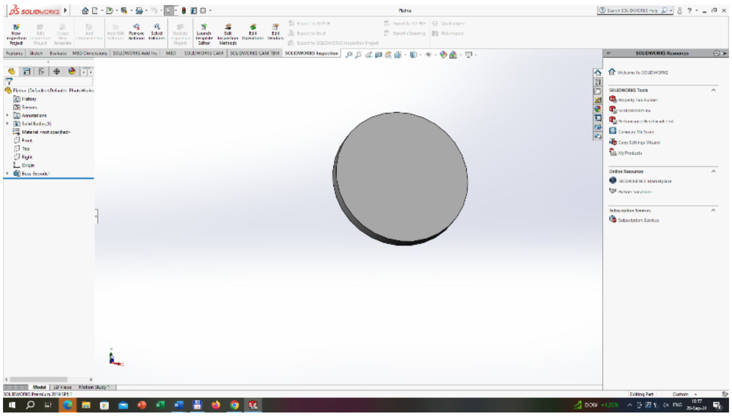

Fig. 1. *3D CAD model of specimen*

The STL file of the specimen is shown in Fig. 2.

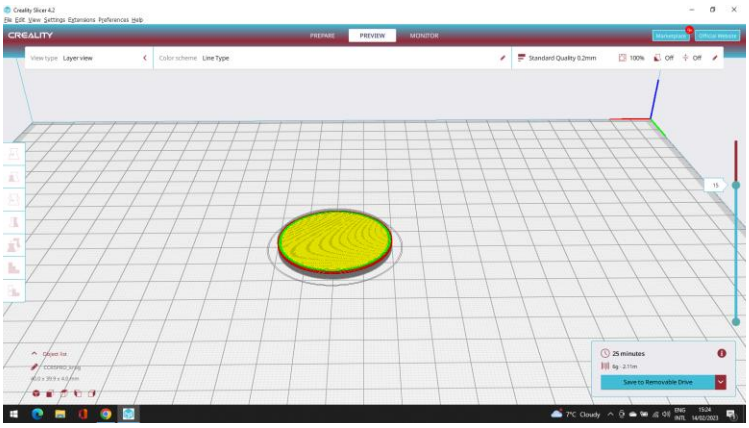

Fig. 2. *STL file of specimen*

After that, the corresponding parameters were varied according to the experimental plan and a series of the specimen with the same external appearance but different characteristics was produced. The characteristics of CR-TPU filament are shown in Table 2. Parameters and styles of sample printing conditions are: Print Temperature (235 °C), Hot Bed Temperature (40 °C), Printing Speed (50 mm/s) and Infill 100%.

Table 2. *Features of Creality TPU filament*

The parameters	**Values**
Filament type	CR-TPU
Diameter (mm)	1.75
Printing temperature (°C)	210 - 240

The characteristics of thermoplastic polyurethane (TPU) filament are given in Table 3, [9].

Table 3. *Characteristics of Thermoplastic polyurethane (TPU) filament*

The parameters	**Values**
Density (ISO 1183)	1.12 (g/cm3 at 21.5˚C)
Vicat Softening Temperature (190 °C /2.16Kg)	9 (g/10 min)
Elongation at break (ISO 527)	780(%)
Hardness Shore A (ISO 7619-1)	95A

In Fig. 3 is shown the 3D printer Creality 5 Pro on which the elements for the experiment were printed, and its technical characteristics are given in Table 4, [7].

Table 4. *Creality 5 Pro 3D Printer Technical Features*

The parameters	Values
Materials	PLA, ABS, PETG, TPU
Max. part dimensions (mm)	300 x 225 x 380
Filament diameter (mm)	1.75
Nozzle outlet diameter (mm)	0.4
Working temperature (^oC)	300
Build plate temperature (^oC)	110

Fig. 3. *3D printer Creality 5 pro*

Procedure of hardness testing

Test specimen was placed on a hard, horizontal, plane surface. Durometer was held in a vertical position with the point of the indenter at least 9 mm from any edge of the test specimen. Recommended masses was 5 kg for the type D durometer and 1 kg for the type A durometer. The scale of the indicating device read after 15 s ± 1s for the type D durometer and 3 s ± 1s for the type A durometer. There were made five measurements of hardness at different positions on the test specimen at least 6 mm apart and determine the mean value. A measure of the indentation resistance of elastomeric or soft plastic materials based on the depth of penetration of a conical indentor (Fig.4). Hardness values range from 0 (for full penetration) to 100 (for no penetration), [8, 9].

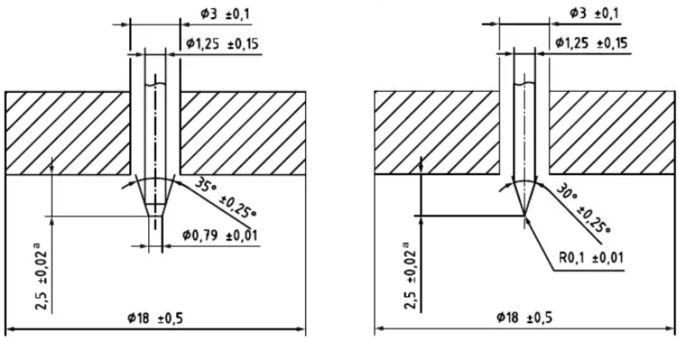

Fig.4. *Indentor Shore A and Shore D [3]*

As measuring instrumentation, the durometer- hardness meter YHD-SHORE D, according to Shore, scale D with a conical shape of the needle at an angle of 330 ^oC, with a accuracy of 0.5 HD and the durometer- hardness meter YHD-SHORE A, according to Shore, scale A with a conical shape of the needle at an angle of 325 ^oC with a accuracy of 0.5 HA shown in Fig. 5, [10].

Fig. 5. *Device for measuring the hardness of TPU parts*

RESULTS AND DISCUSSION

The surface quality of the specimen made of TPU plastic depends on the height of the applied layer in the shell and infill. The lower the height of the applied layer, the higher the quality of the object and the greater the ability to perform details, but the production time is nonlinearly longer.

Macroscopic images of TPU specimen with a layer height of 100, 200 and 400 microns at 5x magnification are shown in Fig.6.

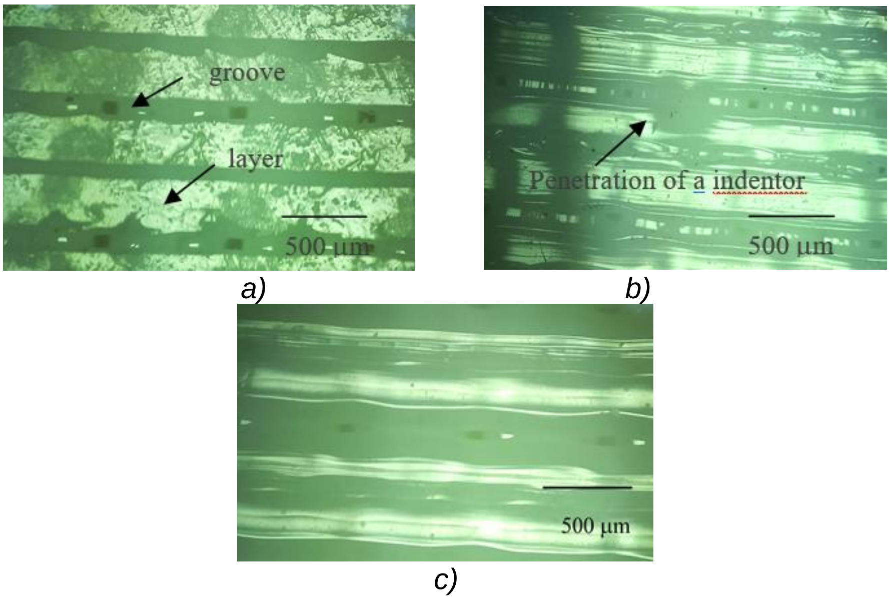

Fig. 6. *Macroscopic image of a ABS object with a layer of 100, 200 and 400 microns high at 5x magnification and a cross-section of a layer with a layer height of 100 microns*

In Fig. 6 the darker lines represent the grooves between the layers, which are places of stress concentration, and the wider they are, the rougher the surface. Macroscopic inspection revealed that the width of the applied layer is the largest at the highest height of the applied layer. It can also be seen that the width of the groove (unfilled), is largest at the highest height of the applied layer.

Unacuracy of measurement, even drastic, comes when indentor hits in between two layers actualy when indentor hits the groove, which can be seen in Fig. 6 b.

A cross section of specimen and the number of layers for an application height of 100 microns is shown in Fig. 7.

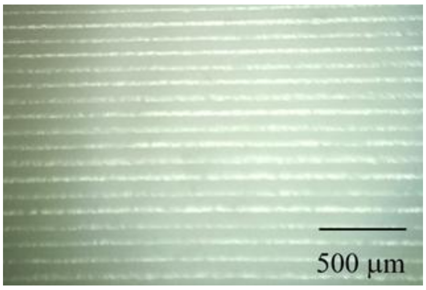

Fig. 7*. A cross-section of a layer with a layer height of 100 microns*

The hardness values HS(D) of the TPU plastic part depending on the height of the applied layer with infill density 100%, line infill patern, printing temerature 235 ^oC, build plate temerature 40 ^oC and printing speed 50 mm/s are shown in Table 5.

Table 5. *Hardness values for different heights of the applied layer*

Pattern	Layer height (mm)	Hardness HS (D)					Hardness HS (D)
		No 1	No 2	No 3	No 4	No 5	Main value
Lines	0.1	43	43	43.5	44	39	42.5
	0.2	40.5	38	41	41.5	41	40.4
	0.4	39.5	39	36	38.5	38	38.2

The hardness values HS(A) depending on the height of the applied layer with infill density 100%, line infill patern, printing temerature 235 ^oC, build plate temerature 40 ^oC and printing speed 50 mm/s are shown in Table 6.

Table 6. *Hardness values HS(A) for different heights of the applied layer*

Pattern	Layer height (mm)	Hardness HS (A)					Hardness HS (A)
		No 1	No 2	No 3	No 4	No 5	Main value
Lines	0.1	94	93.5	93.5	95	94	94
	0.2	93	92	93	92.5	93	92,7
	0.4	91	91.5	91.5	91.5	90.5	91.2

Similary ABS and PLA the hardness of TPU samples made by 3D printing with FFF technology depends on the height of the applied layer, so that it is maximum for the smallest height and decreases almost linearly according to the smallest hardness to the largest height during linear filling. The heating of the board at the same filling and height of the applied layer has a slight effect, so that the hardness is lower by 1%. The hardness is the same for the same layer height, with different filling methods (linear, zigzag and concentric), [11,12].
The characteristics of Thermoplastic polyurethane (TPU) which are given in Table 1. show that the hardness of TPU are 93 HS (D) and 41 HS (A), [5].
The hardness values HS (D) of the 3D prints TPU plastic part with printing temerature 250 ^oC, build plate temerature 60 ^oC, printing speed 25 mm/s, fullfilling 96% and layer height 0.21 mm is 39.9 HS (D) while the difference in max. and min. hardness 14.08%, [13].

CONCLUSION

3D printing with the process of extruding material with FFF technology has a low quality of the processed surface, and from the point of view of hardness, the hypothesis is confirmed that the highest hardness of the specimen made of Thermoplastic polyurethane (TPU) 94 HS (D)

is achieved at the lowest layer height of 0.1 mm both in the casing and in the filling and the best configuration setting layer height for TPU is 0.1 mm.
The max. hardness values HS (D) of the 3D prints TPU plastic specimen with printing temerature 235 ^{o}C, build plate temerature 40 ^{o}C, printing speed 50 mm/s, infill density 100, line infill patern and layer height 0.1 mm is 95 HS (D) and 44 HS (A) while the difference in max. and min. hardness 12.8%
The darker lines represent the grooves between the layers and macroscopic inspection revealed that the width of the applied layer is the largest at the highest height of the applied layer. It can also be seen that the width of the groove is largest at the highest height of the applied layer.

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EVALUATION OF THE TECHNOLOGICAL EFFECTS OF CELLULAR MANUFACTURING FOR A GROUP OF PRODUCTS

Research paper

Dejan Lukic[1], Mijodrag Milosevic[2], Ahmet Cekic[3], Maida Cohodar Husic[4], Djerzija Begic-Hajdarevic[5], Dejan Bozic [6]
[1,2,6] University of Novi Sad, Faculty of Technical Sciences, DPE, Novi Sad, Serbia
[3,4,5] University of Sarajevo, Faculty of Mechanical Engineering, Sarajevo, BiH

Abstract: Cellular manufacturing represents one of the important segments in the application of the concept of Lean production, which is realized through the development and application of flexible manufacturing systems (FMS). FMS represent the basis for the production system to simultaneously achieve a high level of flexibility and productivity, that is, to be considered agile. However, due to their high production and technological capabilities, prices and investment costs, they require conditions that ensure their rational exploitation. Taking into account the increasingly complex conditions of production and placement of products, a systematic approach to the design and application of FMS is necessary, which will include the most important technological and economic characteristics. In this paper, on the example of the formed technological group of gears, the methodology of process planning and evaluation of the effects of cellular manufacturing is presented, as a basis for the rational development and techno-economic application of FMS.
Key words: Flexible manufacturing systems (FMS), Lean production, Manufacturing process planning, Group technology, Gears, Cellular manufacturing

INTRODUCTION

Production systems in the machinery industry are faced with very strict market requirements regarding high quality, short delivery times and low product prices, as well as a wide assortment and different delivery dynamics. Thanks to automation in the conditions of large-scale and mass production, productivity and economy have reached a relatively high level. However, the overall structure of the industry is dominated by individual and small-batch production, the participation of which is increasing due to the desire of customers for an increasing number of different product variants. Therefore, there is a need for modern production systems with the effects of automated large-scale and mass production in terms of productivity and economy, as well as the effects of individual and small-scale production in terms of flexibility and mobility. The solution to this problem is reflected in the application of the Lean concept, that is, the development of flexible manufacturing systems (FMS) based on cellular production, [1, 2, 3].

Cellular manufacturing in a production system is characterized by the grouping and arrangement of machines/workplaces and devices that are required for the production of one product or a group of products that have similar production requirements. This enables the continuous and unhindered movement of materials from the raw materials to the finished product in an individual or group flow of the process, with minimal transport or waiting time, or any other delays. The introduction of cellular manufacturing means the elimination of waste from individual operations, as well as the entire manufacturing processes, [3, 4].

Flexible manufacturing systems (FMS) represent the basis for the production system to simultaneously achieve a high level of flexibility and productivity, that is, to be considered agile, [2, 4]. The basic units of FMS are CNC machine tools, especially at today's level when they are multifunctional and integrate different machining processes (turning, milling/drilling, grinding, etc.) and different processing technologies (cutting, thermal treatments, etc.). By connecting such machines with manipulation, measurement-control and transport systems, as

[1]Corresponding author, lukicd@uns.ac.rs, https://orcid.org/0000-0002-1566-282X
[2]mido@uns.ac.rs, https://orcid.org/0000-0002-8950-4867
[3]cekic@mef.unsa.ba,
[4]cohodar@mef.unsa.ba, https://orcid.org/0000-0002-5423-4027
[5]begic@mef.unsa.ba,
[6]bozic997dejan@uns.ac.rs, https://orcid.org/0009-0009-1095-8101

well as their management using a computer, FMS of different levels of complexity, productivity and flexibility are created, [5].
Due to their high production and technological capabilities, prices and investment costs, FMS require conditions that ensure their rational exploitation. Taking into account the increasingly complex conditions of manufacturing and placement of products, a systematic approach to the design and application of FMS is necessary, which will include the most important technological and economic characteristics. In this paper, on the example of the technological group of rotary parts - gears, the methodology of process planning for cellular manufacturing and evaluation of the effects of the application of FMS elements is presented.

TECHNOLOGICAL BASIS FOR THE DEVELOPMENT AND IMPLEMENTATION OF FMS

In order to rationally develop and implement FMS, a methodology is proposed that consists of three integral parts, i.e. phases (Figure 1):

- *Technological basis for the development and implementation of FMS,*
- *Evaluation and selection of elements FMS,*
- *Modeling and simulation of FMS.*

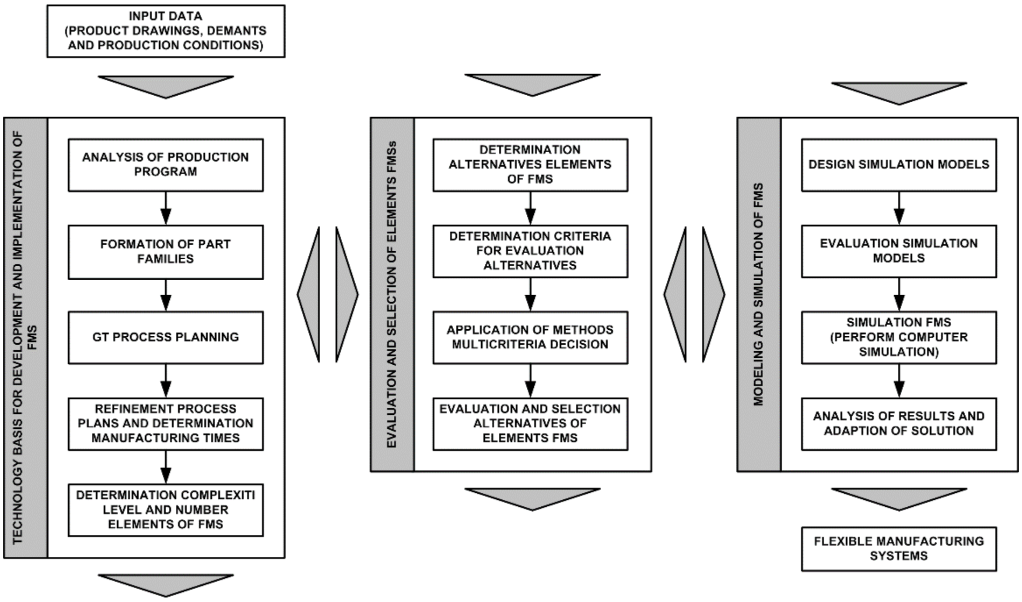

Fig. 1. *Phases of development of flexible manufacturing system* [6]

The first stage, which will be considered in this work, essentially refers to the processes planning of manufacturing products from the production program and the analysis of the effects of the application of FMS elements. This stage consists of the following tasks, [7]:

- *Analysis of a production program, classification of parts and formation groups (families),*
- *Design or selection of complex parts (representatives of part families),*
- *Process planning for group of parts (GT process plans are designed),*
- *Precision of process plans for selected products and determination of manufacturing times,*
- *Determining the level of complexity and the number of FMS elements (machines/workplaces, accessories, tools, measurement and control systems, etc.),and*
- *Evaluation of techno-economic effects of the application of FMS elements.*

Starting from the principle of classification and grouping of products, the total assortment of products from the production system can be systematized according to the construction-technological classifier, that is, divided into certain units for which it is rational to apply the concept of group or individual technology. On the basis of the group technology established by Mitrofanov [8] and as a result of research carried out by Burbidge [9], a new approach in production was developed - a group approach in designing effective production and production structures. Using this approach, based on the classification of parts in the production process, groups of geometrically and technologically similar parts - groups (families) are created, which represent the basis for a group approach in the process planning, Figure 2. By merging individual operational groups that have similar construction characteristics and processplan into larger technological groups creates the possibility for their production on suitable flexible manufacturing systems.

Fig. 2. *An example of grouping parts of a rotary shape* [8]

Figure 3 shows production flows based on the principles of designing individual technological processes, and Figure 4 shows the organized flows for the case of applying the concept of group technology, that is, group technological processes and the application of cellular manufacturing.

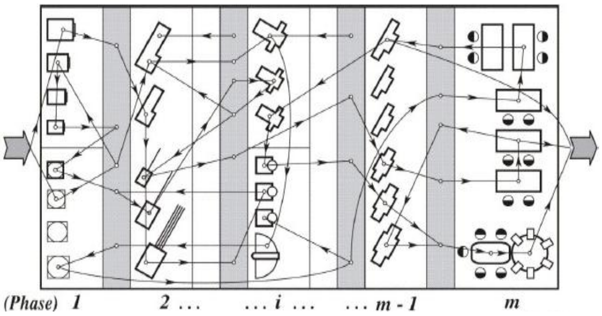

Fig. 3. *Production flow of individual technological processes* [10]

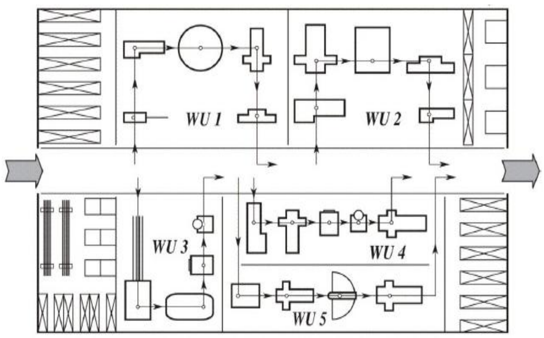

Fig. 4. *Production flow in group technological processes* [10]

Manufacturing process planning based on the principles of group technology aims to increase the number of products within the production program based on the principles of similarity, thereby increasing the number of parts in series and switching to more types of production, enabling the use of machines with a higher degree of efficiency. The group technological process and group operations are designed and realized for the formed technological group of parts, that is, operating groups, using common processing systems, that is, the same groups of machines, fixtures and tools, along with their basic preparation. In order to be able to process all parts from one group according to the group concept, the group technological process must include all process, and the group processes must include all operations, which will process all typical shapes and/or features of parts from the group. Therefore, the design of the group technological process is carried out for the representative of the group, which is called the complex part. This complex part can be a real part of the group, if it contains all typical forms (features) of the other parts, and an imaginary complex part, if it is designed only for the purpose of defining the group technological process, [6, 7, 11].

GT Process planning enables easy and rapid precision of process plans for individual parts of a single group. This is achieved in the following way, [7,12]:
1. Specification of process plans for all parts is done in the case of the detailed/final planning of FMSs, thus providing detailed technoeconomic data (time, costs, degree of utilization, etc.).
2. Specification of process plans for representatives of an appropriate product group is done in the case of the conceptual/preliminary planning of FMSs, thus providing approximate technoeconomic data, whose accuracy depends on the methodology that is being applied.

In order to more rationally and quickly determine the time of manufacturing operations of the technological group in conceptual design, it is necessary to specify the manufacturing operations for the corresponding representatives, depending on the adopted method used. These methods can be graphical and/or analytical and are used to processing time (tk) and setup time (T_{pz}) processing operations.
In the observed case, for the formed operational group of rotationally symmetrical parts - gears, the methodology of defining the technological bases for the development and application of FMS is shown, while the determination of time and resources is shown on the example of a group turning operation using an analytical method based on the representative of a technological group of products. Within this methodology, based on ABC analysis, the selection of products of representatives of the technological group is made, and then the reduced quantity of products is determined, and the process plan and the production time is determined using the aforementioned methodology.

EVALUATION OF THE EFFECTS OF APPLICATION OF CELLULAR MANUFACTURING OF GEAR GROUPS

GT manufacturing process planning

Analyzing the production program of the observed company, applying the IAMA construction-technological classifier, a technological group of rotationally symmetrical parts was formed, among which one operational group of gears was singled out, table 1. Table 2 shows the matrix of classification numbers of the observed group of gears.
Based on the geometric and technological characteristics of the parts from the group, an imaginary complex part was designed, with all associated typical shapes, Figure 5. The same figure shows the 3D models of gears from the group, which were obtained using the Family Table option of the PTC Creo software. Based on the defined model of the complex part, volume of production, available resources and other necessary data, a group process plan was designed, the content of which is shown in table 3.

Table 1. *Basic information about the group of gears*

No.	Name	Part designation	*Quantity* [*pcs/batch*]	*Mass* [*kg*]	*Price* [*€/pcs*]
1	Gear 1	146.02.08.06	310	2.21	75
2	Gear 2	146.02.08.07	270	0,456	80
3	Gear 3	146.02.14.05	440	0.936	82
4	Gear 4	146.02.18.04	390	0.493	45
5	Gear4	146.02.061.02	410	0.760	90
6	Gear 6	146.02.061.05	480	0.495	85
7	Gear 7	146.02.062.04	210	0.796	63
8	Gear 8	146.02.091.01	270	0.451	95
9	Gear 9	146.02.121.0.4	400	0.626	65
10	Gear 10	146.02.122.04	350	0,193	82
11	Gear 11	146.02.161.01	190	0.399	100
12	Gear 12	146.02.200.06	330	0.536	60

Table 2. *Matrix of classification numbers for group of gears*

	1	2	3	4	5	6	7	8
0	0							0
1	1	1						
2		2	2	2				
3		3						
4						4	4	
5				5	5	5		
6					6	6		
7								
8								

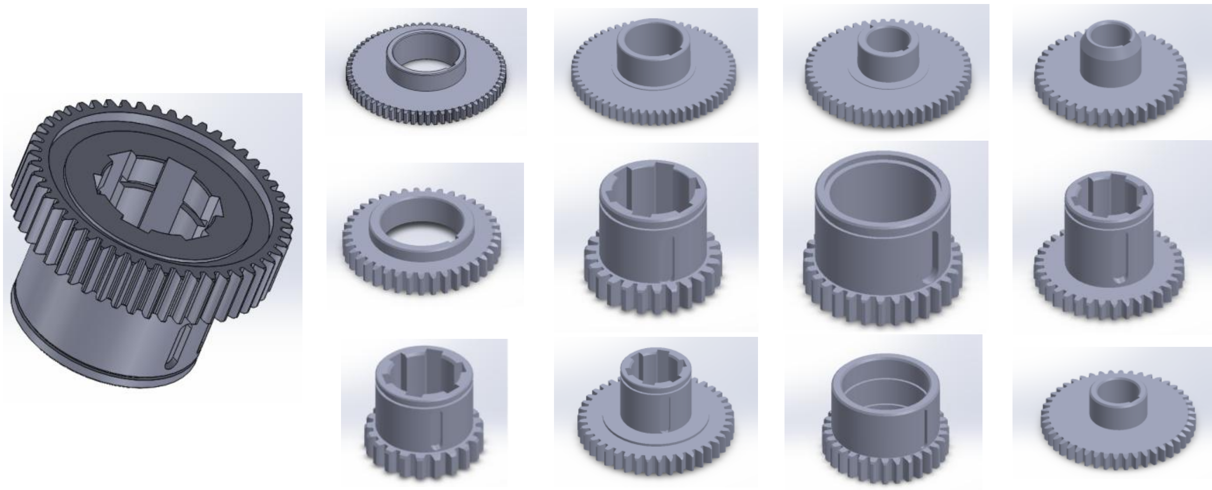

Fig. 5. *3D model of the complex part and all gears from the operating group*

Table 3. *Content of the GT Process plan*

No.	Name of process	Machine/work place/device	T_{pz} (min./batch.)
10	Cut-off	Metalsaw	10
20	Turning	CNC Turning machine	40
30	Gear milling	Gear milling machine	40
40	Gear tooth rounding	Machine for rounding teeth	20
50	Control	Control place	10
60	Internal broaching grooves	Broaching machine	30
70	Doterivanje	Work table	5
80	Cementation	Device for cementation	20
90	Tempering	Device for tempering	20
100	Heat treatment control	Hardness testing device	10
110	Grinding outside	CNC Grinding machine	20
120	Grinding gears	CNC Grinding machine for gears	20
130	Degreasing	Degreasing tub	10
140	Final control	Control place	20

Determining the processing time of a group turning operation

For the observed technological group, it is necessary to select a representative product using ABC analysis, for which the processing operations are specified based on the corresponding group process plan, and then the representative processing operation times (t_{kp}) are determined. Based on the data on quantity, mass and value, the percentages of these parameters were calculated, which are shown in table 4, as a basis for the ABC analysis. Based on quantitative, mass and value ABC analysis, Gear 6 (ident number 146.02.061.05) was selected as a representative product of the observed group of gears.

Table 4. *Data for ABC analysis and product selection of gear group representatives*

Name of part	Quantity Q		Mass m		Price V		Q (%)	m (%)	V (%)
	[pcs/batch]	[pcs/year]	Kg/pcs	Kg/year	[€/pcs]	[€/years]			
Gear 1	310	1240	2.21	2740.4	75	93000	7.65	24.01	7.53
Gear 2	270	1080	0.456	492.48	80	86400	6.55	4.31	7.00
Gear 3	440	1760	0.936	1647.36	82	144320	10.86	14.43	11.69
Gear 4	390	1560	0.493	769.08	45	70200	9.62	6.73	5.68
Gear 5	410	1640	0.760	1246.4	90	147600	10.1	10.92	11.95
Gear 6	**480**	**1920**	0.495	**950.4**	**85**	**163200**	**11.8**	**8.32**	**13.22**
Gear 7	210	840	0.796	668.64	63	52920	5.18	5.85	4.28
Gear 8	270	1080	0.451	487.08	95	102600	6.55	4.23	8.32
Gear 9	400	1600	0.626	1001.6	65	104000	9.87	8.77	8.42
Gear 10	350	1400	0.193	270.2	82	114800	8.64	2.35	9.30
Gear 11	190	760	0.399	303.24	100	76000	4.69	2.65	6.15
Gear 12	330	1320	0.536	707.52	60	79200	8.14	7.32	6.41
Suma	4050	16200		11284.40		1234240	100	100	100

In order to determine the engagement time of a specific processing system (machine tool) for the processing of the observed operation group, it is necessary to determine the reduced number of parts of that group (Q_r). The reduced quantities of individual parts of the operating group are determined based on the expression:

$$Q_{r_i} = Q_i \cdot r_i \qquad (1)$$

in which:

- Q_i - quantity of individual parts from the group
- r_i - degree of reduction of the i-th part

The degree of reduction of a certain part of the observed group includes the reduction for mass (r_m) and complexity (r_s), which can be expressed in the form of:

$$r_i = r_{m_i} \cdot r_{s_i} \qquad (2)$$

The degree of technological complexity of individual parts of the operating group is determined by the ratio of the number of operations of individual parts and the number of processing operations of the corresponding representative. The reduced quantity of all parts of the operating group is determined by the expression:

$$Q_r = \sum_{i=1}^{k} Q_i r_i = \sum_{i=1}^{k} Q_{ri} \quad (3)$$

Table 5 shows the calculation of the reduced amount for the observed group of gears. For the representative product, the turning processing operation (No. 20) was defined, through the specification of the dimensions of the engagement, the processing parameters and finally through the determination of the processing time (t_{kp}). The total cycle time of the observed group of gears during the turning operation (No. 20) is:

$$T_c = Q_r \cdot t_{kp} \quad (4)$$

$$T_c = Q_r \cdot t_{kp} = 21400 \cdot 9.1 = 194740 \text{ (min./year)}$$

Table 5. *Calculation of the reduced quantity of gear group*

Part	Q_i (pcs/year)	m_i (Kg/pcs)	s_i	r_m	r_s	r_i	Q_{ri}
Gear 1	1240	2.21	16/17	4.464	0.888	3.964	4915
Gear 2	1080	0,456	17/17	0.921	1	0,921	995
Gear 3	1760	0.936	16/17	1.890	0.888	1.678	2953
Gear 4	1560	0.493	15/17	0.995	0.882	0.877	1368
Gear4	1640	0.760	18/17	1.533	1.058	1,621	2658
Gear 6	1920	0.495	17/17	1	1	1	1920
Gear 7	840	0.796	16/17	1.608	0.888	1.427	1199
Gear 8	1080	0.451	18/17	0.911	1.058	0.963	1040
Gear 9	1600	0.626	16/17	1,264	0.941	1.189	1902
Gear 10	1400	0,193	17/17	0.389	1	0.389	545
Gear 11	760	0.399	18/17	0.806	1.058	0.852	648
Gear 12	1320	0.536	16/17	1.082	0.888	0.960	1267
Reduced quantity of gear group Q_r=							21400

Calculation of the required number and degree of utilization of FMS elements

If the planned volume of production of a product is Qi, then the total time of occupied the processing system at a certain operation in the manufacturing process plan of this product on an annual basis is determined by the expression (5):

$$T_i = Q_i \cdot t_{ki} + Q_i \cdot \frac{T_{pz_i}}{z_s} = Q_i \cdot t_{ki} + n_{si} \cdot T_{pz_i} \text{ (min./year)} \quad (5)$$

where:

- T_i – total processing time
- T_{pz} – setup time for batch of parts
- z_s - number of parts within the batch
- n_s – number of batch in time period

If it is assumed that the observed facility will work for m_e=250 days per year in s_e= 2 shifts per day with n_e= 7,5 hours per shift and efficiency of η_e=0,8, what follows is that the effective work capacity of machine/workplace equals K_e=180000 minutes per year. Based on the previously calculated processing time, assuming that n_s=10 batch per year, the required number and degree of machine utilization for the observed turning process is (6), (7) i (8):

$$T = 194740 + 4 \cdot 40 = 194900 \text{ (min./year)} \tag{6}$$

$$M = \frac{194900}{180000} = 1.082 \tag{7}$$

$$\eta = \frac{1.082}{1} = 108.2\% \tag{8}$$

If it is assumed that operators work for m_e=250 days per year in s_e=1 shift per day with n_e=7,5 hours per shift and efficiency of η_e=0,8, it follows that Ke equals 90000 minutes per year:

$$N = \frac{T}{K_e} = \frac{194900}{90000} = 2.166 \tag{9}$$

$$\eta = \frac{2.166}{2} = 108.2\% \tag{10}$$

Based on the above, the degree of utilization of the CNC lathe for the processing of the observed group of parts is 108.2%, while two workers would be needed to implement this operation in two shifts. By the same principle, the effects of the application of other machines/workplaces and workers in the cellular production of the observed group of gears would be determined.

CONCLUSION

Cellular manufacturing represents one of the important segments in the application of the concept of Lean production, which is realized through the development and application of flexible manufacturing systems (FMS). Cellular manufacturing is a type of group technology in which parts are grouped into families for production on appropriate machines and devices. A cell is a production structure that can consist of different machines/workplaces and devices in which groups of products/parts that have similar properties are processed. When using cells, emphasis is usually placed on the degree of capacity utilization and their balancing. Efforts are made to maximize the degree of capacity utilization and to balance them, that is, to eliminate "bottlenecks". The manufacturing process plan for parts that are very similar can be realized by applying the concept of group technology. The concept of group technology enables a significant rationalization of the process planning, which means that it is enough to design one, so-called group processing operation, which enables the production of all parts from the operating group on the selected processing system.
On the basis of the previously designed group process plan, it is possible to carry out the design, that is, to specify the process plan of production, both of the product representative of the technological group, and of other parts from the group. In this way, the rationality and standardization of the process plans of manufacturing parts from the production program is ensured. In addition to the rationalization of technological preparation, the product design process is also rationalized based on the principles of grouping and application of the modular concept of product construction. The concept of group technology is also very important for the production process itself, because the serial number of parts increases, for which easier planning and production can be realized at the same time.
On the basis of the designed process plan of the representative product, as shown in the paper, the production cycle of a certain group of parts can be rationally determined, using the appropriate methodology. Based on the appropriate data of the designed group process plan and the calculated cycle times based on the applied methods, it is possible to calculate and determine the necessary production resources for the production of the entire group of parts in an economical and fast way, as well as the effects of their application, which was demonstrated in the work for the group of gears .
In order to define other elements of FMS, it is necessary to determine the necessary quality and quantity of tools, fixtures, gauges, etc., which is not shown here due to the scope of work.

Based on the previous data, the 2nd and 3rd phases, evaluation and selection of FMS elements, ie modeling, simulation and optimization of FMS work, can be realized very effectively [6, 7, 12, 13].

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THE MECHANICAL PROPERTIES OF A CIRCULAR CROSS-SECTION COLUMN MADE OF COMPOSITE MATERIAL PRODUCED USING A NEW MIXED PLASTIC RECYCLING TECHNOLOGY

Research paper

Ljubica Lazić Vulićević[1], Danijela M. Jašin[2], Aleksandar Rajić[3], Valentina Mladenović[4], Ivan Palinkaš[5]
[1,2,3,4]Technical College of Applied Sciences, Zrenjanin, Serbia
[5]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: This paper presents an advanced recycling technology for materials that are traditionally non-recyclable, such as composite plastics. The resulting material exhibits favorable mechanical properties and serves as a sustainable alternative to wood, metal, and various plastic products. The production process and application of this eco-material are fully aligned with environmental standards. Laboratory tests were conducted to evaluate the mechanical and other properties of the newly developed materials, alongside a circular cross-section column product manufactured from these materials. The obtained results indicate the potential of this pioneering technology as a sustainable solution for repurposing complex waste mixtures of plastics, composites, and glass.
Key words: Recycling, innovative technology, non-recyclable materials, mechanical properties, circular cross-section column.

INTRODUCTION

Plastic materials have become an integral part of modern life due to their versatility, durability, and cost-effectiveness. However, their widespread use has led to significant environmental challenges, particularly concerning waste management and pollution. Recycling plastic is a critical solution to these issues, offering a way to reduce waste, conserve resources, and minimize the ecological footprint. By transforming discarded plastic into reusable materials, recycling plays a vital role in creating a more sustainable future. Composite plastic variants containing glass, metal, and other materials don't fall into the category of recyclable, and there is currently no solution for them. Up to today plastic production has been steadily increasing. The worldwide production of plastics reached a staggering 390.7 million tons in 2021, [1]. Only 9% of the mentioned quantity of plastic produced after use is recycled, so it is clear that plastic waste represents a global problem, [2].
The projected scenario foresees the accumulation of plastic waste surpassing one billion tons by 2050, [2], demanding a rigorous commitment to recycling, alongside advancements in innovation in this field and the development of new types of materials.

NEW RECYCLING TECHNOLOGY AND APPLICATION POSSIBILITIES

Conventional plastic recycling methods

Contemporary plastic recycling techniques require careful and detailed sorting of waste materials by type, a task that is both complex and demanding. Proper segregation after collection necessitates prior knowledge of different plastic categories, making the process less straightforward. Present recycling technologies are generally limited to processing uniform, single-type plastics. This sorting becomes particularly challenging when handling large volumes, as many plastics look very similar, and the identification markings indicating the plastic type are often difficult to find or recognize.

[1]Corresponding author, lazic.ljubica@yahoo.com,
[2]danijelajasin@gmail.com,
[3]aleksandarrajic@yahoo.com, ORCID: 0000-0003-3921-1502
[4]mladenovic.val@gmail.com,
[5]ivan.palinkas@tfzr.rs, ORCID: 0000-0001-9253-1375

In practical terms, inadequate sorting during the initial selection phase and the subsequent mechanical shredding of plastic waste in the primary recycling phase often result in the mixing of different types of plastics. From contacts with larger plastic recycling centers in the country and the region, we have information that during one business year, between 5-10% of the amount of plastic waste processed through primary recycling cannot be further processed with known technology. It is also common for plastic pieces to be sent for recycling that consist of multiple parts made of different types of plastic. The costs of separating such parts far exceed the upper limit of profitability, and they need to be manually separated using various tools. Unfortunately, even such an approach is not a guarantee of achieving complete separation, [3, 4]. In such cases, all parts are shredded together and pose a problem for further recycling. At present, there is no established technology for recycling, processing, and repurposing composite and mixed plastics containing glass. Consequently, these waste materials are predominantly either incinerated or disposed of in landfills.

This paper presents an innovative technology for recycling mixed plastics, the mechanical properties of the resulting composite material, as well as a product made from this new material, as a solution for its application. The innovative technology successfully recycles 80% of previously non-recyclable, non-hazardous composite and plastic-glass mix, with only 20% consisting of selected plastic materials. The produced eco-friendly material possesses very good properties, as demonstrated in the following.

A brief overview of the new recycling technology

The innovative recycling technology focuses on the processing and repurposing of various composite and mixed plastics that are typically regarded as non-recyclable. This is accomplished through a specialized method for preparing the initial plastic waste. The core of this innovation is a unique approach to homogenizing the starting material, along with modifications to the sequence of operations within the recycling process (Figure 1). Additionally, the formulation and recipe development that integrate waste materials represent a significant aspect of this innovation, necessitating extensive hours dedicated to experimentation and testing.

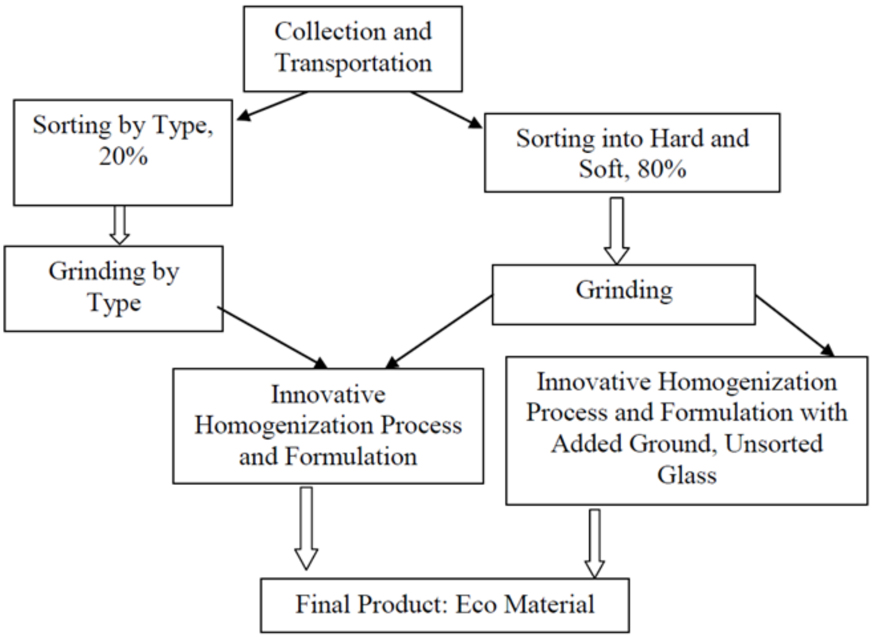

Fig. 1. *Diagram of innovative recycling technology*

In comparison to the conventional recycling process, this one offers the following new solutions:

- A specific process and formulation for blending waste plastic to achieve homogeneity in a straightforward manner.
- Minimizing or potentially eliminating the need for sorting by type (polypropylene, polyethylene, polyvinyl chloride, etc.) due to our formulation incorporating only 20% selected plastic, as previously mentioned. This results in significant time, labor, and storage container savings.
- Removing the necessity for separate processing of sorted plastic through different lines (washing, drying. granulation) or waiting for one type to complete processing before moving to the next.
- Reducing the mechanical processing steps of waste plastic before the final product is produced.
- Engaging in the processing, recycling, and reusing of diverse waste mixtures, plastic composites, and glass.
- Introducing a new process and formulation for blending waste plastic to create a versatile material suitable for various end products.

These findings lead to the conclusion that this innovative technology offers a viable solution for the repurposing of substantial amounts of mixed waste plastics, composites, and glass. It showcases energy efficiency while producing a material with a wide range of potential applications.
A review of the literature in this area reveals that there are analogous concepts concerning the recycling of composite and mixed plastic waste. However, these approaches typically focus on specific combinations of plastics and composites. Our solution differentiates itself by employing a significantly simpler and more comprehensive mechanical treatment of the initial materials. Additionally, these existing concepts often omit a homogenization process and depend on high-temperature methods, which inherently result in higher energy consumption and, consequently, increased costs of recycling.

The formulation of innovative technology involves the following types of waste materials:

- Soft PVC - Index number according to the waste catalog 150201, [7]. After grinding, this mass is homogenized with glass and other non-recyclable plastics, and it is used as a filler for profiles. It is rarely recycled, even though recycling is possible, and is typically subjected to incineration.
- Rigid PVC - Waste index number: 1501002, [7]. It is used as a filler in a certain percentage or for manufacturing profiles.
- Multi-layer HDPE plastic bags with an addition of 10-15% PA or PET are used as a component for filling material. Waste index number: 150102, [7].
- Ground packaging glass, waste index number 150107, [7]. The potential for recycling is significant, but it has almost become inactive in our region, [8].

Implementation of Materials Produced Through Innovative Recycling Technology

From materials obtained in this way, various products can be made, and the paper examines filled or hollow plastic profiles, which can serve as a replacement for traditional columns made of wood, concrete, metal, etc. For this patent, an intellectual property protection certificate number 57664 was obtained in Serbia. In future research, it is necessary to conduct a life cycle assessment of the eco-product using the appropriate methodology, as this would further position this eco-material, [5]. It is important to note that this innovative technology falls within the recycling sector, which is certainly one of the priority areas for development and investment worldwide, in accordance with the principles of Agenda 2030, [6]. Considering that, until now, there hasn't been a cost-effective and beneficial solution for waste materials such as composite plastics, various plastic mixtures combined with waste glass, etc., the market for this innovative technology, eco-material, and its related products is substantial

MECHANICAL PROPERTIES OF ECO-MATERIAL AND FINAL PRODUCT - RESULTS AND DISCUSSION

There are numerous possibilities for using this new material. One of them that we have conducted is a column with a circular cross-section with infill. First, the mechanical properties of the material used for constructing the column and the material used for filling are determined. The tests were conducted in laboratory at the Faculty of Civil Engineering in Subotica.

Laboratory testing of recycled plastic material used for producing columns with a circular cross-section

The mechanical properties testing of the recycled plastic material was conducted on 9 samples, [9]. The test specimens were rotationally symmetrical in the cylinder shape with a length of 50 cm, and a diameter of 30 mm (Fig. 2), with mass per volume m =1,414 g/cm^3. The obtained average values of the results are: the tensile strength, σ = 33.24 MPa, and recovery of strain after tensile failure, δ_E = 98.6 %.

Fig. 2. *Characteristic shape of samples for tension testing, sample during testing and cross section of the sample after testing*

Laboratory Testing of Composite Filler Material

The mechanical characteristics testing of the composite filler material based on hydraulic binder was conducted on 9 samples in the form of a prism with dimensions of 4x4x16 cm. The reported results represent the mean values and pertain to a water-saturated state, with mass per volume m =1.471 g/cm^3. The obtained average values of the results are: the bending tensile strength, σ = 2.68 MPa, and the compressive strength, σ = 6.22 MPa.

Laboratory Compression Testing of Short Circular Cross-section Columns Until Failure

In order to obtain certain mechanical properties of the eco-columns, tests were conducted on hollow and filled plastic profiles. These tests were conducted on samples that were cut out of the columns (hollow and filled) and prepared in a way to avoid slenderness effects during compression testing. The tests were performed on 3 samples of hollow and 3 samples of filled circular cross-section columns. The columns had cross-section dimensions of Ø63.2 mm, an average wall thickness of 8.1 mm, and a composite recycled mixture as the filler, while the height of the samples was 260 mm. Samples during testing are shown on Fig. 3 and obtained diagrams on Fig. 4.

Fig. 3. *Samples during testing: circular cross-section and columns after testing (hollow and full)*

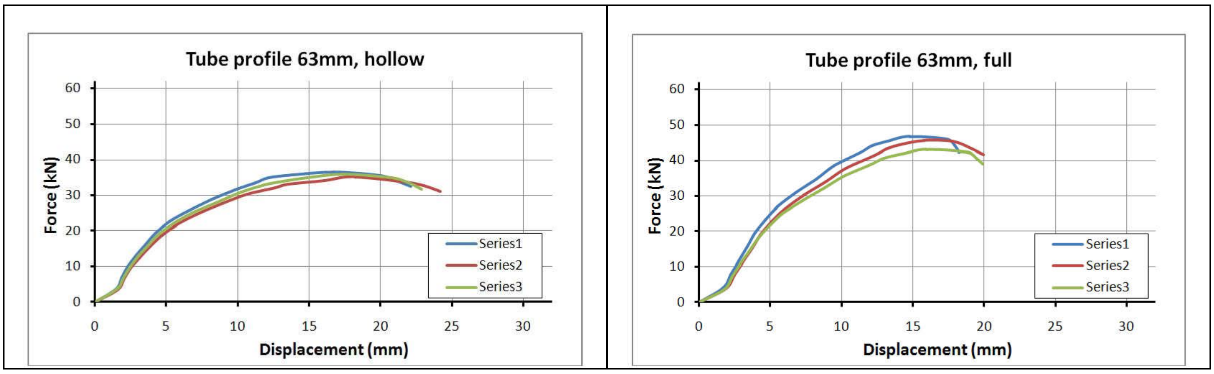

Fig. 4. *Compression testing until failure data of hollow and full circular cross-section (tube) profiles*

The maximum achieved compressive force at the point of failure for the filled column is F = 40.94 kN, and for the hollow column F = 31.74 kN. The maximum deformations (shortening) for the filled column is ΔL = 19.38 mm, and for the hollow column is ΔL = 23.06 mm.

Laboratory Bending Testing of Circular Cross-Section Columns Until Failure

The columns had cross-section dimensions of Ø63.2 mm, an average wall thickness of 8.1 mm, and a composite recycled mixture as the filler, while the average length of the samples was 1997.0 mm. For hollow profiles average profile mass was m=2.05 kg. For the filled profiles average profile mass was m = 8.12 kg. The samples during testing are presented on Fig. 5 and obtained diagrams on Fig. 6.
The bending moment at failure for hollow profiles (measured on the fixed end of the console with a span of L_c =1.0 m, loaded with concentrated force at the free end of the console), the average value, was M = 233.3 Nm, and individual smallest M = 228.7 Nm. The deflection at failure (measured on the free end of the console with a span of 1.0 m, loaded with

concentrated force at the free end of the console) for hollow profiles (average value) was, u = 24.8 cm (L_c/4,0), and individual greatest u =26.2 cm (L_c/3,8).
The bending moment at failure for filled profiles (measured on the fixed end of the console with a span of 1.0 m, loaded with concentrated force at the free end of the console) was, average M = 253.9 Nm, and individual smallest M = 245.1 Nm.

Fig. 5. *Bending testing of circular cross-section columns until failure and reversible deformations on the sample after testing*

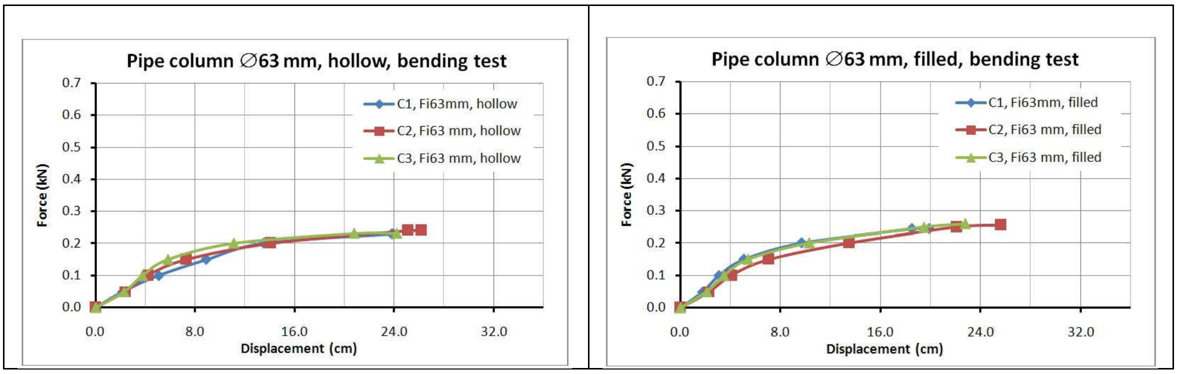

Fig. 6*. Bending testing until failure data of hollow and full circular cross-section columns*

The deflection at failure (measured on the free end of the console with a span of 1.0 m, loaded with concentrated force at the free end of the console) for filled profiles (average value) u = 22.8 cm (L_c/4.4), and individual greatest u = 25.6 cm (L_c/4.1).

CONCLUSION

This paper explores the potential of an eco-friendly material that exhibits functional characteristics along with numerous advantages, including: environmental protection, resource conservation, and the utilization of waste materials previously destined for incineration or landfill instead of primary raw materials. The presented material, as well as the product, demonstrates very good mechanical properties, allowing this product to effectively replace any conventional material (such as metal, concrete, and wood) in the production of versatile products across sectors like construction, agriculture, and transportation. Furthermore, these products can be recycled using the same technology, eliminating the need for additional protective measures like impregnation or painting, thereby aligning with green manufacturing principles.
The critical elements highlighted in this study demonstrate that this innovative technology presents a viable solution for the repurposing of diverse mixtures of waste plastics, composites, and glass. It exemplifies the principles of sustainable development and supports the global pursuit of a circular economy.

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STRESS ANALYSIS OF CRANE SHACKLE USING FEM

Research paper

Srđan Samardžic[1], Spasoje Trifković[2], Miroslav Milutinović[3]
[1,2,3]University of East Sarajevo, Faculty of Mechanical Engineering, Republic of Srpska, Bosnia and Herzegovina

Abstract: Shackle is a device used for lifting heavy loads by cranes. They can be closed type - forged shackles or articulated shackles. The weight of the shackle is the load that the crane always has to lift, which reduces the load capacity and increases the required lifting power. In order to reduce the required lifting power and increase the carrying capacity, it is necessary that the dimensions of the shackle have the minimum required value at the prescribed safety degree. This paper analyses the stress state of shackle analytically and numerically using the finite element method (FEM). At the end of the paper, a comparison of the obtained results is given.
Key words: crane, hook, shackle, FEM.

INTRODUCTION

In the literature [1-9] there is a lot of information about lifting hooks calculation, which is not the case with shackles. For a shackle shaped as in Figure 1 [1] with a load capacity of 800kN, it is necessary to choose the dimensions, so that the shackle has as low weight as possible with the prescribed safety degree.

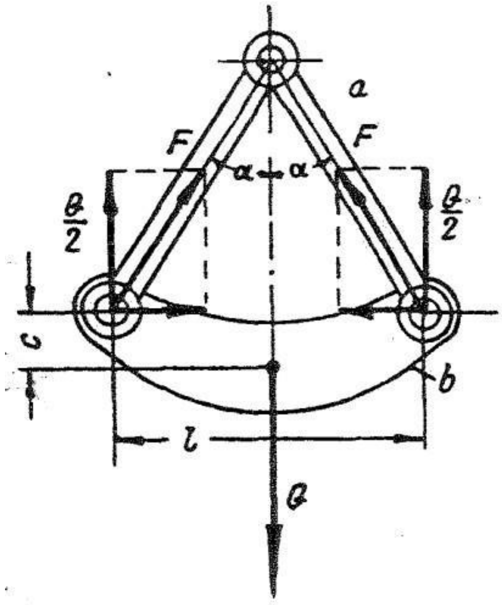

Fig 1. *Schematic presentation of the main dimensions and load distribution*

The chosen dimensions are:

- *l* = 315 mm
- *c* = 20 mm
- *R* = 515 mm (distance from the joints of the shackle to the joint connection of the sides)

[1] srdjan.samardzic@ues.rs.ba, ORCID: https://orcid.org/0009-0003-4096-7523
[2] Corresponding author, spasoje.trifkovic@ues.rs.ba, ORCID: https://orcid.org/0000-0003-0656-5718
[3] miroslav.milutinovic@ues.rs.ba, ORCID: https://orcid.org/0000-0002-1642-951X

After choosing the dimensions, the model was created in the SolidWorks software package. In addition to the above, the dimensions of the characteristic cross-sections (transverse and sides carriers) were also chosen. The dimensions of the transverse carriers cross-section is:

- $b = 100$ mm
- $h = 200$ mm

The dimensions of the sides carriers cross-section are:

- $b_1 = 50$ mm
- $h_1 = 80$ mm

The isometric view of the model is given in Figures 2. and 3.

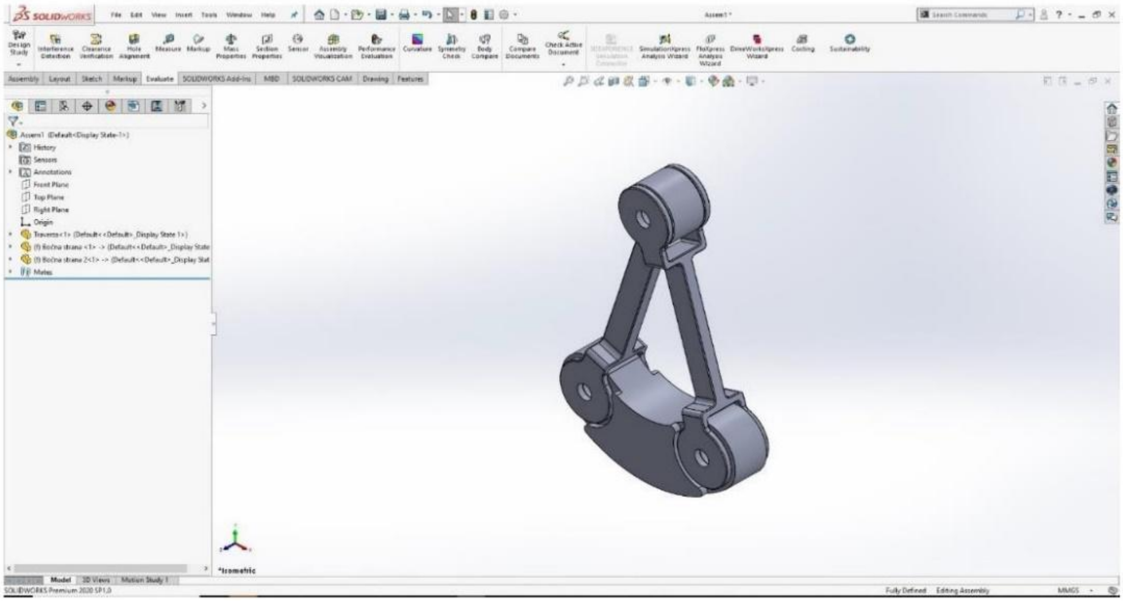

Fig 2. *Isometric view of the articulated shackle model*

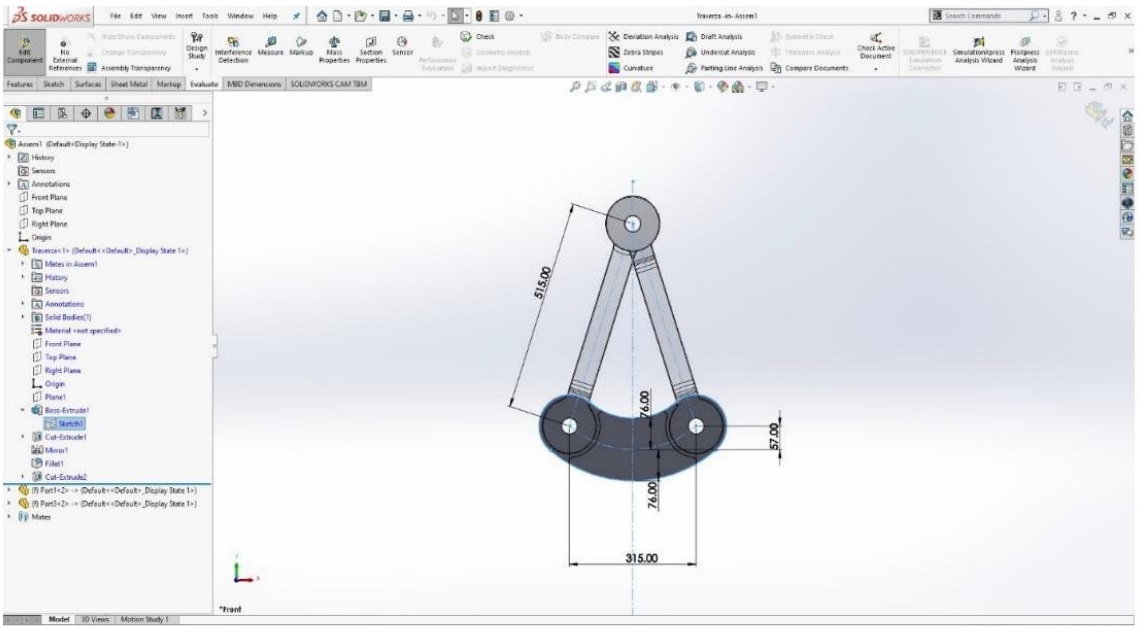

Fig.

Fig 3. *3D model of the articulated shackle model with dimensions*

ANALYTIC CALCULATION

Articulated shackles are composed of segments that are hinged, which relieves the side carrier from the moment of bending. The side carriers are loaded only for tension by the force *F* and the horizontal carrier by the compressive force F_1, the moment of this force and the bending moment due to the weight of the load.
First of all, it is necessary to determine the value of the angle *α*, in order to determine the intensity of the forces of the weight force projections:

$$\alpha = 17{,}81^o.$$

The tension force of side carriers is:

$$F = \frac{Q}{2\cos\alpha} = \frac{800}{2\cos 17{,}81^\circ} = 420{,}134 \text{ kN}. \tag{1}$$

The compression force of horizontal carriers is:

$$F_1 = \frac{Q}{2} tg\alpha = \frac{800}{2} tg 17{,}81^\circ = 128{,}503 \text{ kN}. \tag{2}$$

Then follows the calculation of the relevant characteristics of the cross-section of the horizontal and sides carriers. The resisting moment of horizontal carrier:

$$W = \frac{b \cdot h^2}{6} = \frac{100 \cdot 200^2}{6} = 666666{,}66 \text{ mm}^3 = 666{,}6 \text{ cm}^3 \tag{3}$$

The bending moment is:

$$M_S = \frac{Q \cdot l}{4} + \frac{Q \cdot tg\alpha}{2} \cdot c \tag{4}$$

$$M_S = \frac{800 \cdot 31{,}5}{4} + 128{,}503 \cdot 2 = 6557{,}006 \text{ kNcm} \tag{5}$$

The stress on horizontal carrier is:

$$M_S = \frac{800 \cdot 31{,}5}{4} + 128{,}503 \cdot 2 = 6557{,}006 \text{ kNcm} \tag{6}$$

$$\sigma = \frac{M_S}{W} + \frac{F_1}{A_1} = \frac{6557,006}{666,6} + \frac{128,503}{200} = 10,47 \ \frac{\text{kN}}{\text{cm}^2} \tag{7}$$

The stress on sides carriers is:

$$\sigma = \frac{F}{A_2} = \frac{420,134}{40} = 10,503 \ \frac{\text{kN}}{\text{cm}^2} \tag{8}$$

ANALYSIS USING FINITE ELEMENT METHODS

The finite element method is a numerical method widely used in modern development and analysis processes. It is based on the discretization of the system into a certain number of finite elements.
As previously stated, the model was created in a special software package for modeling, and it was first of all necessary to "import" the given model into the software package for finite element analysis, as shown in Figure 4.

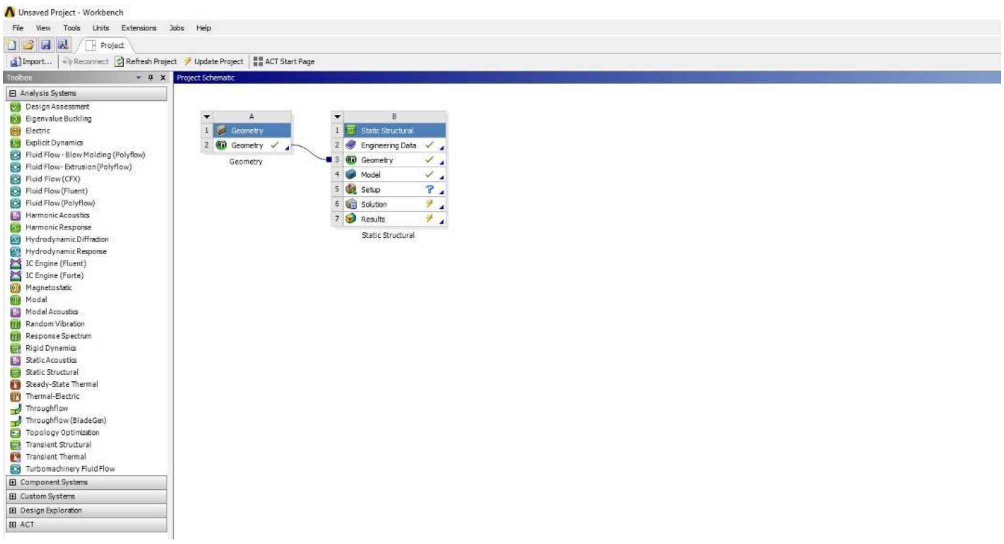

Fig 4. *3D Importing the model into the analysis program*

Now follows the definition of the mesh of finite elements, i.e. of its parameters. The basic parameters that were chosen are shown in Figure 5:

- layout of elements - program controlled
- adjusting the size of finite elements – yes
- number of nodes – 32545
- number of finite elements – 16042

The model with the generated network is shown in Figure 6.

Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	Default
Sizing	
Use Adaptive Sizi...	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Di...	864.39 mm
Average Surface ...	4053.8 mm²
Minimum Edge L...	0.62159 mm
Quality	
Check Mesh Qua...	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic In...	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Lay...	5
Growth Rate	1.2
Inflation Algorit...	Pre
View Advanced ...	No
Advanced	
Number of CPUs ...	Program Controlled
Straight Sided El...	No
Number of Retries	Default (4)
Rigid Body Behav...	Dimensionally Reduced
Triangle Surface ...	Program Controlled
Topology Checki...	Yes
Pinch Tolerance	Please Define
Generate Pinch o...	No
Statistics	
Nodes	32545
Elements	16042

Fig 5*.* *Finite element mesh parameters*

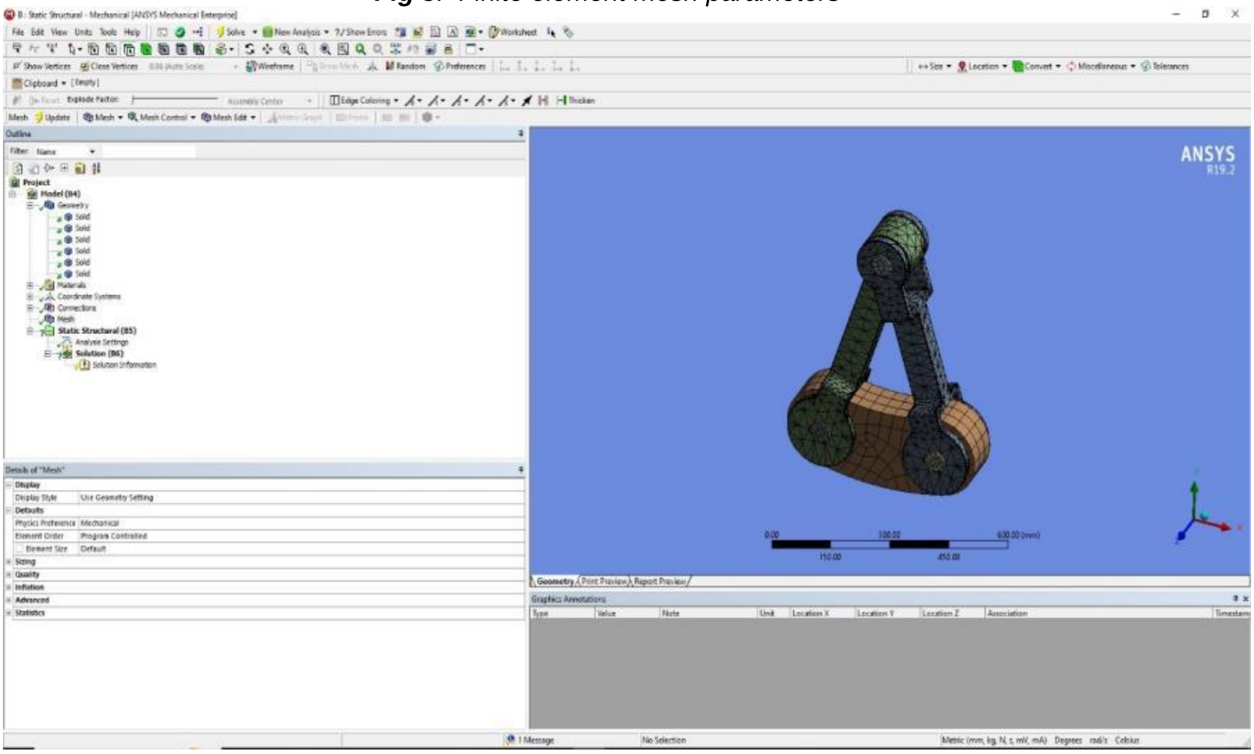

Fig 6*.* *Model display with generated mesh*

The next step is to define the boundary conditions as well as the external loads as shown in Figures 7 and 8.

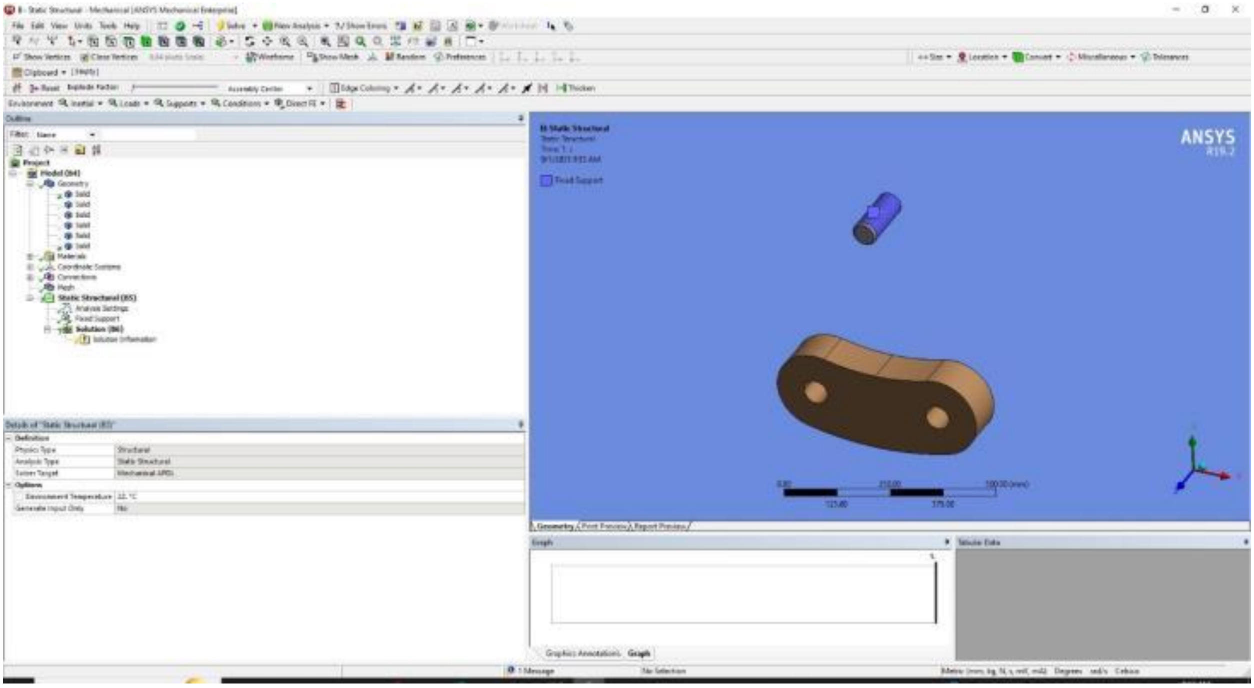

***Fig 7**. Defining the fixed segment*

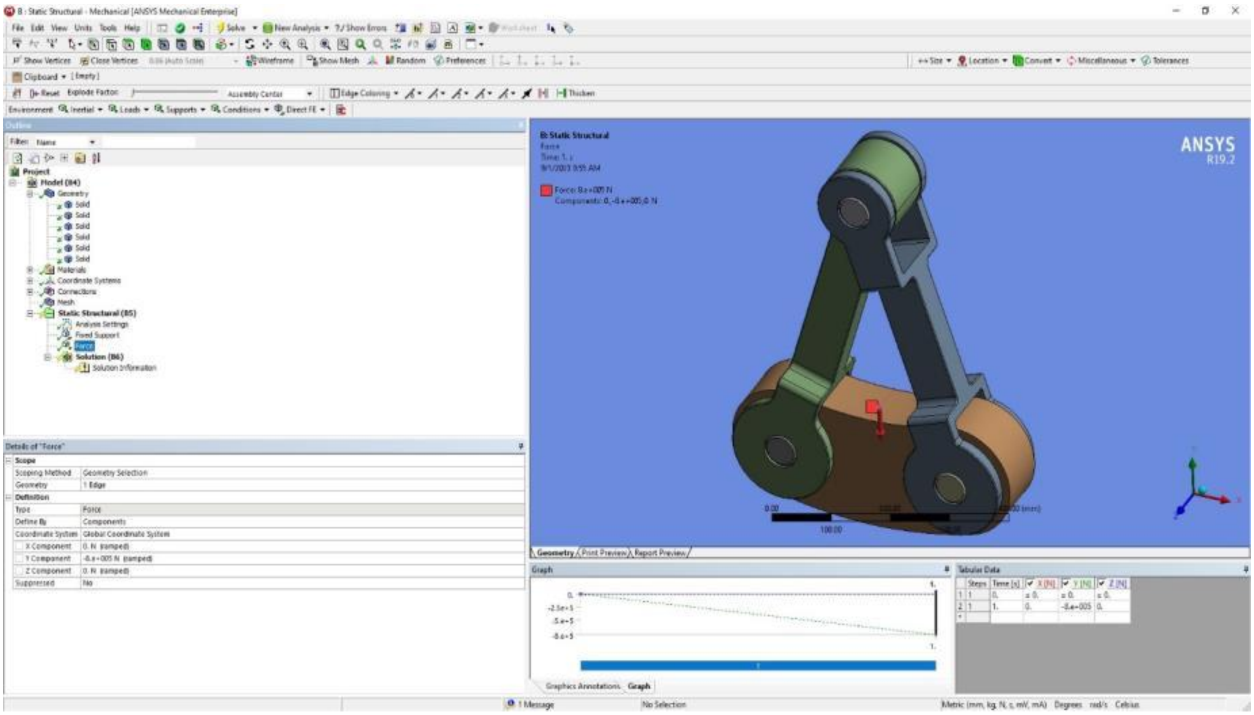

***Fig 8**. Load determination*

The results of the analysis are shown in Figure 9.

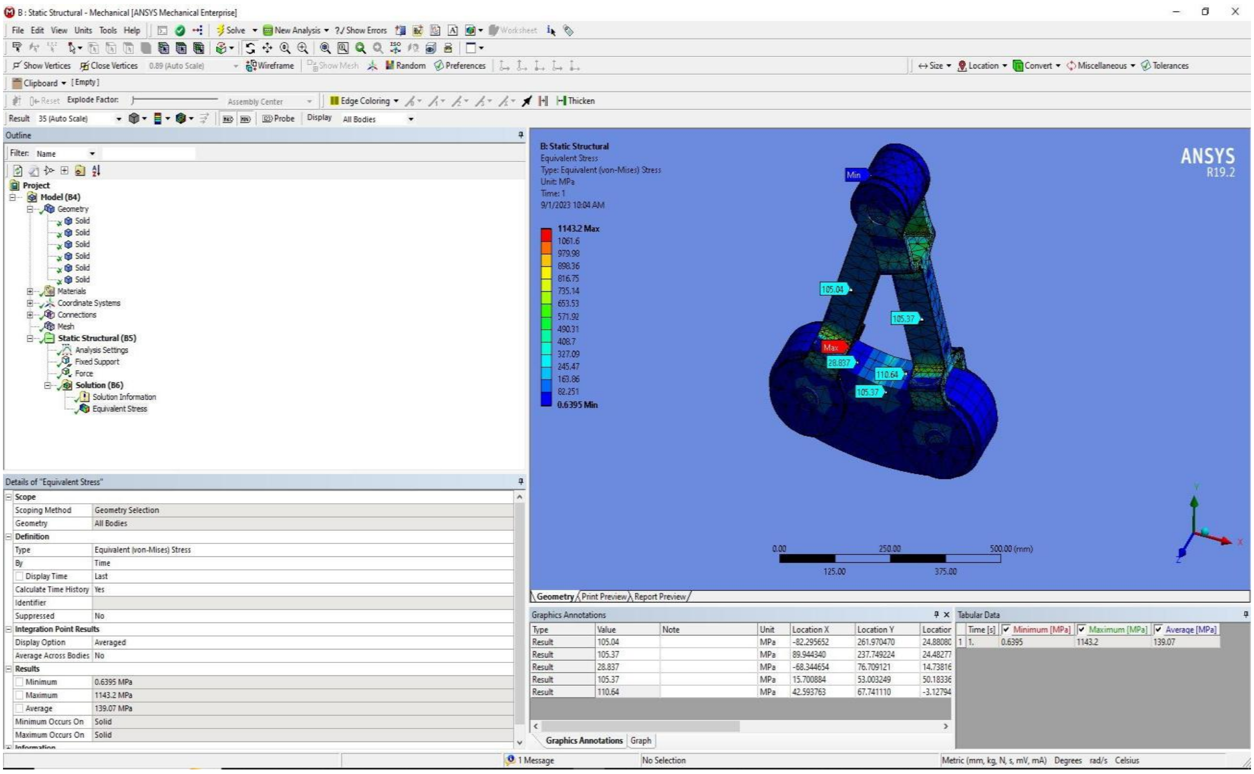

***Fig 9**. Results of FEM analysis*

CONCLUSION

Through the previous chapters, we had the opportunity to see the process of analytical calculation of the stress state of all segments of the articulated shackle, as well as the numerical analysis of the stress state using the finite element method. Based on the above, the following can be concluded:

1. The stress value using FEM and the values obtained by analytical calculation (stresses differ by 0.01kN/cm^2) are almost identical. The difference in values occurred due to the rounding of values in the analytical method.
2. The highest stress value was obtained, as expected, at the point of stress concentration due to the change in the cross-section, and for the relevant cross-section, the location with the possible source of stress concentration must be taken into account.

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BIOMIMETIC APPLICATIONS IN FLUID MECHANICS: FROM NATURE-INSPIRED DESIGNS TO TECHNOLOGICAL ADVANCEMENTS

Review paper

Murat Ispir[1], Muharrem Hilmi Aksoy[2*]
[1,2]Konya Technical University, Faculty of Engineering and Natural Science, Konya, Türkiye

Abstract: The field of biomimetics aims to develop innovative technical and engineering solutions by replicating systems, structures, and functions found in nature. Research in this domain focuses on the highly efficient and sustainable systems found in living organisms created by God over millions of years, seeking novel approaches to address human challenges. A key area within biomimetics is fluid mechanics, which explores how living organisms interact with fluid environments to inspire creative and efficient technological advancements. The multidisciplinary goal of these efforts is to design hydrodynamic and aerodynamic systems influenced by nature's mastery of fluid dynamics. Examples include the microstructure of shark skin, which reduces friction and enables swift and silent movement; the aerodynamic capabilities of birds and insects, which have influenced the design of aircraft wings and wind turbines; and the aquatic locomotion of fish and marine mammals, which has inspired the development of low-drag surfaces and efficient propulsion systems. In conclusion, the synergy between biomimetics and fluid mechanics contributes to the creation of more sustainable, energy-efficient fluid systems, construction materials, and transportation technologies.
Keywords: *biomimetic, fluid mechanics, nature-inspired*

INTRODUCTION

With the continuous advancement of technology, engineering designs are progressively evolving and improving. One critical influence on these designs is biomimetics, the practice of drawing inspiration from nature to solve complex engineering problems [1]. Biomimetic applications are inherently multidisciplinary, merging the study of natural phenomena with engineering expertise to develop innovative solutions [2]. Biomimetic materials, which replicate the patterns, functions, and characteristics observed in natural organisms, exemplify the convergence of these fields. These materials are designed to mimic biological systems found in all forms of life, including microorganisms, plants, and animals. By imitating the inherent roles or properties of natural systems, engineers can develop materials with specific desired attributes, such as strength, flexibility, adhesion, self-healing capabilities, and resistance to environmental factors like corrosion or fouling [3-6]. Biomimetics, as an interdisciplinary field, centers on understanding and emulating natural systems, processes, and designs to address human challenges and advance technological innovation [7]. In particular, animals have developed a myriad of adaptations that offer a virtually limitless source of inspiration for engineering designs, with immense potential to drive future technological advancements. Examples include the use of fin structures for efficient swimming, aerodynamic principles for flight, and the honeycomb structure, which provides an optimal balance between weight and strength [8, 9]. Beyond engineering, biomimetic applications extend into diverse fields such as architecture, where nature-inspired designs contribute to the development of innovative structures, medicine, where biological principles improve human health solutions, and even art, where nature serves as a source of creative inspiration [10]. Figure 1 provides a summarized framework of engineering disciplines that have benefited from biomimetic applications across various organisms.

One prominent area of biomimetic application is fluid mechanics. In recent years, biomimetic principles have been widely employed in fluid mechanics to achieve objectives such as flow control, drag reduction, or enhancement. Research in this field has increasingly focused on

[1]mispir@ktun.edu.tr,ORCID: https://orcid.org/0000-0001-5238-6011
[2]Corresponding author, mhaksoy@ktun.edu.tr,ORCID: https://orcid.org/0000-0002-6509-8112

computational fluid dynamics (CFD) modeling and experimental studies that explore biologically inspired technologies. In this paper, we compile and review various biomimetic studies applied in the field of fluid mechanics, highlighting their current application areas and potential for future development.

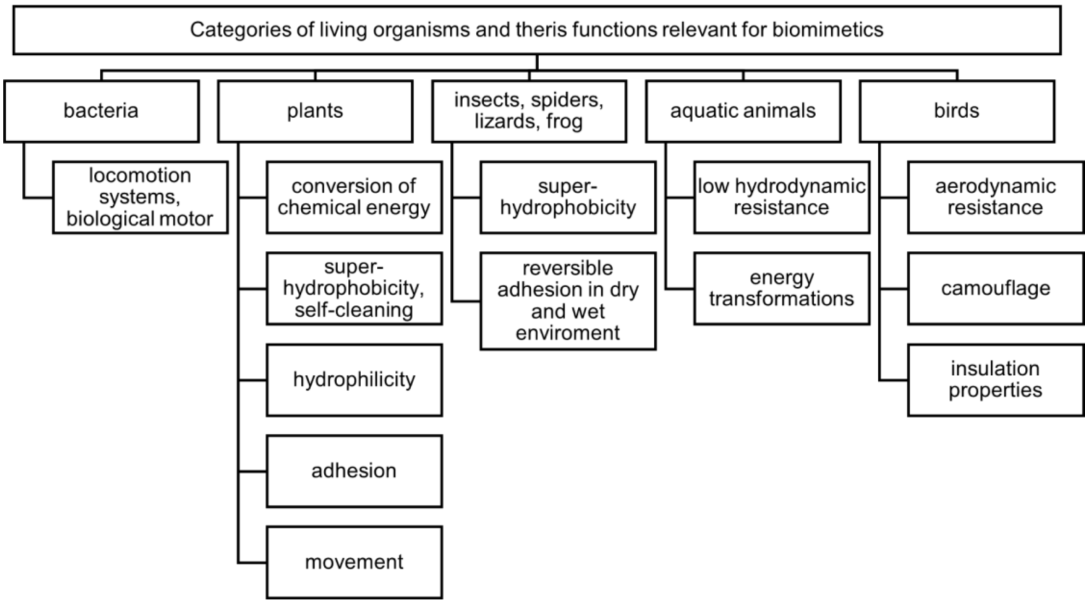

Fig 1. *The roles that organisms play in biomimetics [2]*

BIOMIMETIC APPLICATIONS IN FLUID MECHANICS

Biomimetic applications offer enhanced flow control capabilities compared to conventional methods. In addition to reducing drag and increasing lift, biomimetic approaches can also provide noise reduction benefits. These advantages have led to the widespread adoption of biomimetic solutions in the aviation industry. Currently, biomimetic principles are applied across two main areas to address engineering challenges and optimize designs [11]. A classification of biomimetic methods for aerospace applications is presented in Figure 2.

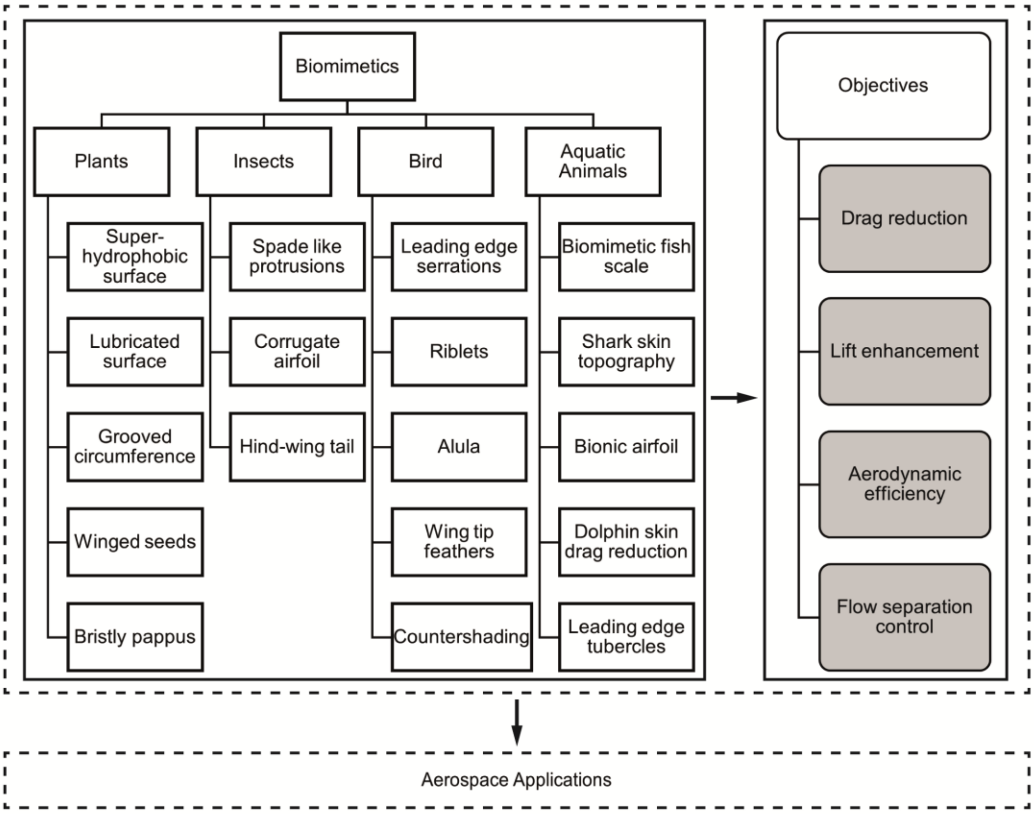

Fig 2. *Classification of biomimetic methods for aerospace applications [11]*

Beyond aerospace applications, hydrodynamic biomimicry has also garnered significant research attention. Biomimetic approaches in underwater environments draw inspiration from marine organisms and ecosystems to develop technologies optimized for aquatic settings. Common applications include hydrodynamic design, surface texturing, sensing and detection, materials and structures, and adaptation to extreme conditions [12-14]. The propulsion and locomotion mechanisms of marine life, characterized by their efficiency and diversity, serve as valuable models for the development of underwater vehicles, robotics, and submarines[15].

Several studies in the literature explore the intersection of biomimetics and fluid mechanics. For example, Yang, Li [16] conducted an experimental study utilizing particle image velocimetry (PIV) to investigate shark-skin-inspired surfaces. Their findings revealed a 4.81% reduction in drag force at a Reynolds number of 190. Similarly, Dean and Bhushan [17] examined drag reduction using shark skin and observed an approximate 10% reduction in maximum drag force. Moscato and Romano [18] in their study on biomimetic wings for micro air vehicles, also employed PIV, concluding that biomimetic wing profiles exhibited approximately 50% better performance than flat wing profiles. Numerous other studies in the literature further explore nature-inspired fluid mechanics. A selection of these studies is summarized in Table 1.

Table 1. *Some research on biomimetic applications in fluid mechanics*

Authors	**Animal**	**Anatomical Structures**	**Application**
Bachmann and Wagner [19]	Barn owl	Feathers	The serrated structure of barn owl feathers provides enhanced flow control and noise reduction on UAV wings.
Salami, Montazer [20]	Dragonfly	Movable wings	Utilizing a dragonfly-inspired wing structure to improve lift

			force in micro air vehicles.
Fish and Battle [21]	Whale	Flipper	Whale flippers are used to control flow and maintain lift at high angles of attack.
Fish and Lauder [22]	Swimming Fishes	Fins	Active and passive flow control mechanisms inspired by the fin movements of swimming fish.
Aftab and Ahmad [23]	Whale	Tubercles	Enhancing the performance of the NACA 4415 airfoil by incorporating tubercle-like structures based on whale anatomy.
Triantafyllou, Winey [24]	Tuna	Fins	Mimicking tuna fins to increase the maneuverability of autonomous underwater vehicles.
Wen, Weaver [25]	Shark	Skin	Reducing drag forces and increasing speed by mimicking shark skin surface textures.
Oeffner and Lauder [26]	Shark	Skin	Shark skin structures are used to minimize drag forces and improve speed efficiency.
Borazjani and Daghooghi [27]	Fish	Tail	Investigating the formation of leading-edge vortices caused by the fishtail motion.
Tangermann, Ercolani [28]	Stork	Multi-element wing	Conducting aerodynamic analysis of wingtip feathers using CFD to examine soaring flight capabilities in storks.
Chen, Rao [29]	Bird	Feather	Investigating drag force reduction using herringbone riblet structures inspired by bird feathers.

CONCLUSION

Biomimicry aims to develop technological and engineering solutions by emulating the structures, functions, and processes observed in the natural world. This field examines the highly efficient and resilient systems that creatures in nature have been endowed with over millions of years, seeking innovative approaches to address human challenges. One key area where biomimicry has proven particularly valuable is fluid mechanics, where the interaction of organisms with fluid environments—such as air and water—serves as inspiration for advanced and efficient engineering solutions. By integrating knowledge from both fields, researchers strive to develop hydrodynamic and aerodynamic technologies that leverage the sophisticated fluid dynamics found in nature. Biomimetic applications have already yielded significant advancements in fluid mechanics, contributing to a variety of innovations, including:

- Observing and analyzing the natural fluid movements of organisms, such as fish and birds, and replicating their physical characteristics and movements in technological designs.
- Developing more efficient wind turbines inspired by the wing movements of birds and bats.
- Creating more flexible and efficient underwater vehicles based on the movement mechanisms of fish species.
- Designing drag-reducing coating materials inspired by natural surfaces, such as shark skin.
- Developing hydrophobic surfaces that resist dirt and water.
- Advancing microfluidic and nanofluidic systems, inspired by studies of micro-scale fluid interactions, such as the ability of certain insects to walk on water.

Through the continued exploration of biomimetic principles, fluid mechanics stands to benefit from nature's time-tested innovations, leading to more sustainable and efficient technologies.

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THE DEVIATION BETWEEN INJECTED MOLDED PLASTIC PART AND FDM MANUFACTURED PART

Research paper

Ivan Matin[1]*, Branko Štrbac[2], Miloš Ranisavljev[3], Miodrag Hadžistević[4], Đorđe Vukelić[5]
[1,2,3,4,5]University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Novi Sad, Serbia

Abstract: This paper presents comparation of the deviation between part made by Fused Deposition Modeling (FDM) and injected molded part. The paper also presents a system for determine deviation of plastic parts. The presented system is used for part design and both types of manufacturing.
Key words: FDM, CMM, plastic, injection molding

INTRODUCTION

Considering that additive manufacturing technology (AM) has evolved significantly over the past few decades, understanding of deviation and mechanical properties became important part of researches with the goal of further improvement of production. Among the seven different AM technologies, in this research Fused Deposition Modeling (FDM) was used. The FDM 3D printing, also known as Fused Filament Fabrication, is an AM process which involves material extrusion. The FDM builds part layer by layer by selectively depositing melted material in a predetermined path. It uses thermoplastic polymers that come in filaments to form the final physical objects. An FDM 3D printer works by depositing melted filament material over a build platform layer by layer until the completed is completed. FDM uses digital design files that are uploaded to the machine itself and translates them into physical part. Materials for FDM include polymers such as ABS, PLA, PC, PS, PEEK and PEI which the machine feeds as threads through a heated nozzle [1-5]. Composing the largest installed base of 3D printers worldwide, FDM is the most widely used technology across many industries, and it's likely the first process that draws attention when 3D printing comes up [6, 7]. The advantage of FDM technology is the ability to save time in the design and development process. Advanced technologies are used for quick fabrication functional models, physical prototypes and small series of parts directly from CAD models [6, 7]. Additive manufacturing of thermoplastic polymers is highly popular for rapid prototyping, offering flexibility and design freedom. In recent years, there has been a significant increase in academic and industry research, leading to the widespread growth and adoption of thermoplastic materials [8-12]. As previously mentioned, the FDM includes material deposition from the tip of a nozzle while a thin thermoplastic filament is heated to the point where it is partially molten [10-15]. 3D printing is a method that uses 3D CAD data in. stl format to produce 3D physical models. The principle of 3D printing is the use of 3D models for the reconstruction of the physical model by adding layers of materials. With the additive fabrication, the machine reads data from the CAD model and successively adds layers of material, and in this way forms the physical model. The main advantage of the additive fabrication is the ability to create almost every complex form such as free form medical components. The AM process can be constituted by two phases: the first phase is a virtual phase during which a CAD model is prepared using CAD software packages, and the second phase is a physical phase to develop the physical object. The AM is defined as: "Process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" [16,17]. Historical terms are additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication [18].

[1] Corresponding author, matini@uns.ac.rs, ORCID: https://orcid.org/0000-0003-1470-5100
[2] strbacb@uns.ac.rs, ORCID: https://orcid.org/0000-0003-3892-2767
[3] ranisavljev@uns.ac.rs, ORCID: https://orcid.org/0000-0002-9130-5103
[4] miodrags@uns.ac.rs, ORCID: https://orcid.org/0000-0002-6753-3691
[5] vukelic@uns.ac.rs, ORCID: https://orcid.org/0000-0003-2420-6778

The popular 3D desktop printer called "WANHAO Duplicator i3 plus" is widely used today for research applications [1, 3, 4, 6, 13, 17, 19].

MATERIAL AND METHODS

The authors created the system for advanced manufacturing and measurement of injected molding plastic parts and parts manufactured by AM. The system consists of following hardware: PC, injection molding machine, 3D printer and CMM, and its appropriate software. The system for advanced manufacturing and measurement of plastic parts is shown in Fig.1.

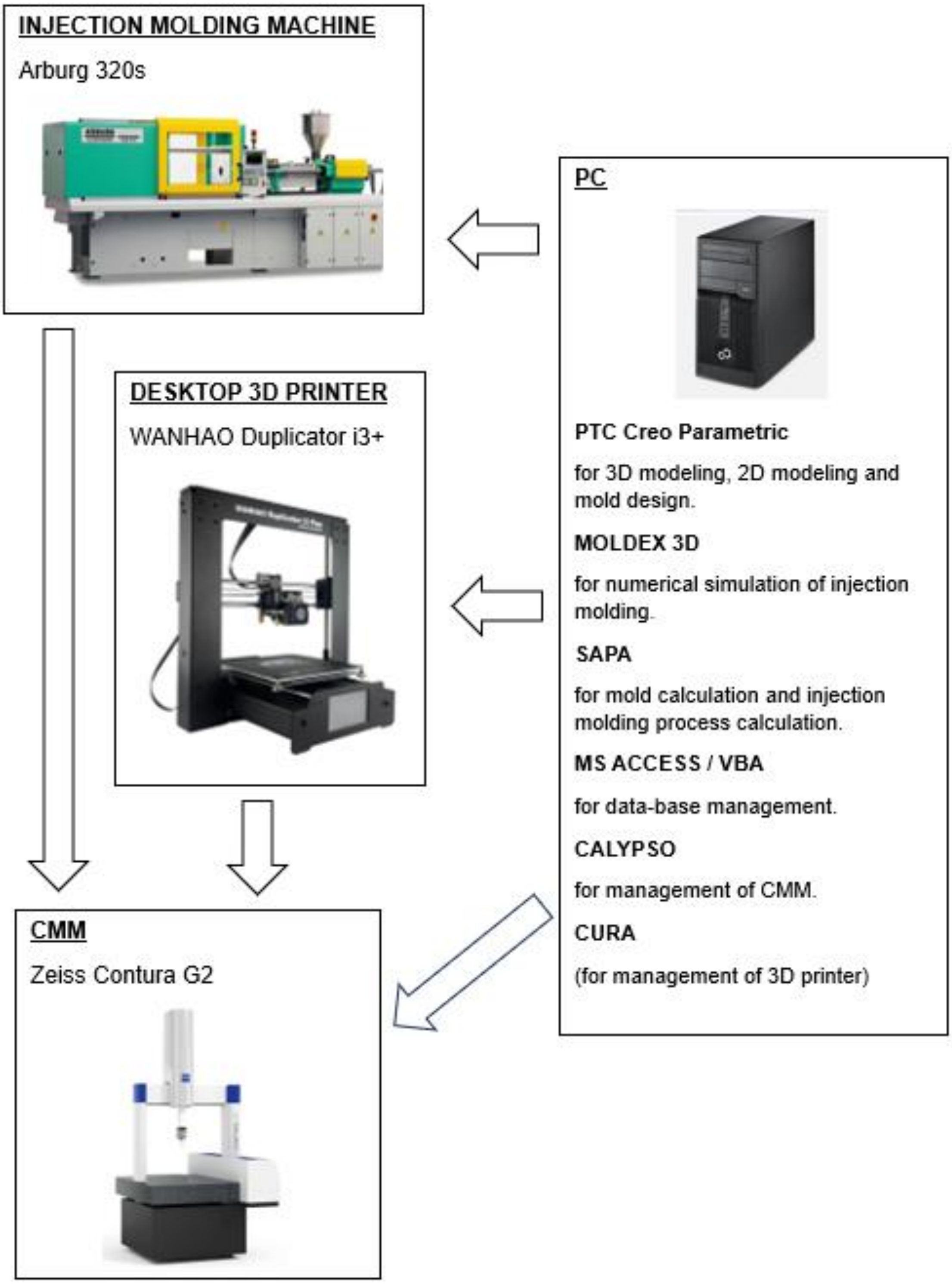

Fig. 1. *The system for advanced manufacturing and measuring of plastic parts*

The polymer material Acrylonitrile Butadiene Styrene (ABS 720) is a widely used material for 3D plastics printing, and in this study, it is chosen in for the FDM printing process, but also as and granule (average diameter size is 4,2 mm) for injection molding. The material has an amorphous structure which means that the numerical simulation of injection molding according to the Modified Cross Wiliams-Landel-Ferry viscosity model will be applied. The properties of the material are taken from the Moldex 3D software data-base. Warping is one of the most common defects in FDM. When extruded material cools during solidification, its dimensions decrease. For instance, ABS is generally more sensitive to warping than PLA, PC, or PETG, for instance. As newly deposited layers cool, they shrink, pulling the underlying layer upward resulting in warping i.e. defect. To operate an FDM machine, authors first load a spool of this thermoplastic filament into the printer. Once the nozzle hits the desired temperature, the printer feeds the filament through an extrusion head and nozzle. This extrusion head is attached to a three-axis system that allows it to move across the X, Y and Z axes. The printer extrudes melted material in thin strands and deposits them layer by layer along a path determined by CAD design (see Fig. 2). Once deposited, the material cools and solidifies. To fill an area, multiple passes are required, like coloring in a shape with a marker. When the printer finishes a layer, the build platform descends and the machine begins work on the next layer. In some machine setups, the extrusion head moves up. This process repeats until the part is finished. The technical drawing of plastic parts using for both type of manufacturing (FDM and injection molding) is shown in Fig. 2.

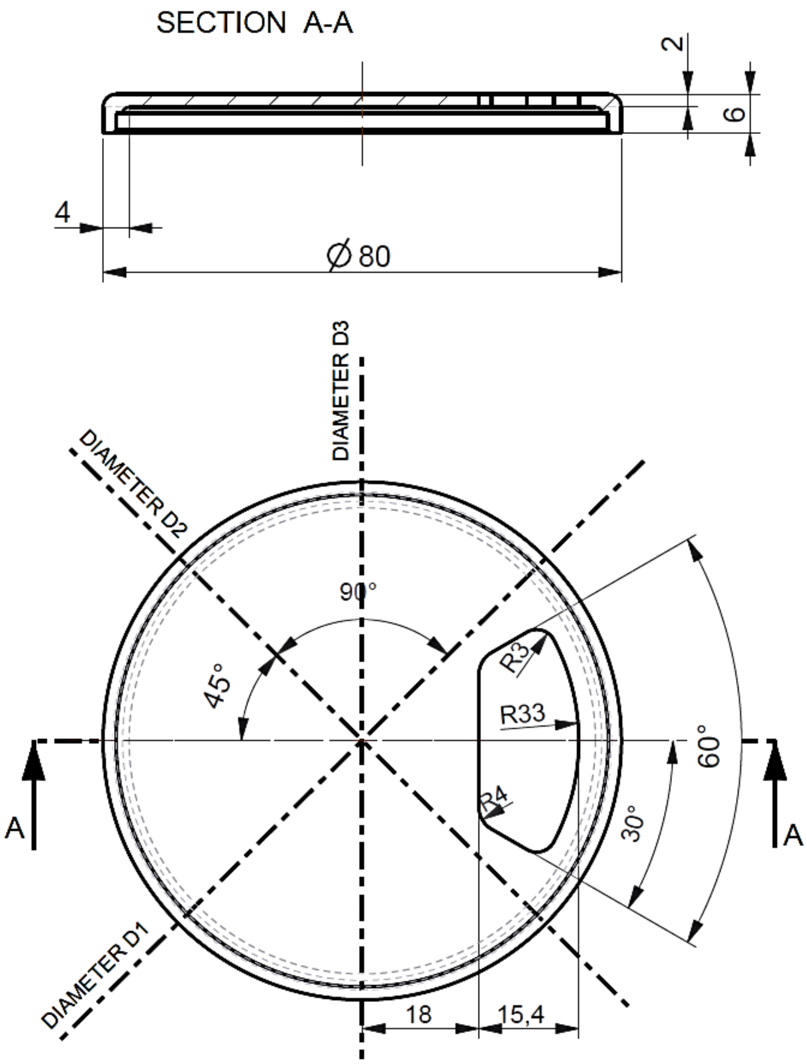

Fig. 2. *Technical drawing of the part*

After modelling of the 3D model of the part, it is then converted from PTC Creo Parametric *prt to *stl file format. The specifications of the printer called "Duplicator i3 Plus"by Wanhao company are shown in Table 1. The production parameters are also shown in following Table 1.

Table 1. *Parameters of FDM printer Duplicator i3 plus*

The parameters	Values
Plastic material	ABS 720
Filament diameter (mm)	1.75
Nozzle diameter (mm)	0,4
Dimension of workspace (mm)	200x200x180
X-Y positioning accuracy (µm)	12
Z positioning accuracy (µm)	4
Layer resolution (the highest quality)	0,11 mm
Print speed (mm/s) (the higher value)	60 mm/s
Operating nozzle temperature (the highest value)	240°C
Platform temperature (the highest value)	60°C
Number of fun	2

The authors installed an additional fan to the extrusion head to accelerate cooling in this case.

RESULTS AND DISCUSSION

The circumference of the model has been divided into six equal portions using three diameters (D_1, D_2, D_3), see Fig. 2. After printing the specimens of the experiment, the measurement was done of the geometries using CMM. Each diameter (D_1, D_2, D_3) was measured, and the average percentage deviation for the geometry was calculated using Equation (1).

$$D = (D_1 + D_2 + D_3)/3 \tag{1}$$

The average diameter of the injected part is 79,993 mm, and the average diameter of part manufactured by FDM is 80,093 mm, as indicated in Table 2.

Table 2. *The average diameters for injected molded part and AM part*

Method	Diameter measured at various position (mm)			Average (mm)
	D_1	D_2	D_3	D
FDM D_{FDM}	80.110	80,108	80,063	80,093
Injection molding D_{IM}	79.987	79.996	79.996	79.993

Moreover, the deviation from the target value (80 mm) is defined as the difference between the manufactured diameters and the design diameter as in Equations (2,3) [20]:

$$\text{Deviation (mm)} = | D_{design} - D_{FDM} | \tag{2}$$

$$\text{Deviation (mm)} = | D_{design} - D_{IM} | \tag{3}$$

Clearly the deviation difference between injection molded part and FDM part is about 0.010 mm, as indicated in Table 3.

Table 3. *Deviation of the manufactured parts*

	Diameter (mm)	Deviation (mm)
Original design	80	----
FDM result	80,093	0,093
Injection molding result	79,993	0,007

CONCLUSIONS

FDM is the most cost-effective way to manufacture custom thermoplastic parts and prototypes on the market today. Desktop FDM is the absolute most cost-efficient option, but produces lower quality part than injection molding. FDM printers can produce quality parts from durable materials, able to retain good mechanical properties. The FDM machines offer high dimensional accuracy, and even at the industrial level, FDM tends to be more cost-efficient than other AM processes. Parts created with injection molding are highly repeatable and exhibit very consistent quality. While injection molding has higher initial setup costs, it is much more cost-effective for large production runs with a lower per-unit cost than 3D printing. The printed parts are created layer by layer. This means layer lines are usually visible on finished parts, and would require post-processing to achieve a smooth surface. Injection molding part have smooth surfaces without post-processing.

Although the FDM process contains many factors, many of them are interconnected. In this paper, the effect of wall thickness, infill density, build plate temperature, print speed, layer thickness, and operating nozzle temperature on dimensional accuracy observed in parts printed was determine using trial and error method, and based on experience. The proposed system for advanced manufacturing and measuring of plastic parts proved to be suitable for determining deviation and manufacturing using different technologies.

Each diameter (D_1, D_2, D_3) was measured two times by CMM. Of course, multiple readings were taken to minimize human and equipment errors, but the authors measured only three diameters on the parts, and that is the smallest satisfactory number for correct circle measurement.

In future research, the number of measurements will be increased and will be processed statistically. Future work could include FDM parameters optimization by using statistical methods which could offer even more reliable insights on how to reduce deviation in 3D printed parts. The next research could incorporate fabrication of parts with least deviation and with maximizing other properties like mechanical strength.

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ALGEBRAIC DIAMETER PROPORTION EXPRESSIONS DERIVED AND EXAMINED FOR EQUAL FLOW DISTRIBUTION BY MANIFOLD NOZZLE COUPLE

Research paper

Eyüb Canli [1*]
[1]Mechanical Engineering Department, Technology Faculty, Selcuk University, Konya, Türkiye

Abstract: Manifolds are key components regarding equal flow distribution for their outlets. They are simple in shape and cheap in economic terms, yet they are very effective on flow distribution control. On the other hand, nozzles generally operate in groups in serial or parallel configurations, and they need to be equally fed. Another solution for the nozzles is active flow control measures at each nozzle. However, sophisticated flow control solutions come with their complexity and high cost though they also offer better precision. Accordingly, flow distribution to nozzles by manifolds seems to be the simplest and low cost yet powerful solution. Designing manifolds may involve analytical solutions, empiricism, numerical analyses, and/or computational simulations. In the present paper, algebraic expressions of dimensionless ratio between nozzle feeding line diameter and the manifold diameter is sought for incompressible laminar flow in the nozzle feeding line. Nozzle outlets generally generate jets and therefore generate turbulence. However, most of the time, nozzle feeding lines have laminar flow due to small confinement and low rates of mass flow and therefore mean velocity. Analytical solution of friction factor for circular pipes with laminar flow is utilized together with mass balance and algebraic pressure drop equation in order to obtain algebraic expressions for diameter ratios of nozzle feeding line diameter and manifold diameter. The diameter ratios expressions are then used to foresee 1% variation of a measure, i.e., variation between mass flow rate of initial nozzle and last nozzle in an inline arrangement of multiple nozzles. Computational simulation data from a previous work is used for evaluating and assessing the algebraic expressions. The initial estimates of diameter ratios in the previous work were based on three different criteria, which were manifold flow velocity over nozzle feeding line velocity, manifold pressure drop over nozzle feeding line pressure drop, and initial nozzle mass flowrate over last nozzle mass flowrate. The results show that simple expressions with strong simplifications perform better than more complex expressions that lower the simplification levels. This unintuitive result is evaluated to be due to the nozzle feeding line inlet effects that invalidate the procedures for obtaining more complex expressions. Future studies are necessary to focus on the nozzle feeding line inlet for lowering energy consumption and obtaining better forecast ability.
Key words: Diameter ratio, dimensionless expressions for design, flow control, mass flowrate variation, pressure drop.

INTRODUCTION

In industry, nozzles are being used in countless applications with numerous different styles for various purposes that necessitate several different fluids. Every application has its unique claims in terms of operational parameters such as feeding line pressures, flowrates, temperatures, material types such as nozzle materials, fluids, conditions such as ambient temperature and pressure, and design such as single or multiple nozzle utilization. Accordingly, control of the feeding lines of the nozzles is also variable and diverse. However, specific applications, setups, and arrangements may necessitate a certain solution to be preferred over others. Flow visualization techniques frequently use seeding particles. Nozzles can be used to generate seeding particles. Since the particle sizes are in the order of micrometer or submillimeter most of the time, nozzle diameters are also small. This imposes laminar flow in the nozzle feeding lines due to small diameter values and low flowrates. Again, in most cases, there are numerous nozzles working simultaneously to seed the flow sufficiently for enough illumination that is created for good quality flow visualization. Feeding numerous nozzles simultaneously, providing equal flowrates, and controlling the flow rates may not be an easy task. Manifold, as a mechanical device, is great for distributing the fluid source to numerous nozzles with acceptable variation and favorable simplicity. In the present study, the diameter of the manifold is aimed to be determined based on a ratio that is calculated

[1] Corresponding author ecanli@selcuk.edu.tr, ORCID: https://orcid.org/0000-0002-9358-1603

considering nozzle feeding line diameter and number of nozzles to be used in a seeding project. The main idea and motivation lie under the fact that if determining such ratio would be easy, one can benefit from it by carefully selecting a manifold diameter that can cover a wide range of nozzle numbers or quickly determine the manifold diameter according to the necessary nozzle number and produce the manifold without much design effort.

Literature works generally do not address analyses of manifold diameter. Instead, abundant works mention an effort of manifold design to realize another analysis on a physical problem. Nevertheless, there are some works on the design of manifolds and at this part, those works are being summarized in order to emphasize several aspects of the topic. Keller [1] addressed the manifold problem, as an example of one of the earliest works. The author provides the analysis for a general definition of the manifold device, which encompasses manifolds that distribute flow to multiple other pipes, gas burners, heat exchangers, and similar other devices. However, the author states that internal engine manifolds are out of scope. On the other hand, a similar work to Keller [1] is very hard to find if not impossible in the recent literature. This may be due to the fact that concurrently common engineering tools and information resources are sufficient so that scientific communication on the topic may not be motivating. Nevertheless, it is believed here that the content of the present paper may be beneficial for in-house workshop development of flow seeding systems for flow visualization. Bianco, Szubel [2] utilize Computational Fluid Dynamics (CFD) for optimizing design of a manifold for air supply to a biomass boiler. The authors use an entropy generation objective function to drive their optimization approach. This derivative quantity indirectly addresses flow distribution variations by enabling detection of sources of irreversibility. So, the authors proposes entropy generation objective function over primitive indicators such as mass flowrate distribution. However, from the perspective of the present paper, it can be asserted that such methodology that is recommended by Bianco, Szubel [2] may necessitate additional data and may not be convenient for every case. Also, as another point that should be considered, the entropy generation objective function is more related to the energy consumption per delivered matter rather than flow distribution variations. Nevertheless, their work is a great example of evolution of an engineering design in favor of us, and also underlines the potential of studying manifold geometry. CFD is again utilized in another work for assessing two manifold geometries for distributing two phase flow [3]. The air-grain type gas-solid two-phase flow system is driven by vacuum. The manifold geometry is investigated regarding the pressure distribution homogeneity. The work targets a system that has 924 nozzles. The authors compare circular and rectangular manifold body geometry. Unexpectedly, the rectangular manifold geometry is found better. An example of manifold utilization in distributing fluids that are used for flow visualization is reported by Parobek, Boyer [4] as an example of an earlier work. The authors used a network of manifolds to obtain fifteen outlets. The flow seeding is for a closed loop wind tunnel. Another grain-air two phase flow case that involves manifold investigation is reported as being examined via CFD [5]. The authors report a variation coefficient of 1.58% considering the air flow velocity at the seed tube outlet. In the mentioned work, the manifold line and seed line diameters are different in value, but they are in same order of magnitude. An illustrative work on the utilization of circular cross section manifold and connected lines that have axes perpendicular to the manifold axis can be viewed from Binsirawanich [6]. The manifolds in the mentioned study are different from the manifolds that distributes flow to inline feeding lines, since the manifolds in the mentioned work receives the flow from a center and distributes it to feeding lines, which are aligned in an axisymmetric manner and conduct flow in radial direction according to the manifold axis. Accordingly, the feeding line alignment has an important effect on the ratio of diameters of manifold and feeding lines. Before finishing this part, a good example containing great visuals on manifolds that are for distributing flows through heat exchanger channels is reviewed [7]. This very recent work provides visuals to grasp the relationship between the flow channels and manifold design. As the flow channels are altered, the manifold geometry is also adjusted.

Reviewed literature shows several different aspects of the manifold and feeding lines. Each application has its unique needs to be addressed. In the present paper, feeding lines of nozzles that are for seeding flows that are visualized for flow measurement, and that are in inline configuration are desired to be fed by a manifold that has a diameter enabling equal flow distribution. According to the nozzle number, the manifold diameter is aimed to be determined as a ratio based on feeding line diameter. The reason for this approach comes from the fact that the nozzle geometry and feeding line operational parameters such as flowrate and pressure are predetermined and fixed. The diameter ratio is tried to be expressed in terms of nozzle number, nozzle flowrate, and feeding line and manifold line pressure drops by means of analytical solution of laminar flow pressure drop in circular pipes, mass balance, and algebraic pressure drop formulation due to flow shear starting from the line walls. Obtained algebraic diameter ratio expressions are then compared to different CFD cases that were previously reported [8]. Some expressions are found usable while remaining ones are not found proper. In the following sections, methodology is introduced first, followed by results and discussion, and then a conclusion section finalizes the paper.

MATERIAL AND METHODS

A system of nozzles, their feeding lines, and the manifolds can be imagined according to the diagrams that are given in Figure 1.

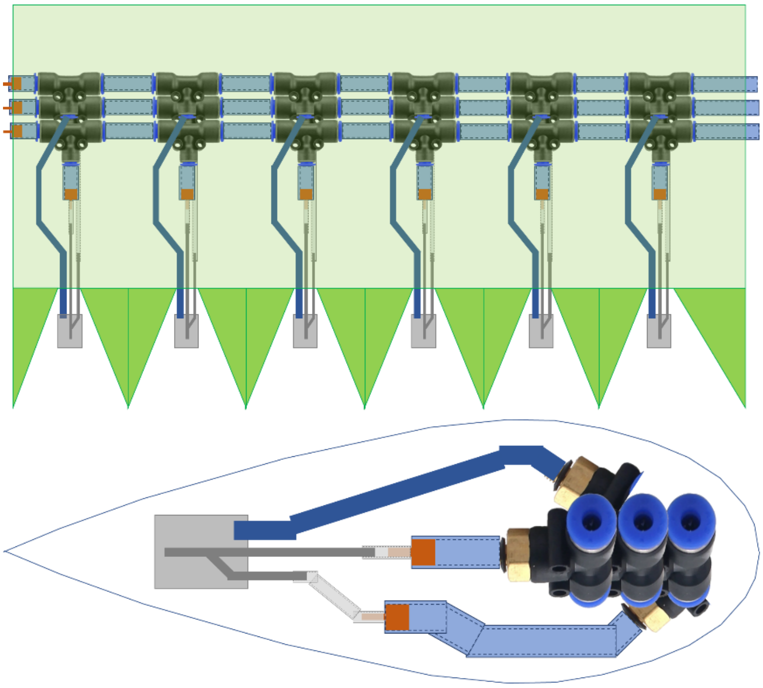

Fig. 1. *Schematic representation of a system where several inline nozzles are connected to manifold channels via supply lines.*

The system that is hypothetically built is in an airfoil type case not to disturb the flow that is to be seeded by the nozzles. The nozzles have three supply lines indicating a flow balance system with triple inputs. However, in the present paper, only one manifold line, the feeding lines that connect the one manifold to the nozzles, and the six nozzles are considered to derive and examine aforementioned expressions.
The expressions that base the foundation of the present approach are given below and then the terms and symbols are explained in the following:

$$\dot{m} = nV_d A_d = V_D A_D = nV_d \pi \frac{d^2}{4} = V_D \pi \frac{D^2}{4} \tag{1}$$

$$\Delta P_d = f \frac{L_d}{d} \frac{\rho {V_d}^2}{2} = \frac{64}{\mathrm{Re}_d} \frac{L_d}{d} \frac{\rho {V_d}^2}{2} = \frac{64}{\frac{d\rho V_d}{\mu}} \frac{L_d}{d} \frac{\rho {V_d}^2}{2} = \frac{32\mu L_d V_d}{d^2} \tag{2}$$

$$\Delta P_D = f\frac{L_D}{D}\frac{\rho {V_D}^2}{2} = \frac{64}{\mathrm{Re}_D}\frac{L_D}{D}\frac{\rho {V_D}^2}{2} = \frac{64}{\frac{D\rho V_D}{\mu}}\frac{L_D}{D}\frac{\rho {V_D}^2}{2} = \frac{32\mu L_D V_D}{D^2} \tag{3}$$

$$P_D = \Delta P_d + \Delta P_D \sim \Delta P_d \tag{4}$$

In above expressions, from (1) to (4), $\dot{m}$ is mass flow rate, n is the number of nozzles, V is velocity, A is the cross flow cross-section area, d is the feeding line diameter, D is the manifold diameter, subscripts d and D indicate that the magnitude belongs to that line, P is static pressure, f is the laminar friction factor in circular pipes and tubes, L is the line or manifold length, ρ is the fluid density, Re is the Reynolds number, μ is the absolute or dynamic viscosity. The dimensions of the magnitudes that are represented by symbols are not given since only nondimensional ratios are sought as resulting expressions, and such a search eliminates the dimensions naturally during the algebraic manipulations.
In the following, derived algebraic equations are presented in an order from simple to complex. After the expressions, the ideas behind them are explained. The step by step algebraic manipulations are not provided here due to their high volume but one can easily grasp the process by viewing the derived expressions and equations 1-4 together.

$$\frac{V_D}{V_d} = \frac{nd^2}{D^2} \tag{5}$$

$$\frac{\Delta P_D}{\Delta P_d} = mn\frac{d^4}{D^4} \tag{6}$$

$$\frac{\Delta P_D}{\Delta P_d} = \frac{\frac{f_d L_D n d^3}{D D^3}}{\frac{f_d L_d}{d} + 1 + C\left(1 - \frac{d^4}{D^4}\right)} \tag{7}$$

$$\frac{\dot{m}_{d,1}}{\dot{m}_{d,n}} = 1 + \frac{d^2}{D^2}\sqrt{\frac{(n^3 - n^2)64L_D}{Re_D D}} = 1 + \frac{d^2}{D^2}\sqrt{(n^3 - n^2)f\frac{L_D}{D}} \tag{8}$$

$$\%\Delta\dot{m}_d = 100\frac{d^2}{D^2}\sqrt{\frac{fn^3L_D}{2D}} \tag{9}$$

¶

$$\%\Delta\dot{m}_d = 100\frac{d^2}{D^2}\sqrt{\frac{fnL_D}{2D_n}} \tag{10}$$

$$\%\Delta\dot{m}_d = 100\frac{d^2}{D^2}\sqrt{\frac{fL_D}{D}\left((2n-1) + \sqrt{\frac{fL_D}{D}}\right)} \tag{11}$$

The idea behind (5) is that if the manifold velocity would approach to zero, then the pressure drop through the manifold would approach to zero since there would be almost no momentum diffusion to wall from the flow by shear or friction. So, the user can set a numerical goal for left hand side of equation 5, say 0.01, and then extract the necessary diameter ratio and consequently the diameter value of the manifold. Equation 6 directly has ratio of the pressure drop in the manifold to pressure drop in the nozzle feeding line. Again, the left hand side of (6) can be set to a value very small such as 0.01 and then the diameter ratio and manifold diameter can be extracted. One can observe that right hand side of equations 5 and 6 would yield very different values for a certain diameter ratio. This means that the objective number of the equations should be different in order of magnitude. This point will be addressed in the results section. Equation 7 is a revised (6), which tries to involve nozzle feeding line inlet effect, i.e., sudden contraction, while the C symbolizes a proper coefficient of contraction pressure drop. The C coefficient can be empirically or computationally determined. Equations 8 tries to have a target value on its left hand side that is almost unity, indicating that the first and the last nozzle have almost same mass flowrates. That equation relies on the fact that the manifold static pressure at the cross section that is on the same plane with the nozzle feeding line axis creates a certain amount of mass flow rate which can be calculated starting by (12).

$$V = \sqrt{\frac{2P}{\rho}} \tag{12}$$

$$P_{d,1} - P_{d,n} = n\Delta P_D \tag{13}$$

$$\Delta V = \Delta V_{d,1} - \Delta V_{d,n} = \sqrt{\frac{(n-1)64\mu L_D V_D}{\rho D^2}} \tag{14}$$

Equations 12 to 14 are used to calculate mass flowrates of the first and the last nozzle and then they are put in algebraic manipulation to obtain (8). Expression 9 is obtained by using mass flow rates of first and last nozzle in a percentage change ratio for a constant diameter manifold and considering the change in the mass flowrate and rate of pressure drop through the manifold due to passing outlet numbers. Expression 10 is a modified version of (9) by changing manifold diameter in the axial direction to compensate for the mass flow deficit due to passing outlets and try to keep the manifold flow velocity constant. Finally, equation 11 tries to consider the decreasing mass flowrate through the manifold and related change in the pressure drop calculation by an iterative like approach, writing explicit forms of the differences in the expression repeatedly during manipulation stages. In a way, it reminds Taylor series expansion, as each new explicitly written difference has a smaller magnitude that can be truncated at some point.

Further efforts could be made to obtain more detailed and complicated expressions based on above-described approaches in order to assess manifold diameter change contraction effects. However, as will be shown in the next section, the initial simple expressions performed better than the more complex ones in providing results close to computational results. Nevertheless, a more accurate analytical model of the present problem still remains as a goal.

Before proceeding further, it should be noted that the necessary manifold static pressure to provide flow to nozzle feeding lines can be calculated approximately by (15) or (16). These two equations imply that the manifold pseudo constant static pressure value is about to be (slightly higher) to the static pressure that drives the flow in the nozzle feeding line. Equation 16 also tries to consider sudden contraction effect and outlet effect.

$$P_D \sim P_d = \frac{1}{2} f_d \frac{L_d}{d} \rho {V_d}^2 \tag{15}$$

$$P_D \sim P_d = \frac{32\mu L_d V_d}{d^2} + \frac{1}{2}\rho {V_d}^2 + C\frac{1}{2}\rho {V_d}^2 \left(1 - \frac{d^4}{D^4}\right) \tag{16}$$

In a previous work [8], the CFD scheme on investigating the present problem was presented with most of its details and spatial data was shown. Data from that own work is used here to evaluate and assess the expressions between (5)-(11).

RESULTS AND DISCUSSION

In the previously CFD work that was partially reported [8], manifold Reynolds number (Re) was set to 50 and 500 for six nozzles and diameter ratio of 10. Then, for constant nozzle feeding line velocity, nozzle number varied from one to six with one-point increments. Then, diameter ratio was set to 5 for six-nozzles case and two different manifold-Re numbers were tried, i.e., 50 and 125. The CFD runs were arranged as nondimensional by cleverly arranging thermo-physical properties of the fluid and computational domain. Examples of such arrangement can be viewed from [9-11]. The trial pattern and obtained results are shown in Table 1.
¶

Table 1. *The CFD trial pattern and obtained results*

$\frac{D}{d}$	Re	n	Eq. 5	Eq. 6	Eq. 7	Eq. 8	Eq. 9	Eq. 10	Eq. 11	Eq. 15	Eq. 16	Comparison with CFD by percentage difference, respectively.								
10	500	6	0.06	0.012	0.007	1.15	11.8	1.96	3.94	426.6	704.4	0.8	72	54	13	95	69	84	75	6.5
10	50	6	0.06	0.012	0.011	1.48	37.2	6.19	13.7	4266	4544	0.2	48	45	32	99	92	96	2.9	8.8
10	8.33	1	0.01	0.002	0.001	1	6.2	6.19	27.4	4266	4544	0.4	15	9.4	N/A	N/A	N/A	N/A	2.7	8.6
10	16.66	2	0.02	0.004	0.003	1.12	12.4	6.19	18.8	4266	4544	0.3	41	37	10	98	96	98	2.8	8.7
10	25	3	0.03	0.006	0.005	1.21	18.6	6.19	16.0	4266	4544	0.3	41	37	17	98	96	98	2.8	8.8
10	33.33	4	0.04	0.008	0.007	1.3	24.7	6.19	14.8	4266	4544	0.3	35	31	23	99	98	99	2.8	8.7
10	41.66	5	0.05	0.01	0.009	1.39	30.9	6.19	14.1	4266	4544	0.3	42	38	27	98	94	97	2.8	8.8
5	125	6	0.24	0.361	0.167	2.72	133	22.2	48.2	226.6	244.0	1.4	74	45	61	96	79	90	2.8	9.7
5	50	6	0.24	0.361	0.175	3.72	210	35.1	81.1	566.6	584.0	1.8	72	44	71	97	84	93	9.0	11

Table 1 shows that results of (1) are very consistent with results of CFD. However, this coherence is just for the velocity ratio that is seen in expression (1) and it does not imply anything more. On the other hand, equations 9 to 11 are approximately two times different than the CFD results. Results of equations 6 to 8 have the same order of magnitude differences comparing to the CFD results. Roughly 40% can be mentioned about them. Consequently, The mass flowrate difference between nozzles for the conducted CFD cases are plotted versus equation results to determine some limits of those equation results, which then can be used to obtain diameter ratios that yields favorable mass flowrate differences. In the meantime, equations 15 and 16 predicted pressure drop through the nozzle feeding line with acceptable accuracy. However, equation 15 has lower percentage error though it is not considering contraction effect and expansion effect. This implies that contraction and expansion effects are much lower than expected.

In Figure 2, equations 5 to 8 are plotted versus percentage mass flow rate difference between the first and the last nozzle. The regression expressions can be viewed from the graphics. Those expressions can be set to 0.1 or 1% to find the independent variable value and then the diameter ratio can be extracted from the independent variable expression. Another approach may be trying different diameter ratios to find results of equations 5 to 8, and then calculate the mass flowrate difference to decide on the proper diameter ratio value.

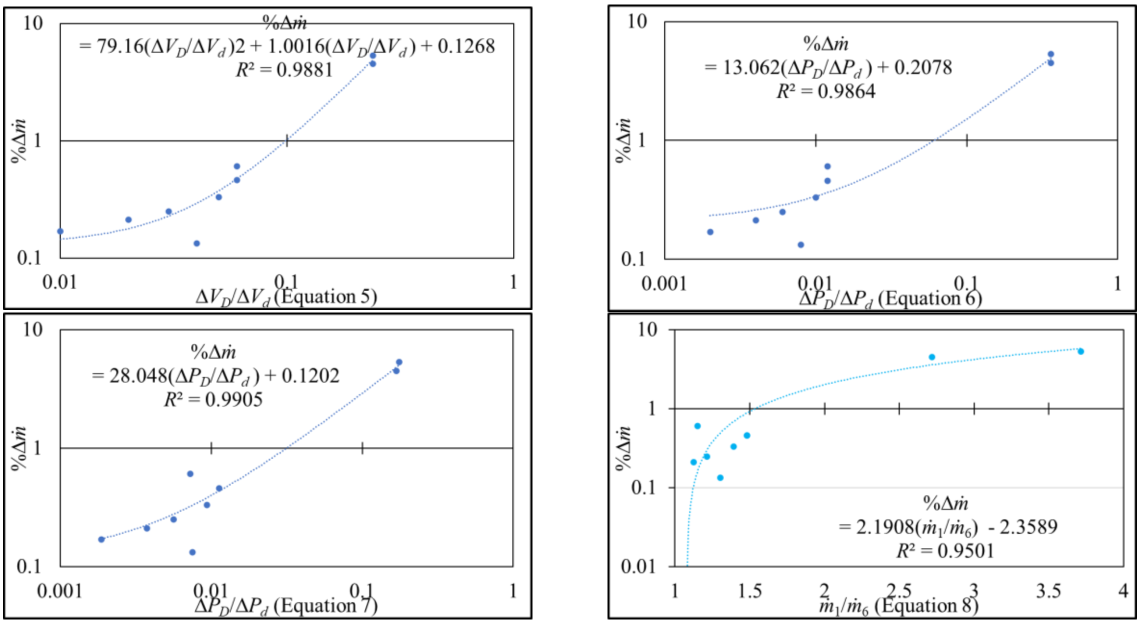

Fig. 2. *Plots of percentage mass flowrate difference between the first and the last nozzle versus expressions 5 to 8 and obtained regression expressions.*

So, if equation 5 results below 0.34, the mass flowrate difference between the first and the last nozzle results below 10%. For lower mass flowrate difference, for instance 1%, equation 5 should yield 0.1 or lower than that. Regarding remaining graphics, those values are 0.08 for equation 6, 0.05 for equation 7, and 1.5 for equation 8.

The presented approach is yet to be tested in a real-world scenario by experimentations. Therefore, it is a future goal.

CONCLUSION

In this work, analytical solutions of friction factor in circular pipes and tubes for laminar flow is used together with mass balance and algebraic pressure drop equation in order to derive several algebraic expressions that can give ratio of diameters belonging to a manifold and inline nozzle feeding lines. The expressions are for carefully selecting manifold diameter for a specific type of nozzle and its certain diameter feeding line, in a way that different nozzle mass flowrates do not create a variation between nozzles. The expressions can also be used to select a manifold diameter to produce one, for different nozzle operational parameters. However, the CFD benchmark of the expressions layout a result that only some of the equations can give similar results to the CFD ones. Therefore, percentage mass flowrate difference between nozzles are plotted versus consistent expression parameters and 1% limit for the mass flowrate is used to determine expression parameter values that can further be utilized to determine the manifold diameter. General scheme and the obtained expressions should be tested experimentally in the future for assessing feasibility of the approach. Also, several other geometrical features such as smoothing sudden contractions at the nozzle feeding line inlets can be included into the analysis.

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OPTIMAL LQR CONTROL OF A PENDULUM BASED OVERHEAD CRANE USING THE WHALE OPTIMIZATION ALGORITHM

Research paper

Abdullah Çakan[1*]
[1]Konya Technical University, Faculty of Engineering and Natural Sciences,
Department of Mechanical Engineering, Konya, Turkey

Abstract: This study represents an optimal LQR control approach to controlling the trolley movement of an overhead crane and sway reduction of its payload. The aim of the study is to improve the crane's positioning accuracy and ensure smoother and safer operations with less swinging motion of payload. To achieve this, a Linear Quadratic Regulator (LQR) controller is proposed, which generates optimal control signal as input force. However, instead of manually tuning the LQR gains, The Whale Optimization Algorithm (WOA), a nature-inspired method that mimics the hunting behavior of whales, is used to tune control parameters. The results show that this LQR-WOA combination effectively improves the system's stability, reducing oscillations efficiently and precisely the position of trolley. This approach offers a practical solution for industries where precise and safe overhead crane operation is essential.
Key words: Whale Optimization Algorithm, Linear Quadratic Regulator, overhead crane.

INTRODUCTION

Overhead cranes are important machines in industries which need heavy material handling and heavy loads by travelling along rails mounted on the ceiling. However, one of the biggest challenges in controlling overhead cranes is generating both precise positioning of the trolley and reducing the sway of the payload during movement. The dynamic behavior of this type of crane causes oscillatory movements of the payload, usually during the initial movements and sudden stops. If these oscillation movements are not controlled, it causes safety risks for equipment and personnel. In order to solve these kinds of issues, designing an effective control strategy is essential. Various controllers have been proposed to control overhead crane position and sway reduction in the literature such as proportional integral derivative, sliding mode, fuzzy logic and input shaping controllers [1-5]. Moreover, LQR controllers are also proposed to control these kinds of systems [6]. Additionally, in the literature, various optimization algorithms are used to obtain controller parameters of overhead cranes [7-9]. In the author's previous work, optimization of LQR controller using the Genetic Algorithm (GA) is proposed [10]. In this paper, the results obtained using the Whale Optimization Algorithm (WOA) for tuning LQR control gains are compared with the previous GA-based approach, highlighting the performance differences in terms of crane trolley positioning, sway reduction and applied control force.

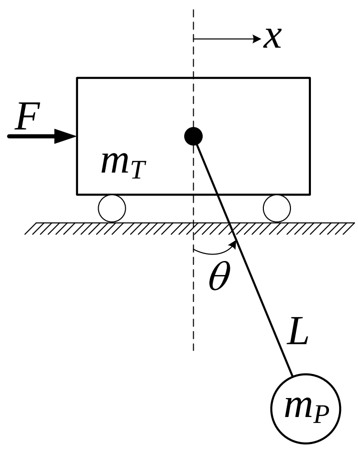

Fig. 1. *Single pendulum based overhead crane.*

[1] Corresponding author, acakan@ktun.edu.tr, ORCID: https://orcid.org/0000-0003-3923-4069

MATERIAL AND METHODS

Mathematical Modeling

In this section, mathematical modeling of a pendulum based overhead crane is presented. The mathematical modeling of an overhead crane system basically represents it as a combination of a cart (crane's trolley) and a pendulum (payload), which can be modeled as a pendulum [5]. When deriving the mathematical model of overhead cranes, the system can be represented as either a single pendulum or double pendulum configuration. In this study, focused on the single pendulum based overhead crane, as shown in Fig. 1. In this figure, x, θ and F represent the horizontal position of the trolley (cart), angle of the pendulum (payload sway) and control force applied to the trolley, respectively. These parameters vary as a function of time.

The equations of motion (1) and (2) for a single pendulum based overhead crane describe how the trolley and the swinging payload move. These equations can be derived using Newton's laws or Lagrangian mechanics. The trolley’s motion depends on the control force and the swinging of the payload, considering the masses of both. The pendulum's swing is influenced by gravity and the trolley’s movement.

$$(m_T + m_P)\ddot{x} + m_P L cos\theta \ddot{\theta} - m_P L sin\theta \dot{\theta}^2 = F \quad (1)$$

$$m_P L cos\theta \ddot{x} + m_P L^2 \ddot{\theta} + m_P g L sin\theta = 0 \quad (2)$$

For small angles of the pendulum sway, the system is typically linearized using approximations $sin\theta \approx \theta$ and $cos\theta \approx 1$ This simplification makes the model easier to work with, especially for control design. To design LQR controller, it's required to represent the system in state-space form shown in equation (3). The state variables and output variables can be defined as in equation (4).

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (3)$$

$$x^T = [x \quad \dot{x} \quad \theta \quad \dot{\theta}]\,, y^T = [x \quad \theta] \quad (4)$$

In state-space form, A is the system matrix, B is the input matrix, C is the output matrix and D is the direct transmission matrix. For the pendulum based overhead crane, these matrices are defined and given in (5).

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{m_T g}{m_P} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -\frac{(m_T + m_P)g}{m_P L} & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ \frac{1}{m_P} \\ 0 \\ -\frac{1}{m_P L} \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, D = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (5)$$

For the purpose of simulating the system, the system parameters used in the model are presented in Table 1. These parameters are selected based on the author’s previous work to enable a direct comparison of the results between two different optimization methods.

Table 1. *Overhead crane system parameters*

The Parameters	m_T	m_P	L	g
Value	3.9 kg	1 kg	0.3 m	9.81 m/s^2

The Whale Optimization Algorithm (WOA)

Optimization algorithms are widely used to find the best solution for a problem by either minimizing or maximizing an objective function. This is an important significance in engineering, these algorithms help improve the control systems' performance and stability. In this paper, The Whale Optimization Algorithm (WOA) is used, a popular method inspired by the hunting behavior of humpback whales [11]. By mimicking their spiral movements that are constantly narrowing by releasing bubbles which are only seen in humpback whales shown in Fig. 2. WOA efficiently searches for optimal solutions in complex problems. The hunting strategy of humpback whales consists of three basic stages; coral loop, forming a circle around the prey (the best solution) by releasing air bubbles, lobtail; then narrowing the circle and approaching the prey with a spiral movement and capture loop; searching for prey.

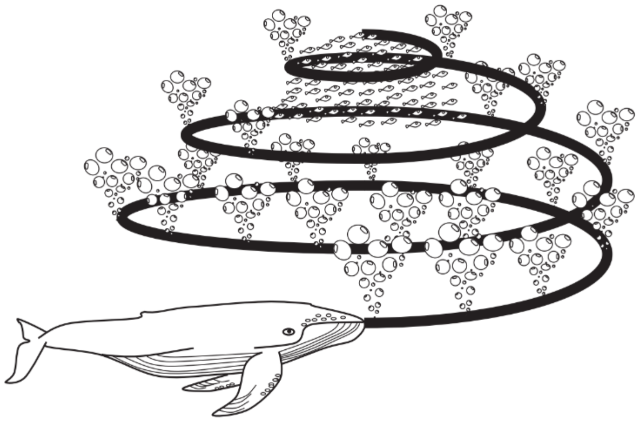

Fig. 2. *Hunting behavior of humpback whales [11].*

In control systems like LQR controllers proposed in this paper, selecting the right control gains is essential but often difficult. Optimization algorithms simplify this by automating the process of finding the optimal gains, obtain to better system performance via selected objective function. In this paper Q and R matrices of the Linear Quadratic Regulator (LQR) is optimized for obtaining the optimal state feedback gain matrix K, as explained in following section.

Optimization of Linear Quadratic Regulator (LQR)

In an overhead crane system, controlling the trolley position while reduction the sway angle of the payload is an important process for smooth operation and safety. The Linear Quadratic Regulator (LQR) is an optimal control technique that can effectively handle this problem by minimizing both the error in trolley position and the swing of the payload [10]. It is also minimizing the control signal which applied force to the trolley in this study. The main goal of LQR is to minimize a cost function, which typically combines state and control input penalties. The cost function is generally of the form shown in equation (6).

$$J = \int_0^\infty (x^T Q x + u^T R u) dt \tag{6}$$

By selecting appropriate Q and R matrices shown in previous equation, based on the desired trade-offs between state error and control effort, the optimal control input u is derived from the state feedback law shown in equation (7). In this equation, K is the gain matrix derived by solving the Riccati equation. Moreover, LQR need A and B matrices defined in systems state-space representation.

$$u = -Kx \tag{7}$$

In this study, The Whale Optimization Algorithm (WOA) is utilized to obtain the optimal Q and R matrices. Once these optimal matrices are determined, they are used to compute the gain matrix K which is then implemented in simulations to obtain results. All simulations are conducted on the MATLAB platform using both the MATLAB programming language and Simulink, a block diagram environment used to design systems, on a system equipped with an Intel(R) Xeon(R) CPU E5-1620 v2 @ 3.70GHz and 16 GB of RAM. The block diagram of the control system, created using MATLAB Simulink, is shown in Fig. 3.

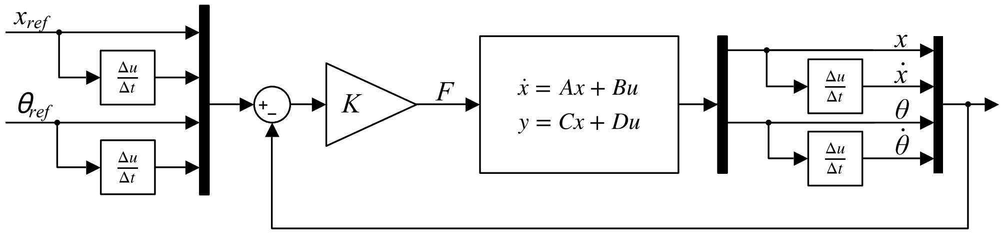

Fig. 3. *LQR Control block diagram of overhead crane system.*

30 search agents and a maximum number of 30 iterations are utilized to solve the proposed problem. The objective function of this study is given in equation (8). The objective function includes the parameters of rise time, settling time, peak time, maximum peak and steady state error which are obtained from the trolley position and sway angle results during the optimization process. To achieve the best results, specific ranges of values are chosen for use in the optimization process. The selected ranges for optimization are presented in Table 3.

$$J = (x_{tr} + x_{ts} + x_{tp} + x_{max} + x_{sse}) + (\theta_{norm} + \theta_{ts} + \theta_{tp} + \theta_{max} + \theta_{sse}) \quad (8)$$

Table 3. *Ranges of the optimization parameters.*

	Q_{11}	Q_{22}	Q_{33}	Q_{44}	R
Min	0	0	0	0	0
Max	200	100	200	100	2

Optimal Q and R matrices are obtained shown in equations (9). The gain matrix K is derived shown in equation (10) by optimal Q and R matrices.

$$Q = \begin{bmatrix} 199.6957 & 0 & 0 & 0 \\ 0 & 47.1646 & 0 & 0 \\ 0 & 0 & 11.6723 & 0 \\ 0 & 0 & 0 & 35.4262 \end{bmatrix}, R = 0.1037 \quad (9)$$

$$K = [43.8837 \quad 37.8594 \quad -61.3007 \quad -9.3122] \quad (10)$$

Minimization of the objective function (J) shown in Fig. 4. which demonstrates that the number of iterations is sufficient to observe the results.

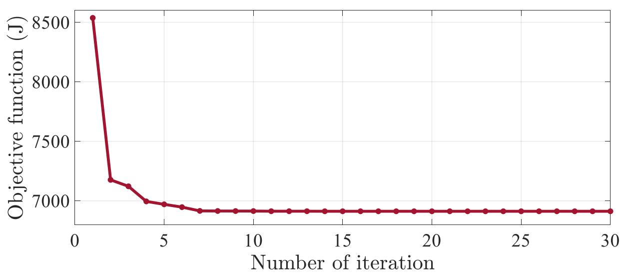

Fig. 4. *Minimization of the objective function (J).*

RESULTS AND DISCUSSION

The optimization of the Linear Quadratic Regulator (LQR) using the Whale Optimization Algorithm (WOA) is compared with the author's previous work. The results displayed in graphical form demonstrate the effectiveness of the selected Q and R matrices. Simulation outcomes reveal that the optimized gain matrix K significantly reduces both overshoot of the trolley position and oscillation of the payload, thereby minimizing the sway angle in Fig. 5. and Fig. 6. respectively.

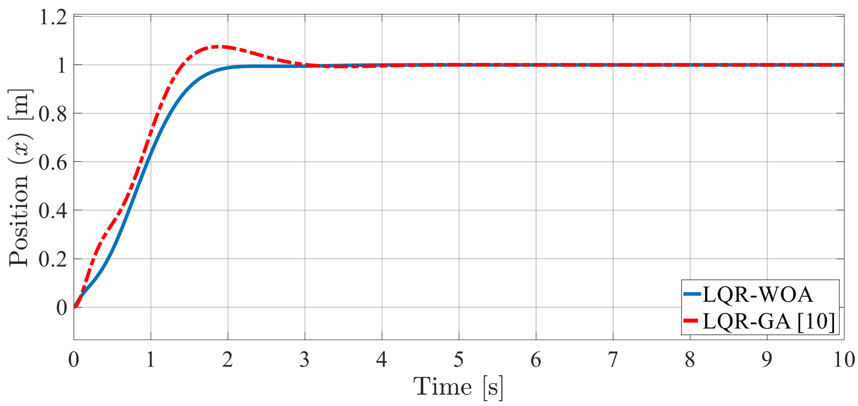

Fig. 5. *Trolley position results of the overhead crane*

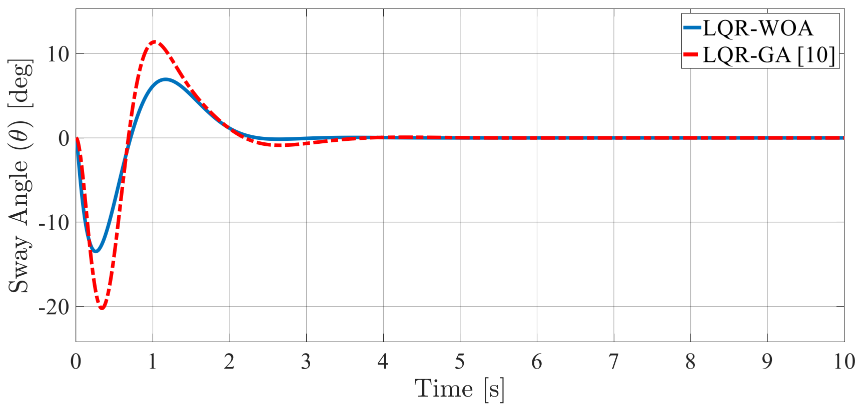

Fig. 6. *Sway angle results of the overhead crane*

The control force applied to the trolley, as determined by the optimization process shown in Fig. 7. presents a reduction in the overall force applied to the trolley. This means WOA optimized LQR control applies less force to achieve the desired motion.

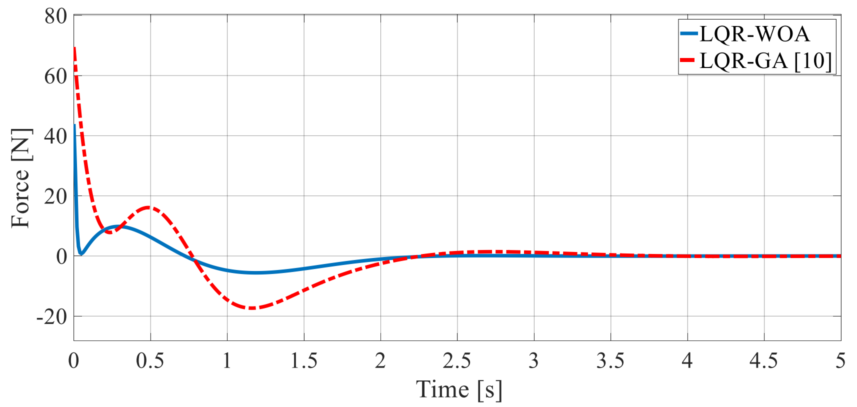

Fig. 7. *Input force results applied by LQR controller*

CONCLUSION

In this study, the LQR (Linear Quadratic Regulator) control strategy for an overhead crane was optimized using the Whale Optimization Algorithm (WOA). By tuning the Q and R matrices optimally, it is demonstrated how WOA effectively minimizes the cost function, enhancing the performance of overhead crane systems, ensuring safer and more effective operations in various industrial applications. And it can be said that it provided energy efficiency in this case because the system requires less force. The resulting optimal gain matrix K ensures precise positioning of the trolley while significantly reducing payload sway. These enhancements underscore the successful implementation of the LQR controller and highlight the potential of integrating WOA with LQR for optimal control applications, marking an improvement over prior result. Overall, the integration of optimization algorithms with control methods provides a robust and efficient solution for enhancing the performance of control systems.

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ANALYSIS OF THE SYSTEM FOR ACTIVE VIBRATION REDUCTION DURING WHEEL LOADER MOVEMENT

Review paper

Jovan Pavlović[*], Dragoslav Janošević[2], Vesna Jovanović[4]
[1,2,3] University of Niš, Faculty of Mechanical Engineering, Niš, Serbia

Abstract: Wheel loaders are mobile machines where vibrations occur during transport of loaded material. One common cause is an imbalance in the load being carried, especially when the load is unevenly distributed in the bucket, when the center of gravity shifts. Paper presents the concepts of hydrostatic systems for vibration regulation of the wheel loaders during transport of loaded material in working cycle of the machine. The motion regulation is based on the ability to change the volume of the hydraulic oil in the hoses and in hydro-cylinders for manipulation of the wheel loader's arm. Whereby, hydro-cylinders of arm are acts as a "hydraulic spring", whose dynamic characteristics is changing by the change of hydraulic oil volume thus stabilizing the movement of the machine.
Key words: wheel loaders, machine vibration, stabilization module

INTRODUCTION

A basic (primary) function of the loader is cyclic transport of bulk material to a certain distance (max. to l=50 m). Generally, the basic function of the loader has the following partial functions - operations: loading F_1 (Fig.1a), transport F_2, unloading F_3 of materials and again return to a new place of loading F_4. The cycle starts by selection of the loading workspace. The loading operations can be achieved in different ways that are adjusted to the type and configuration of the disposed material. After loading, the material is raised to the required height above the supporting surface and transported to the unloading place. During the transport, and approaching to the unloading space at the same time is done raising of materials on certain dump height.

Unloading is doe in a pile or in a trailer (bucket) of transport equipment. Basic function of loader of all sizes, is realized by general configuration of the kinematic chain consisting of: a back part L_1 (fig. 1a) and the front part L_2 of the support-moving mechanism and manipulator with an arm L_3 and bucket L_4. Support-moving mechanism is mainly performed on the tires. An actuator C_3 of the arm's drivetrain mechanism are two hydro-cylinders of bidirectional effects, which are directly connected to the support-moving mechanism and arm. An actuator C_4 of bucket's drivetrain mechanism is hydro-cylinder of bidirectional effects and it is indirectly connected to support-moving mechanism and bucket with "Z-working mechanism". The hydro-cylinders of powertrain mechanism are powered with hydraulic pumps in an open hydraulic circuit.

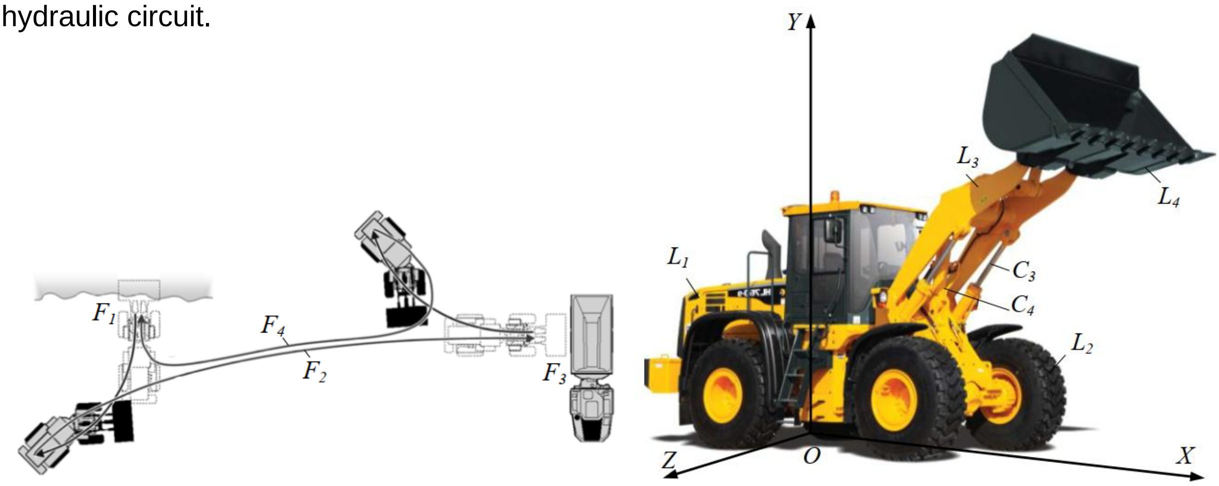

***Fig. 1.** a) Functions and b) physical model loader*

[1]Corresponding author, jovan.pavlovic@masfak.ni.ac.rs, https://orcid.org/0000-0002-8825-7307
[2]dragoslav.janosevic@masfak.ni.ac.rs
[3]vesna.jovanovic@masfak.ni.ac.rs, https://orcid.org/0000-0001-9252-7894

The analysis of functions shows that the operation of transport is largest in the cycle duration, and it is achieved with different paths of the movement of loader, depending on site of loading and unloading of materials. It is characteristic that the path of the movement is usually achieved on a unarranged terrain. At the transport operation wheel loaders are moving with a full and at return with an empty bucket [1].
The speed and the mass to be transported are decisive for high economy. In this respect, wheel loaders struggle with the disadvantage that the bucket with the load acts as a mass around the pivot point of the front axle. Owing to the bucket mass and the distance between the bucket and the front wheel, which has the effect of a tilting fulcrum, wheeled loaders are particularly susceptible to rocking motions, particularly as they have no shock absorber system between the wheels and the chassis such as the dampers.
For technical reasons, they have instead only a limited wheel damping capability via the tires. One effect of this is that, depending on the load and ground conditions, rocking oscillations can occur. The vehicle, the load and the driver are all exposed to these sometimes heavy movements. Aside from the mechanical stress placed on the machine, which can greatly increase wear in the long term, it has also been proven that this motion also harms the health of the driver. Other consequences of rocking include reduced handling efficiency, increased braking distances, impaired steering response and lower transportation speeds [2][3].

DYNAMIC ANALYSIS

In aim to analyze the oscillatory behavior of the loader's movement it has been developed different dynamic mathematical models. Where the loader's physical model is observed as a system with two rigid bodies: the moving mechanism and the manipulator with the following assumptions (Fig. 2a) [4] [5]:
• members of the loader's kinematic chain and the loader's supporting surface are rigid bodies,
• tires and hydro-cylinders of the manipulator's drivetrain are elastically-damping elements,
• tires has point contact with the ground,
• continuous tires-ground contact,
• linear movement of the loader,
• the center of mass of the support-moving member and manipulator lie in a longitudinal vertical plane.

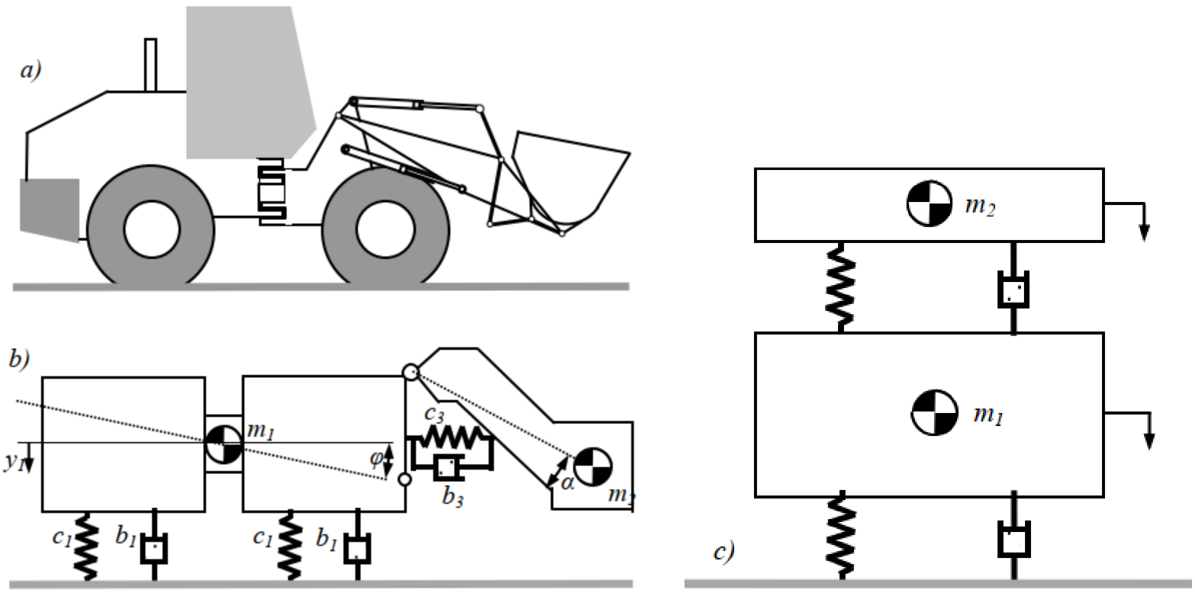

Fig. 2. *Models of the wheel loaders: a) physical, b) mathematical, c) dynamic absorber*

Generalized coordinates of the system are: vertically displacement y_1 of the support-moving mechanism (Fig.2b), the angle of inclination φ of the support-moving mechanism and the angle α is displacement of manipulator around the horizontal axis of the linkage, which is linked to the support-moving mechanism.
Seted dynamic mathematical model of the wheel loader is similar to dynamic mathematical model of the absorber (Fig. 2c). In principle, the dynamic absorber consists of two masses: m_1 - in the case of the loader that is the mass of the support-moving mechanism and m_2 mass absorber or mass of manipulator. The masses are connected with elastically-damping elements of specific stiffness c_i and damping b_i that depend on the characteristics of tires, geometry of hydro-cylinders of the loader's manipulator, volume and characteristics of the hydraulic oil in their working working ports.
An aim of the dynamic absorber is that the specific characteristics of elastic-damping elements leads to reduction of the amplitude of mass m_1, apropos support-moving mechanism on which there is a cabin and in it is machine's operator.

MOTION REGULATION

When wheel loaders move with velocity higher than 10 km/h, they are subject to intense longitudinal vibrations. These vibrations are experienced particularly unpleasantly by an operator. Contemporary wheel loaders, which are required to move relatively fast reaching the speed of 60 km/h, are often subject to intense longitudinal vibrations.
By using the effect of the dynamic absorber it has been developed an active and passive regulation of motion systems of the loader in order to decrease the vibration that act on the machine's operator.
The active regulation systems of the loader's movement are based on a change in the flow of hydraulic pump that powers the drivetrain of the manipulator's hydro-cylinders. By changing the flow of hydraulic pump in same time the elastic-damping characteristics of the manipulator's hydro-cylinders are changing so that the vibration of the loader's support-moving mechanism is reduced.
The change of hydraulic pump's flow depends on the size of the following loader's state variables [6].

- vertical displacements y_1 and velocity $\frac{dy}{dt}$ of the support-moving mechanism,
- angle φ and angular velocity $\frac{d\varphi}{dt}$ of inclinaition of the support-moving mechanism,
- the angle α and the angular velocity $\frac{d\alpha}{dt}$ of displacement of the manipulator,
- pressure on the piston's side of the hydro-cylinder of the arm's drivetrain mechanism.

The passive regulation systems presents hydraulic amortization by using elastic-damping connections of the manipulator for the support-moving mechanism. Whereby, the manipulator of machine is using like amortization mass of support-moving mechanism. The passive systems enables flexible upgrade of the wheel loaders where result is reduction of vibration motion of the machine apropos increasing of operater's comfort and safety. The passive systems have possibility of adjusting the characteristics and turning off the system when the loading operation is active.
As an example, here is given scheme of hydrostatic system (Fig.3) of the manipulator's drivetrain with the passive hydraulic stabilization module. The hydrostatic system of manipulator's drivetrain of the
wheel loader contain: main hydraulic pumps (1) which are powering via valves (3) the actuators of the manipulator: the hydro-cylinders of arm (5) and the bucket (6). The boost pump (2) powered the pilot valves (4) and the stabilization module (7) with accumulators (8). The manipulator's operating is realized by pilot valve (4.1) which actived movement of the arm's hydro-cylinders (5) and by pilot valve (4.2) movement of bucket's hydro-cylinder (6) is actived.

During driving the stabilization module (7) is activated via solenoid valve (7.1) dependent on the driving speed (between 4 and 7 km/ h) and thus the arm's cylinder cap side is connected to the hydraulic accumulators (8). At the same time, solenoid (3.1) in the control block (3) is operated for switching the stabilization module spool, which connects the piston rod side to the tank. This ensures cavitation-free oscillating of the arm's cylinder.
During the working process, solenoid valves (7.1) and (3.1) are switched off and the accumulators are loaded up to a maximum value of the set pressure during the lifting operation. If the pressure on the cap side of arm's hydro-cylinders is lower than the peak pressure in the accumulator (8), the 2-way cartridge valve (7.1) closes. The accumulators are not subjected to continuous pressure fluctuations (service life). The sequencing valve (7.3) and the pressure relief valve (7.4) in the module limit the maximum accumulator pressure.
As the pressure in the accumulator always equals or is higher than that in the arm's cylinder, the bucket is always slightly raised and cannot drop during driving when the stabilization system is connected. The stabilization system improves the driving characteristics irrespective of whether
the bucket is empty or loaded. The main elastic-damping characteristics of the stabilization module depend on accumulator (8). The elastic-damping characteristics of the accumulator are determined depend on state values of pressure and volume of filling of accumulator's gas [7].
Filling the accumulator presents thermodynamic process where is heat changed between the hydraulic accumulator and an environment by a law of politrope, which is expressed with equation [9]:

$$p_i \cdot V_i^n = const \quad (1)$$

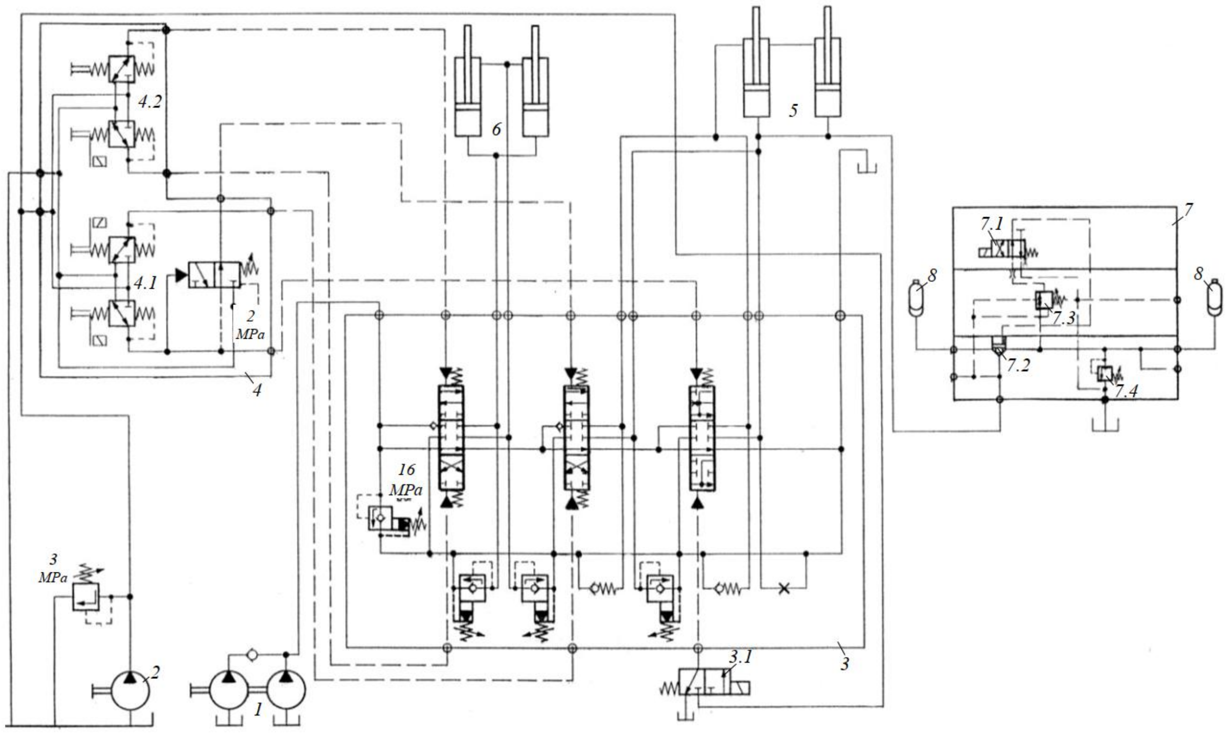

***Fig. 3**. Functional scheme of the wheel loader's hydrostatic system with stabilization module of motion [8]*

Based on previous equation it can be determined elastic characteristiks of the hydraulic accumulator:

$$c = \frac{n \cdot p_i \cdot A_k^2}{V_i} \left(\frac{1}{1 - \frac{A_k}{V_i} \cdot s} \right)^{n+1} \tag{2}$$

where is: n - exponent of politrope, p_i - pressure of system, A_k - area of piston, V_i - volume of inert gas, s - motion of piston, c - stiffness of accumulator.

At the hydraulic accumulator's construction must pay attention that between arm's hydro-cylinder and hydraulic accumulator short ports with big nominal diameter is seted.

It has been done researches of the wheel loaders with and without stabilization module at difference condition of movement in term off the terrain configuration and the speed of movement with the loaded and empty manipulator's bucket [9].

For the comparative evaluation of behaviour at loader's movement it has been measure on the front and rear axles on moving mechanism: a vertical loads (Fig.4), seat's acceleration, motion of piston of arm's hydro-cylinder and speed of movement.

The results of researches, shows that with stabilization module, dynamic's loads of axles of loader's moving mechanism are less from 40% to 65%, while seat's acceleration are less from 48% to 60%. A spectrums shows that at the largest value of axle's load are at frequency: f=1.64 Hz and f=2.68 Hz.

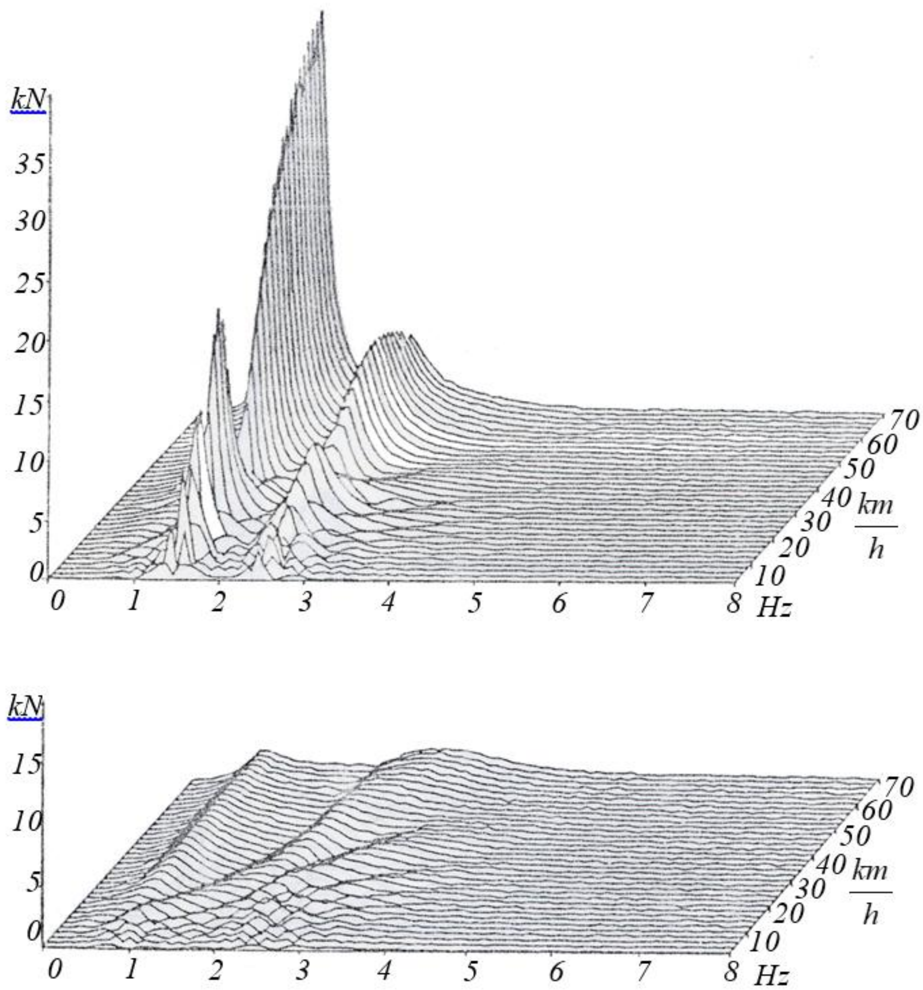

Fig.4. *Loads of loader's front axle: a) without stabilization module, b) with stabilization module [9]*

CONCLUSION

When the wheel loaders are doing their manipulative task and special at the operation of transport from loading site to site of unloading of the materials, they acting like very sensible dynamic systems with appearance of disadvantage oscillations on control site of the machine's operater.
From that reason the researches are done with aim to appease oscillations at loader's motion and to reform ergonomic conditions of the maintenance. Using the principle of dynamic apsorber, it has been developed stabilization modules which construction in present hydrostatic systems of the loaders, can be done successful motion stabilization and comfort of maintenance.
Principally, the stabilization modules content the hydraulic accumulator with membrane, which stiffness in dynamic system of the manipulator, is damping oscillations of the support-moving mechanism, apropros the operator cabin.

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THE DIGITAL FACTORY – PRESENT AND FUTURE

Research paper

Stanko P. Stankov[1*]
[1]University of Niš, Faculty of Electronic Engineering, Niš, Serbia

Abstract: In just the last decade, the concept of the smart factory like a key element of modern manufacturing has turned from a curious idea into a reality. This was greatly contributed by progress in the field of sensors and sensor networks, the introduction of intelligent functionality and their increasingly affordable prices. With the help of sensors, devices based on the Industrial Internet of Things (IIoT) and appropriate platforms for connection and control, not only newly built high-tech plants, but also existing production capacities can be completely digitized. Thanks to digital factories, modern industrial manufacturing has evolved–from the production of various components and products to a complex product creation process, including planning, development and design, logistics and supply chain management. The entire constellation of the so-called disruptive technological innovations, including artificial intelligence, machine learning, IoT, edge computing, cloud platform, robotic process automation (RPA), virtual and augmented reality, machine vision and many others are in the function of achieving a common aim–optimization of quality, efficiency, productivity, security, cost and profit management. Among the key trends that define the development of the modern concept of smart factories are: IIoT, additive manufacturing, predictive maintenance, Big Data, Data mining etc. The characteristic of the new generation of smart production is the transition to market models - from B2B (Business to Business) on B2C (Business to Consumer).
Key words: big data, artificial intelligence, additive manufacturing, cloud computing

INTRODUCTION

In the recent past, there was undisguised excitement about the fourth industrial revolution, about the role of connectivity and intelligent functions, about cyber-physical systems, autonomous machines and artificial intelligence, about digitization as a direct and correct path to the production of the future. Today, it is safe to say that all these then seemingly rather bold and futuristic concepts are part of the present. Industrial enterprises around the world are already actively exploring and exploiting the potential of each successive major innovation in automation, robotics, artificial intelligence and data processing. And just when you think that the new global production paradigm Industry 4.0 and visionary platforms like the Industrial Internet of Things have already shaped a complete picture of smart factories, the next generation of industrial digital technologies for automation and optimization with an even wider range of practical applications appears. In recent decades, machines in the industry have experienced a dynamic evolution - from a physical infrastructure composed of individual units to a connected ecosystem that communicates and functions as a single entity, and this turbulent process of technological development does not stop there [1]. Modern manufacturing is increasingly being talked about as an IoT-based metasystem, pervasive and autonomous, more connected and intelligent than ever before. The penetration of 5G - the fifth generation of wireless connection technologies through cellular networks, from the field of telecommunications and services to other spheres including industry, is one of the most powerful drivers of this trend. 5G networks are expected to soon serve tens billions of IoT based devices making M2M (machine-to-machine) connections, including smart factories. As a result of digitalization, industrial companies can significantly increase their productivity, minimize resource losses, accelerate turnover and thus overall increase the efficiency of their production. Some of the potential solutions, for example sensors, IoT based field devices and platforms for continuous monitoring and diagnostics of connected tangible assets, do not require significant initial investments, and the positive results of their integration into the metasystem are literally immediate [2]. Other technologies, such as virtual and augmented reality and wearable devices, are still considered by many to be more challenging to implement, mainly because of the role of the human factor and the revolutionary new ways in which humans and machines interact. In practice, however, the main purpose of AR (augmented reality glasses), VR (virtual reality glasses) and VRH (virtual

[1] Corresponding author, stanko.stankov@elfak.ni.ac.rs, ORCID: https://orcid.org/0009-0002-4264-3111

reality headset), for example, is to drastically facilitate the interaction between operators and equipment at remote locations, simplify and shorten the training process when introducing a new system or technology into production and thus save valuable time and money. The new smart factories are completely transforming access to the workforce, optimal utilization of its potential and its safety. For this purpose, complex combinations of augmented reality, collaborative robotics, machine vision, robotic process automation and IoT platforms are used. One of the most fundamental innovations for the transition to next-generation digital manufacturing is the digital doppelganger–computer-generated virtual models of physical components, machines or systems that reflect their actual operating status, functionality and capabilities to interact with other components or devices. Through a virtual replica, a physical object can not only be configured, managed and monitored in real time, but various functions related to predictive maintenance, modeling and simulation of various standard and extraordinary practical scenarios can be added to it without any real risk of its damage [3, 5]. The new generation of smart factories also has a special focus on sustainable solutions: intelligent management of energy, resources, waste and carbon dioxide. For this purpose, many different devices designed to monitor work, environment and microclimate are integrated. With the help of AI algorithms and machine learning, the energy needs of individual systems, their operating modes and their consumption are continuously monitored, eliminating idle operation, as well as that with excess power when it is not needed. Modern factories are now capable of achieving even zero-loss production. In modern warehouses and logistics centers, smart solutions such as automated storage and retrieval systems, mobile robots, self-guided vehicles, drones, etc. they help save one of the most valuable resources for order fulfillment, namely time. Among the applications technologically striving to achieve absolute perfection through digitization are visual inspection, quality control and traceability–with the help of advanced machine vision systems, intelligent sensors and the latest generation of real-time analysis software tools. Other features of the new smart factories are the possibilities of digitizing entire supply chains, monetization of data, integration of advanced analytical tools, blockchain technologies, quantum computing, neural interfaces and even nanotechnology in addition to already traditional solutions such as robotics, artificial intelligence, additive manufacturing and wearable electronics. As a result, these metasystems are able to self-diagnose, self-adapt and autonomously perform a large part (and even all) of the necessary technological operations [1].

DIGITAL FACTORY CONCEPT

The most important characteristics of the digital factory (Fig. 1) are [1, 5]:

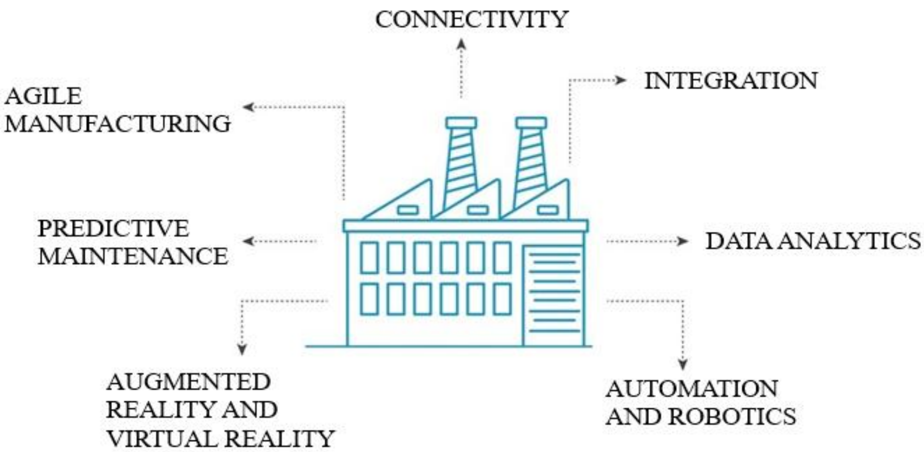

Fig. 1. *Basic characteristics of the Digital Factory*

- Connectivity: Refers to the flow of data through the networked ecosystem of devices and components that make up the factory. It is the ability of gadgets to "talk" to each other that

enables technologies such as the Industrial Internet of Things (IIoT), wireless communication and cloud computing.
- Integration: It implies connection and coordination of different systems and processes involved in production. Digital technologies such as data sharing and automated work processes enable a coordinated blend of design, manufacturing, supply chains and other elements.
- Data analysis: the acquisition and analysis of big data that is generated daily in a particular plant is the process of turning that data into meaningful insights that help in making business decisions.
- Automation and robotics: make it possible to automate monotonous, repetitive, and often risky tasks and processes in one plant. Automation echnologies of the digital factory may include robotic process automation (RPA), autonomous vehicles, and certain machine learning (ML) and AI applications.
- Augmented and virtual reality: Augmented reality (AR) and virtual reality (VR) technologies are used in digital factories to help train workers. While AR technologies, such as smart glasses, integrate with workers' real-world settings to help them perform tasks, VR technologies, such as VR headsets, allow workers to be trained through simulation in a risk-free environment.
- Predictive maintenance is a production maintenance strategy that uses digital solutions such as AI and IoT sensors to predict when a machine will break down. In a digital factory environment, predictive maintenance uses data collected from sensors to predict and optimal time for machine overhaul.
- Agile production: Digital factories are focused on the client, and the basis of the strategy called "agile production" is rapid adaptation to changes in the market, efficient management of resources and reduction of waste. Agile principles encourage collaboration, continuous improvement, and rapid adjustments to meet set requirements and criteria. Agile software development is based on the principles of lean manufacturing (creating more value for users with fewer resources) and organizational learning. Acceptance of changes and adaptation to changes, team cooperation, development, improvement and high quality of products, fulfilling the needs and wishes of clients are the basis of agile methodology [5-7]. According to predictions, by 2030 there will be a significant acceleration of digitization and the application of modern technologies. However, according to the World Economic Forum (WEF), more than 70% of global manufacturing is at the pilot stage related to IIoT. Only a few global companies have effectively implemented advanced digital and sustainable manufacturing at scale. At the same time, it is evident that digital solutions and services are becoming more and more ready for real application in all industrial sectors. A factory that is green, lean and digital at the same time will surpass the competition in terms of profitability and sustainability (Fig. 2). On the other hand, there are several key challenges that need to be addressed when embarking on the road of factory digitization. In production as in any other business potential transformations will take place in a VUCA environment (volatility, uncertainty, complexity and ambiguity), which is becoming even more visible in today's turbulent times. Manufacturers will have to work in a rapidly changing world. Events will become less predictable, and planning capabilities will therefore have less reliability. It sure is that one thing is certain, and that is uncertainty, which will last and we need to find a way to deal with that reality. Some companies tend to rush the idea of implementing IIoT solutions at high speed. However, in many sector, people often lack the knowledge to select and adopt the right technologies that could be most beneficial to the company [8]. In the worst case the chosen technology does not fulfill its purpose due to the lack of consistent knowledge about digitization and automation. In addition, there is another major challenge. The aging of the population and society means that the labor market will shrink in the medium and long term, especially in Europe and America, but already in some Asian countries. This demographic change will significantly reduce the available workforce. Therefore, the existing human resources should be supported by automation and digitization in order to facilitate their business and productivity for a longer period.

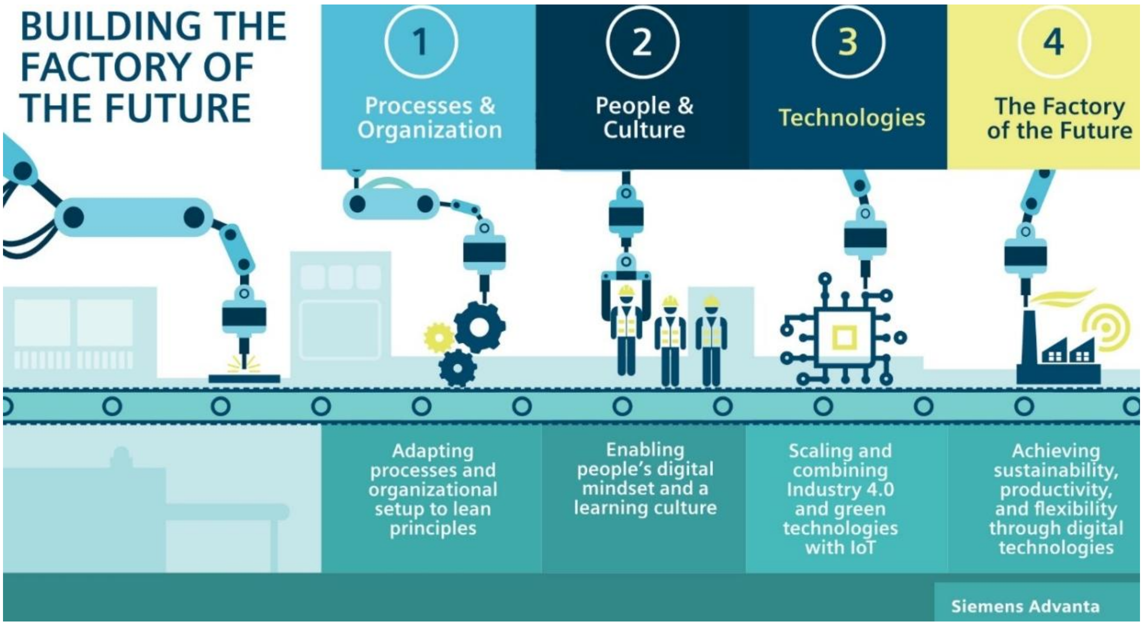

Fig. 2. *The Green & Lean Factory of the Future* [8]

Digital transformation will not work without the right knowledge of people, so retaining and training them is a top priority. This transformation encompasses the entire organization, including processes and technology, as well as human resources. In manufacturing, there are three specific goals for creating the factory of the future: productivity, flexibility and sustainability. Productivity is the most obvious and has been there since the beginning. Even without digital factory transformation, 10% annual productivity growth is optimistic for many manufacturers. Undoubtedly, this increase is the lower limit for creating lasting commercial success and ensuring competitiveness. These productivity gains can already be achieved through the application of classic lean processes, as well as through connectivity and automation. The idea of creating a digital twin in production imposed is the increasing connectivity. It's a concept that allows manufacturers to monitor product performance in real time using a digital model which responds identically to a real-world product. As Industry 4.0 continues to drive the manufacturing sector, there is a growing need for digital twin designs [9]. Figure 3 shows a digital twin of a three-phase induction motor.

Fig. 3. *The digital twin of a three-phase induction motor* [9]

A digital twin is created on the basis of real-time data and therefore enables the digital visualization of a real product, system or process as a whole, discovering its weak points and making operational and strategic decisions based on data analysis. The goal is to ensure optimal performance in the physical world, gain better insight into production, improve customer service, and thus increase the efficiency of the entire company. Thanks to huge technological advances, especially in IIoT, digital twins have become a valuable decision-making tool for companies in a wide range of industries. In particular, their ability to provide answers to questions about how business processes work and the potential impact of process changes and optimization make digital twins a very useful tool in digital transformation [10]. Digital twins as digital 3D replicas of objects from the physical environment can be modified and updated along with the elements they copy. An example of a company using digital twins to support its physical production is Rolls Royce, whose engineers create precise virtual copies of their jet engines, then install sensors and satellite networks to send data to the digital copy in real time [11].

THE INNOVATIONS THAT INFLUENCED ON DEVELOPMENT OF THE DIGITAL FACTORY

In less than two decades, the industry has undergone changes not seen since the time of the first industrial revolution, which is an unprecedented pace of change. Key technologies and breakthroughs that have enabled the metamorphosis since the invention and popularization of computers include the Internet of Things, big data, 3D printing, cloud computing, smart factories. Every business leads to a unique goal: reducing costs, increasing revenue and profit. All technological inventions of the modern age are subordinated to this original purpose. By combining information and communication technologies, today's businesses automate work, thereby reducing the likelihood of errors and allowing busy people to discover the true value of their work. Current trends are efficiency, innovation, adaptation.

Internet of Things and Industrial Internet of Things

IoT are among the basic levers of modern automation. These are online devices that communicate with the outside world and are controlled by algorithms. They replace people in boring, monotonous and often dangerous jobs. In industry, such inventions are of far greater value than individual comfort at home. If a production machine whose lubricating oil is damaged and needs to be replaced can generate an alarm, the lubricant can be replaced before its failure leads to performance degradation. In industry, IIoT relies on sensors that measure important parameters of all resources, algorithms to detect "events" and Internet connectivity. The combination allows alerts of important events to be sent to a central control unit or responsible team [1, 2].

Big data

The equipment in the plant is monitored by sensors from which data is accumulated day by day, which enables monitoring of trends. On the one hand, the manager has a large amount of data in front of his eyes, which enables him to follow trends and make adequate decisions. However, with the accumulation of a large amount of data, it becomes impossible for a person to correctly track all changes. This leads to the need to create data processing software that can generate reports, including graphs, and even forecasts of expected development. The sheer volume of data from multiple devices gave rise to the term Big Data. Their processing and transformation into meaningful knowledge is covered by the concept of "analytical tools" [12].

3D printing

The so-called additive manufacturing, which is also called 3D printing, is one of the most avant-garde inventions in recent times. It emerged as a rapid prototyping technology. Using 3D CAD models, 3D printers can produce different parts in one or more units. Not long after, it was seen that the technique could do much more. Today it is used to create limited series of products for which it is not profitable to reconfigure entire production lines. Some of the most active users of additive manufacturing are automotive companies. It is profitable for them to create some of the car's components through 3D printing, for example interior elements. So they can, for example, to achieve a specific shade in the body modules or to enter customers' personal names [2, 3].

Lean production

The digitization of production has led to the development of the Lean management methodology, which has gained popularity due to its philosophy of "doing more with less". The invention eliminates unnecessary steps in the process. This eliminates waste in the broadest sense: everything (material, plant or process) does not add value to the final product or service. This "cleaning up" of production increases its productivity and efficiency and ultimately reduces the unnecessary cost burden on users [2, 3].

Cloud computing

The idea of cloud computing was born back in the 1960s, but technological developments in modern life have made it possible only recently. Computing resources are viewed as a communal service. This means that it is used regardless of where the servers are located and what their parameters are, and that it is paid according to consumption. This is one of those inventions in today's world that has a revolutionary effect on the industry, because it eliminates the need to build your own computer infrastructure. This invention solves at least two problems. The first is a large initial investment–for server infrastructure, network, storage systems, software licenses, applications. Another is poor utilization of own computing infrastructure. Cloud technologies, on the other hand, offer computing power "on demand", with one click. No need for large in-house support teams either. This invention saves the financial burden, which is often overwhelming for smaller businesses [2, 3].

Smart factory

All these innovative solutions have led to the creation of a "smart factory"–a new generation production plant in which everything is digitized, networked, automated and, most importantly, subject to constant optimization. Accumulation of data and their analysis enable more adequate planning of resources, management of supply chains and development of new products and services. The smart factory is sustainable because it flexibly reacts to all changes in the surrounding world: fluctuations in consumer demand, changing priorities of shareholders, dynamics of the global economy and natural cataclysms. But above all, constant self-improvement dominates [2, 3].

NEW APPLICATIONS AND CHALLENGES

The new concept of intelligent factories is finding more and more applications in the automotive, food, packaging, chemical and pharmaceutical industries, semiconductor industry, oil and gas, mining and mineral industry, metal processing, mechanical engineering, space sector, defense, etc. Among the interesting phenomena related to ubiquitous digitization in industry is the emergence of the so-called digital lean methodology. Analogous to the traditional lean philosophy, which preaches maximum saving of resources, the new version of the concept takes advantage of even more efficient and functional digital tools that provide even more accurate, comprehensive and timely information about technological processes in the factory. Advances in artificial intelligence and machine learning are expected to lead to a kind of hybrid workplace boom based on so-called augmented intelligence – a combination of human and machine cognitive abilities. This technology found its first application in the automotive, food and pharmaceutical industries. The concept of distributed manufacturing, based on the remote use of the company's global knowledge with the possibility of diversifying the supplier network and local production of parts, is also gaining popularity. Its main component is 3D printing. Another interesting group of applications (along with machine vision) this technology finds in the food industry, where, in addition to packaging, the method can also be used for the production of food products themselves [2, 3]. In smart factories, a large number of process parameters such as temperature, pressure, speed, flow, level, etc. they must be continuously measured in order to ensure the smooth flow of technological processes. The solution for this is wireless sensor networks, which in combination with SCADA platforms and other intelligent devices in the field enable real-time monitoring and management. For the efficient joint operation of various devices in the production metasystem, their interoperability is critical. Distributed control systems and programmable logic controllers, the core of modern process automation, can be controlled using the Open Process Automation Standard (O-PAS), specialized for "open process automation" (OPA) communication [13]. Interoperability between information technology (IT) and operational technology (OT) is considered to be the leading challenge in implementing the smart factory concept in modern manufacturing. These infrastructure systems initially use different protocols and architectures, and their work in synergy is key to the realization of a functional digital ecosystem with seamless data exchange between machines and other physical systems of different manufacturers. Data processing in modern factories is expected to become increasingly "hyperlocalized" using edge computing and local servers, or at the field device level (pump, motor, generator, etc.) instead of centralized data centers. This approach enables a faster and more reliable exchange of data on technological processes in real time.

VIRTUAL REALITY, CONTINUOUS CONNECTIVITY AND COLABORATION

ABB company is a leader in digital technologies for industry, developing and offering complete solutions for energy networks, power products and electrical equipment, as well as propulsion technology and complete solutions for robotics. Among the main advantages of ABB Abiliti is the ability to compare all collected data with identical connected ABB devices around the world and process them in real time. This is the first step towards a complete digitized process through which it is possible to monitor and react proactively in case of malfunctions. Connecting ABB robots with ABB Abilities' "Connected Services" results in up to 25% fewer incidents and 60% faster response and shorter time to problems solving. "By connecting ABB's proven portfolio of robots with the revolutionary ABB Ability digital platform, any plant can become smarter and more flexible. By applying these state-of-the-art technologies, it is possible to provide digital industrial production capable of predicting failures, controlling productivity and enabling highl efficiency. ABB has made remarkable progress in the field of virtual reality, using digital twins, which ABB has made remarkable progress in the domain of virtual reality and the production of industrial robots, using digital twins, which reduces design time by up to 20% and optimizes costs by up to 30%. The IRB 120 and IRB 1200 robots are designed for flexible material handling that allows cage sizes to be reduced by up to 15% and cycle times to be shortened by up to 10%. Their design allows them to be mounted almost anywhere without restrictions–in a cage, on a machine or near other robots at any angle [14]. YuMi is the first truly fully collaborative robot created by ABB for a world where humans and robots work together. By combining the unique ability of humans to adapt to change and the tireless endurance of robots to perform precise, repeatable tasks, process automation in the assembly of various types of products becomes possible. YuMi is fast and accurate, returning to the same point in space with an accuracy of 0.02 mm. If it senses an unexpected impact with a worker, the robot can stop its movement in a few milliseconds and start again easily. This ensures the safety of people in production lines. Fig. 4 shows the IuMi robot in THT (Through Hole Technology Mounting) assembly action [15]. be effective, robots must be able to move quickly, making them potentially dangerous to humans working near them. As the „Factory of the Future" is smarter, ABB's SafeMove2 safety solution provides greater flexibility, space savings and state-of-the-art commissioning tools – for greater productivity with lower total investment costs.

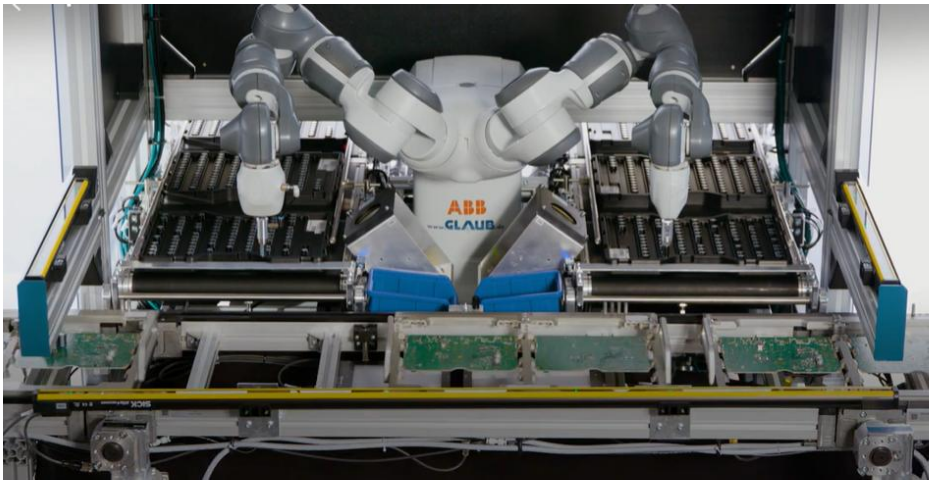

Fig. 4. YuMi takes over THT assembly [15]

SafeMove2 is an innovative technology for human protection and increased robot safety. To Thanks to SafeMove2, the movement of the robot is precisely limited only to the necessary range for the given operation [16]

CONCLUSION

In the last ten years, the concept of the smart factory has turned from a curious idea into a reality and has become a key element of modern manufacturing. Modern factories are increasingly referred to as IoT-based metasystems, comprehensive and autonomous, more connected and intelligent than ever before. The new generation of digital factories is completely transforming access to the workforce, optimal use of its potential and its safety.
Designers of production plants are faced with the question of how digitization in the production process will affect services. Companies that carefully preserve their traditional strengths while implementing new value-added technologies will have the best chance of maintaining their positions as pioneers in the future digital age. At the heart of Factori 4.0 is the idea of intelligent planning, production and maintenance. Digitization capabilities and solutions must be included in the overall production vision already at the design stage, so that the manufacturing company can have greater flexibility and efficiency later. Industrial enterprise designers can rely on networked digital planning and simulations, followed by virtual commissioning of entire factories and facilities. An important plus is the fact that with good planning of production can achieve more sustainable production with maximum profit. Designers of factoryes can send their data from the planning and commissioning phases to the end user or factory operators, who can then use this data in the production phase to optimize the process. Later, if any changes are made in the factory, the digital double will be able to adapt to those changes immediately.

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A SUPERVISORY CONTROL OF WATER SUPPLY SYSTEM

Research paper

Stanko P. Stankov[1*]
[1]University of Niš, Faculty of Electronic Engineering, Niš Serbia

Abstract: The methods for online monitoring and control of water networks are becoming increasingly popular, through which remote event registration is possible. SCADA systems are widely used by water utilities to control the flow, pressure and quality of drinking water in accordance with regulatory requirements. Network monitoring tools (sensors and measuring devices) are installed at key points in the network to get a complete picture of its condition. Pipeline integrity checks are performed periodically, usually using mobile leak detection devices. Since water distribution systems are under pressure, leaks and other unplanned events, such as improper opening or closing of valves, can also be detected remotely. An important component of the remote monitoring platform are tools to identify and locate pressure drops associated with punctures, leaks or faulty valves, as well as various hydraulic anomalies. Drinking water distribution systems transport water from springs, reservoirs, etc. to industrial, business and residential buildings in the water supply network, through complex networks of pipelines. Adequate water supply in terms of quality and access is the primary goal of every water company, which is why planned and unplanned service interruptions for repair and maintenance should be minimized. The paper describes the application of the SCADA system that monitors and manages the infrastructure of the one water supply system.
Key words: water supply system, control, monitoring, pumping station, tank

INTRODUCTION

Water capture, preparation, transport and distribution systems represent a serious challenge for monitoring and management technologies. The water system contains complex networks of pipes buried underground that are relatively inaccessible to observation. At the same time, maintaining the integrity of these networks is essential to ensure clean drinking water for the users of the water company that operates the system. To ensure efficient management of water supply and smooth operation of facilities, centralized platforms for monitoring and control of water networks with locally located measuring devices and sensors throughout the system to send data in real time to the dispatch center (DC) are necessary [1, 2]. Modern platforms for control and monitoring of water networks manage and analyze data from devices in the field, such as intelligent wireless sensor nodes, which continuously monitor hydraulic, acoustic, qualitative, quantitative and other parameters of the system. They are combined with software tools for dynamic predictive modeling and simulation of various scenarios related to given consumption, hydraulic status of the network and specific combination of operating conditions. Thus, it is possible to prevent critical events such as pipeline breaks, water losses and water supply interruptions. In addition, databases are generated to identify trends in chronological order. SCADA (Supervisory Control And Data Acquisition) systems for water supply and sewage usually process and display the following variables and parameters: pressure, flow, water level, degree of turbidity, pH value, temperature, electrical conductivity, statuses of pump aggregates and electric valves, consumption of active and reactive electricity [3, 4]. These systems allow operators and dispatchers to monitor the hydraulic characteristics of the water network in real time. Based on the comparison of forecasted and archived values, unexpected situations and problems can be identified relatively quickly, which enables activities to be taken to eliminate these problems in a timely manner. When creating a SCADA system, it is necessary to take into account modularity, autonomous and integrated operation of devices and equipment, as well as a good ratio of costs/exploitation characteristics, which ensures effective monitoring and management in real time. Most SCADA systems for water and sewage systems have a decentralized configuration consisting of two levels - a local level (programmable controllers) for the control of water intakes, well facilities, break chambers, pumping stations, and a

[1] Corresponding author, stanko.stankov@elfak.ni.ac.rs, ORCID: https://orcid.org/0009-0002-4264-3111

central monitoring and control system (high performance of industrial computers) which is available to the operator in the dispatch center (DC). Communication between these two levels takes place using data transmission techniques-cable, optical cable, telephone network, radio/wireless system, GSM, etc. [5, 6]. As an illustration, the water supply system in town Vranje is taken, which technologically consists of several units: Accumulation Prvonek, Water Factory, First main tank - SARAINA, Tank - ĆOSKA, Tank - third altitude zone, Second main tank - ČERENAC, Tank - second altitude zone, Tank - Vranjska banja (a sketch of the Water Supply System is shown in Figure 1) [1].

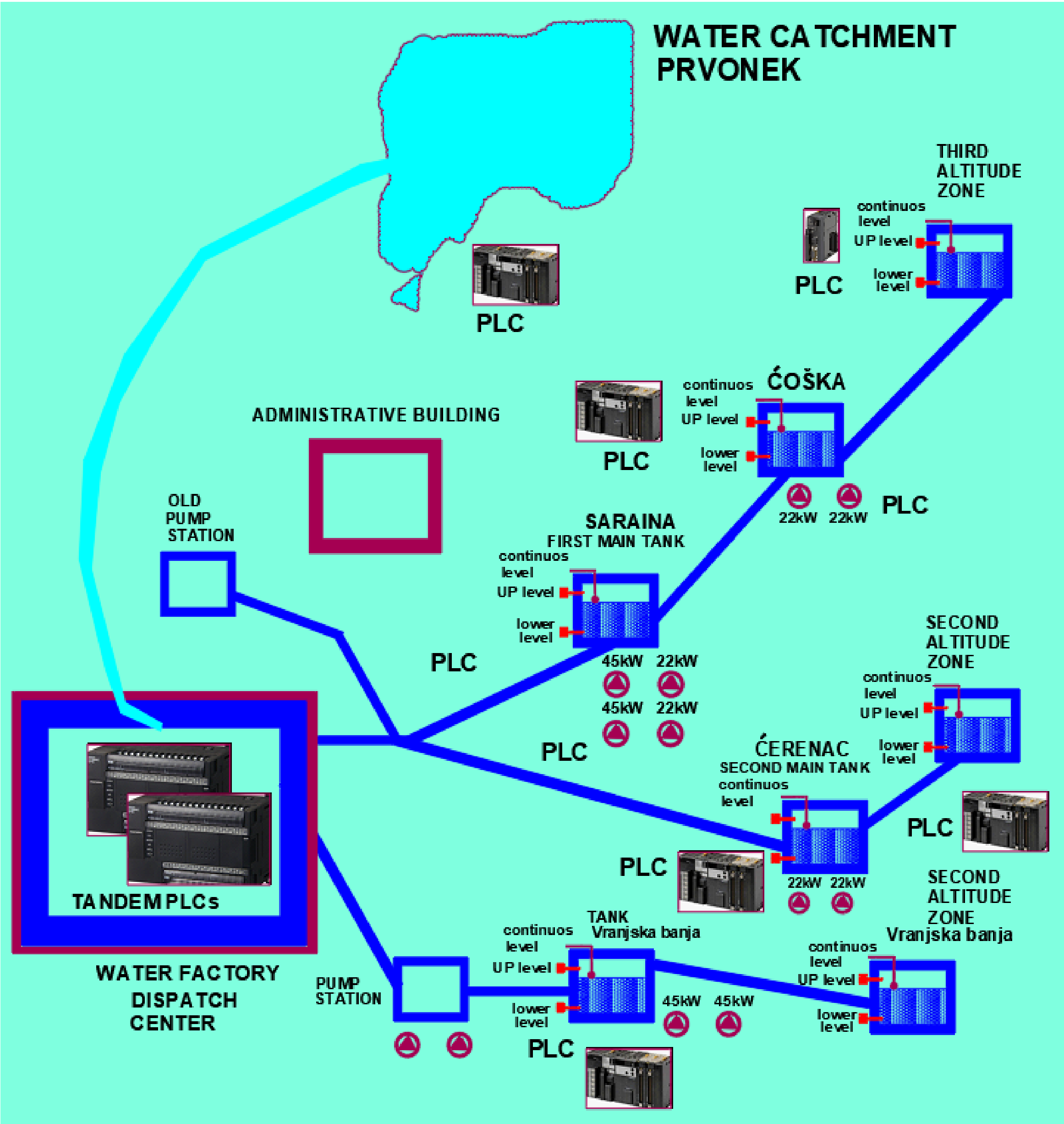

Fig. 1. *Schematic representation of the water supply system in Vranje city*

CONFIGURATION OF THE CONTROL AND SUPERVISION SYSTEM

From the point of view of SCADA architecture, the system for water supply and sewage systems is often designed as a distributed network model for processing a large amount of data with a high degree of reliability, which supervises and control the technological process in order to optimize the use of resources and achieve maximum production, whereby it is executed:

- acquisition and processing of data from measuring transducers,
- determination of technological limit values based on collected data and generation of alarms in case of reaching those limits,
- management of pump aggregates based on flow or pressure in water and sewage systems,
- report generation,
- maintenance of the information system through the creation of a complete and secure database,
- providing information to the operator, which enables him to undertake adequate activities,
- communication with other information systems.

Each local pumping station has devices for management and data acquisition, whereby automatic measurement of relevant parameters, primary data processing, comparison with limit values, generation and sending of warnings and alarms in case of reaching limit values, as well as communication with higher hierarchical levels are carried out [1, 2]. Pressure control is one of the biggest challenges in the water supply system, especially in networks with pronounced gravity action. Pressure is naturally defined as the difference between the elevation of the water source and the elevation of the supplied territory. Since the territory fed by a certain reservoir is relatively large with natural unevenness of the terrain within the territory itself, it is necessary to increase or decrease the pressure so that its value is in accordance with the prescribed norms. Increasing the pressure is done by means of pumping stations, and lowering it by means of reduction. When designing the capacity of the SCADA system, the basis is the hardware configuration of the control system as well as the input and output values and parameters of the controlled plant. Based on that, the number of input and output signals (digital and analog) is determined and the number of SCADA tags is planned. In terms of hardware, the SCADA system includes two industrial PCs - SCADA servers, which work in redundant mode. OPC servers, Web servers and client servers are also installed within these servers. In the role of Web servers and SCADA clients are PCs of appropriate performance. Computers (two SCADA servers, Web server and CLIENT computers are installed in the dispatch center (DC). The system for acquisition, monitoring and control provides: water level measurement in all tanks, water level measurement in water production plant pools, continuous measurement of temperature, turbidity and pH value of raw water, continuous measurement of the flow of raw water based on which chemicals are dosed is carried out, measurement of chlorine concentration, level of lime solution, sulfate and polyelectrolyte, oxygen content in water and flow of clean water [1, 3, 7]. The SCADA system enables the monitoring of all technological units and all important parameters of the factory. On the monitors in the DC and the management, plant supervision is carried out with the possibility of insight into the state of subsystems at any moment, such as: water inlet to the factory, water outlet from the factory, separation chamber, pulsators, filter room, dosing room, chlorine station, machine room, dam, pumping stations. Distributed supervision and management based on the PLC configuration according to the "master-slave" principle are foreseen, that is, the independent operation of certain technological units within their own PLC units in which the software for managing that part of the process is implemented. Each unit functions with the parameters it receives from the DC (there is also the possibility of local adjustment). The main tandem-two master PLCs are installed in the DC, next to which the visualization of the entire plant and the complete technological process, as well as each technological unit individually using the menu system, is realized on the PC screen. All subordinate PLC units (slaves) are connected to the master unit in an appropriate manner, which ensures the elimination of interference, safe data transmission and reliable operation of the plant.

The computer system enables memorization of all technological parameters that are permanently measured or parameters set by responsible persons. Various analyzes can be performed on the basis of those memorized parameters, such as:
- defect inspection and certain manipulative actions related to equipment, technological process and technological procedures in the event of breakdowns of either technical or technological nature,
- analysis of procedural orders and procedures in work,

- preparation of statistical analyzes for future rational management of the system,
- optimization of technological processes,
- minimization of operating costs,
- making shift reports.

For the needs of the maintenance department, it is possible to view all documentation, photos of installed equipment, brochures, connection diagrams, etc. Documentation management is an important condition for the proper functioning of the plant and the development of the water production process. This means:
- updating every technological change in the production process with the correction of the work instructions,
- updating the technical documentation of the performed state after each replacement of equipment,
- formation and updating of technical documentation of each device and installation as a prerequisite for quality maintenance [1, 2, 3, 7].

CONTROL AND SUPERVISION

The SCADA is a computer system that is used for monitoring and acquisition of data in real time, storage and processing of data, comparison of operating parameters with set limit values and automatic parameter setting, which enables monitoring of the technical condition of installed devices and equipment, and timely elimination of potential problems. In the introductory part, the functional units of the considered water supply system are indicated. These units can be seen on the SCADA screen (Fig. 2). In addition to this, a certain number of characteristic SCADA screens are also shown.

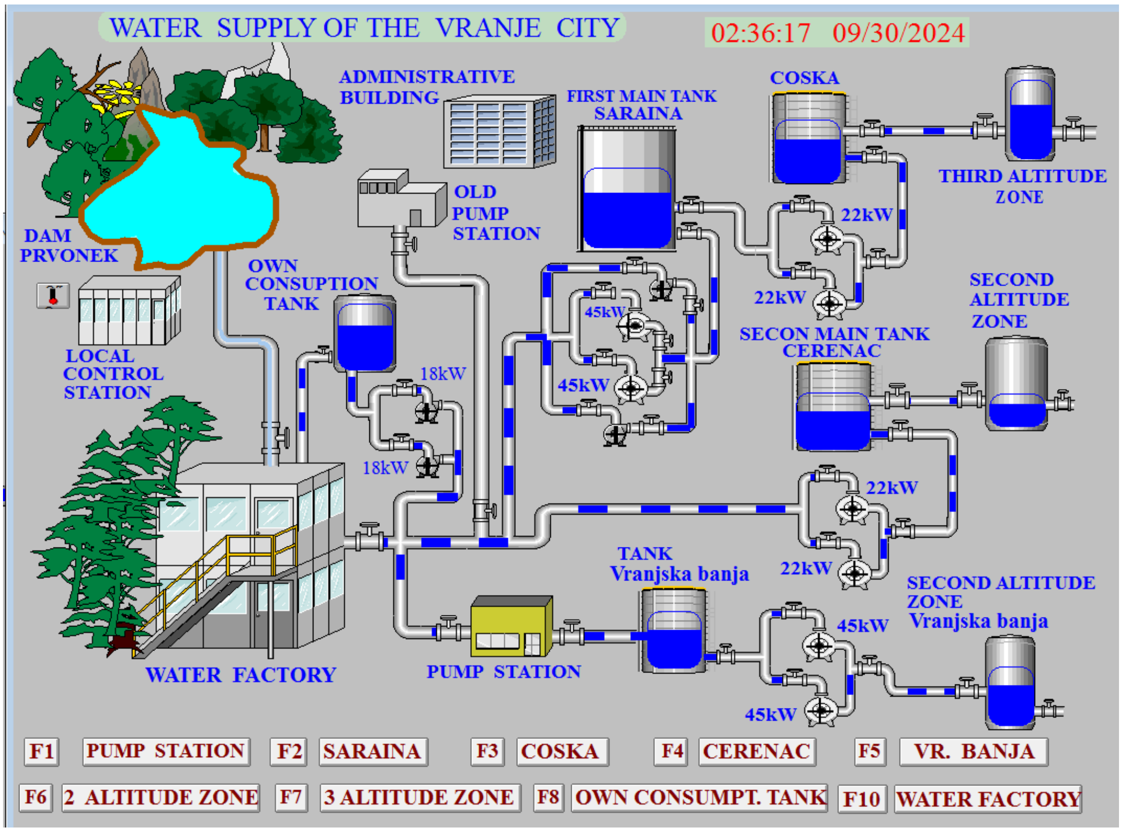

Fig. 2. *Initial SCADA screen of the water supply system in Vranje city*

There are six intakes of water at the dam. Water parameters are measured and displayed at the water intake tower: turbidity, pH, temperature, dissolved oxygen concentration at all water intakes and value of incoming water flow. In all tanks of the water supply system, measurements of discrete levels - lower and upper, and continuous measurement of the current level are carried out. All pumps installed at the reservoir and certain pumps in the Water Factory are with variable variable frequency drives, with the controlled variables being pressure, flow or level. Pumping stations within the water supply system can operate in the following operating modes: local manual, local automatic, remote manual and remote automatic. The local manual operation mode is intended for service and repair. Control is performed via the touch panel. The local automatic mode of operation takes place via the PLC. The remote manual mode enables the control of the plant from the DC, where they can be included individually e.g. pump or electric valve drive. The normal operating mode of the plant is automatic remote, when the operation is programmed via PLC and under the supervision of the SCADA system [1, 2, 3, 7]. The Saraina tank (Fig. 3) is also fed by gravity from the Water Factory. Here, 4 pumps are installed that work in the working-reserve system (2 power of 45 kW and 2 power of 22 kW), with the task of sending water to the Ćoška tank. The operation of the pumps is conditioned by the levels in this tank.

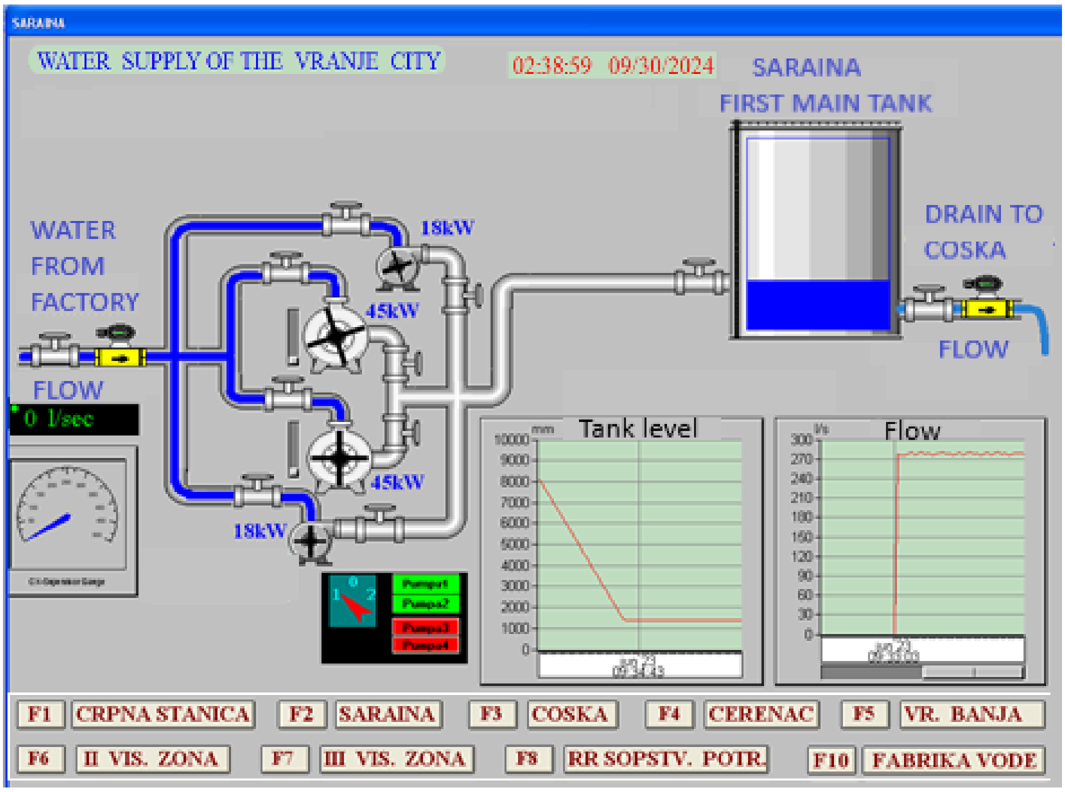

Fig. 3. *One SCADA screen of the Saraina tank*

With the help of pumps (2 power of 22 kW each) near the Ćoška tank, water is drained into the third altitude zone reservoir, the levels of which depend on the operation of the pumps themselves (Fig. 4). The Ćerenac tank (Fig. 5) is supplied with water by gravity from the Water Factory. 2 pumps with a power of 22 kW each are installed here. The pumps send water to the tank of the second altitude zone, and the operation of the pumps is conditioned by the levels of this tank. And the Vranjska banja tank (Fig. 6) is supplied with water by gravity from the Water Factory. Two 45 kW power pumps are installed here. The pumps send water to the tank of the second altitude zone. The operation of the pumps is conditioned by the levels in the tank.

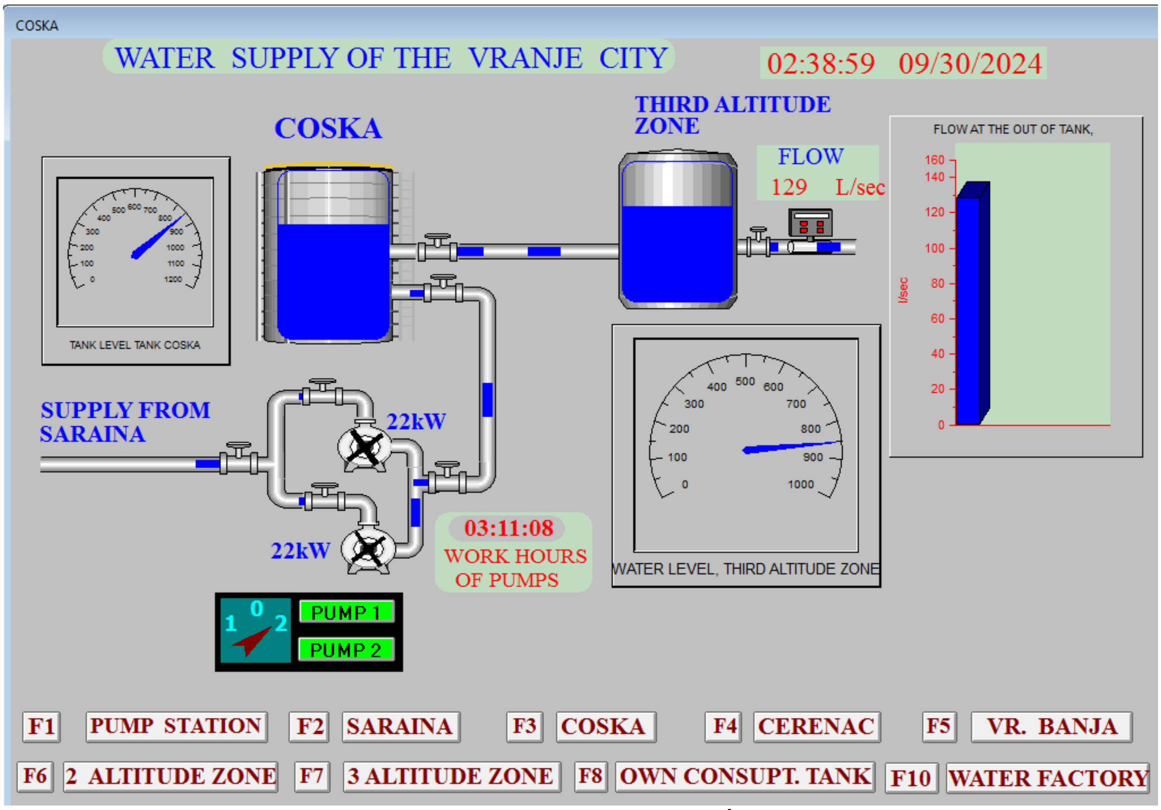

Fig. 4. *One SCADA screen of the Ćoška tank*

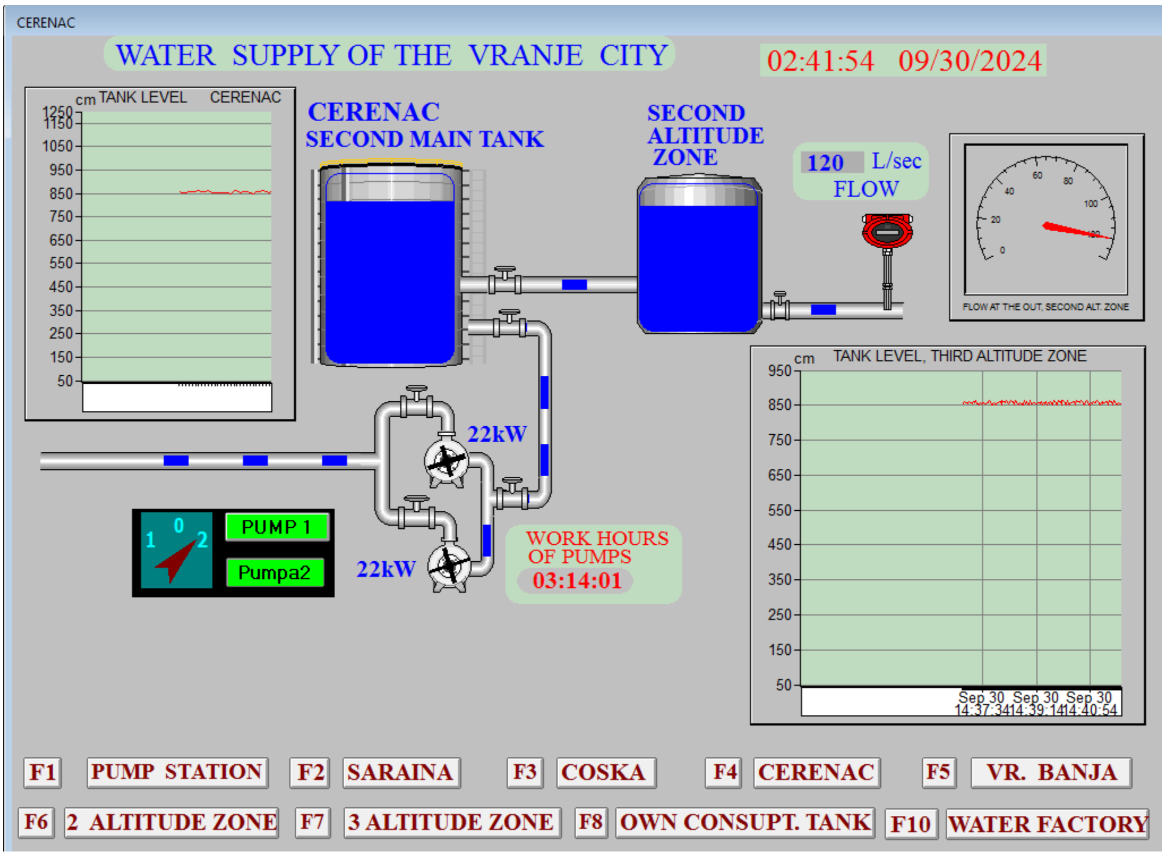

Fig. 5. *One SCADA screen for the Cerenac tank*

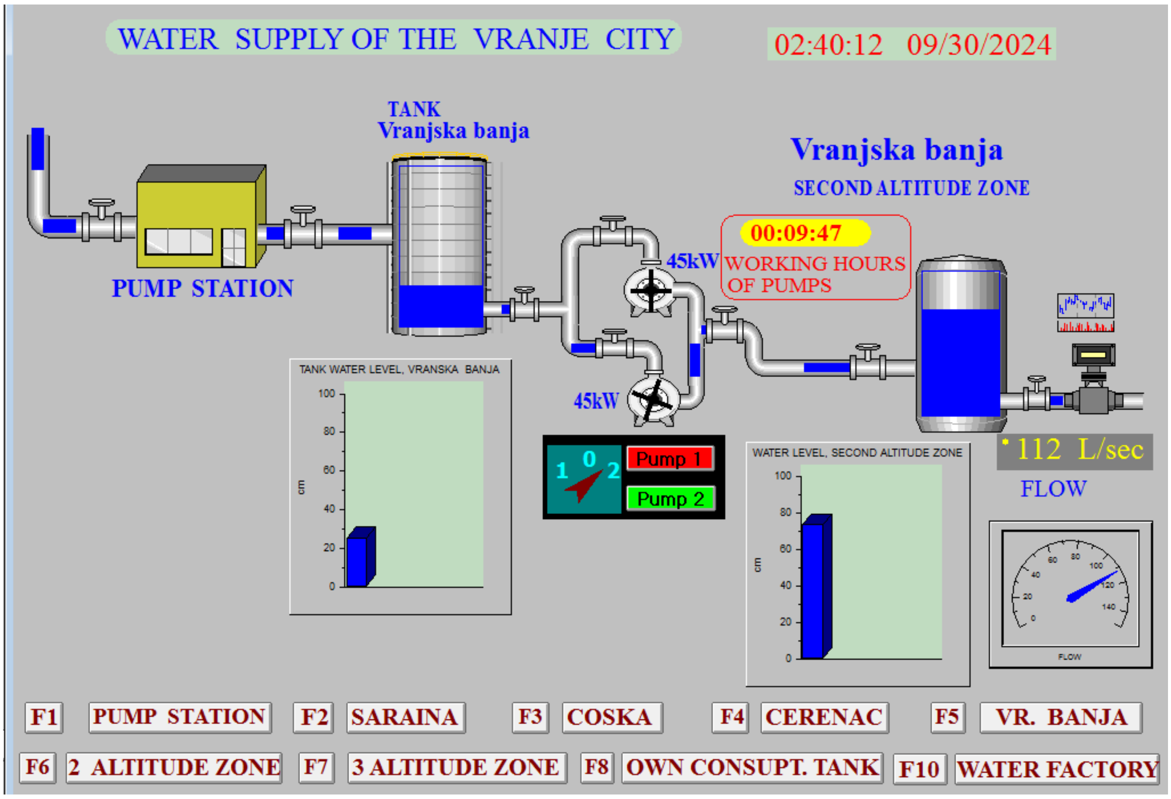

***Fig. 6.** One SCADA screen of the Vranjska banja*

Raw water enters the Water Factory through an electromotor regulating valve behind which the flow is continuously measured. Three chemicals (aluminum sulfate, polyelectrolyte, hydrated lime) are dosed in the separating chamber. The speeds of the three dosing pumps are regulated by variable frequency drives. The pulsator works with two motors with fan load characteristics. They are turned on as needed, and the time of interval-pause is adjustable. There are six fields in the filter hall. Each of the fields has electropneumatic valves that are controlled by a signal from a level meter. If the level increases due to dirty filters, the pneumatic regulator opens the valve by which the water is brought to the tank. Drainage valves for waste water work as needed, especially when fields are washed. There are six dosing pumps in the dosing room. Flow meters are installed behind the pumps. In the dosing tubs there are mixers that work at certain time intervals. The operation of the pumps is a function of the level in the tubs. The chlorine station is also under the supervision of the SCADA system (the value of the concentration of chlorine in the air is monitored and in case of an increased value, the alarm and the neutralization pump are activated. The chlorine pressure in the branch of the control bottle is also measured. The operation of the compressor station and all pumps in the engine room is also monitored (pumps for washing the filter fields and pumps for the internal tanks) [1, 2, 3].

DATA TRANSFER

Modern technologies of wireless sensors enable the construction of networks of increasingly affordable devices for monitoring water systems in real time. Combined with appropriate data processing techniques and decision-making tools, these tools provide a continuous flow of data to a centralized monitoring and management platform, enabling efficient management, adequate response to crisis situations and prevention of adverse events. Waterworks monitoring platforms use a combination of predictive modeling systems, data flow analysis and simulation tools. The primary data source is wireless sensor networks integrated into the water supply infrastructure, which provide real-time information on the hydraulic behavior of the system, the operation of facilities and the quality of drinking water. These technologies are flexible and can be integrated into a water supply system of various scales - from a few sensor nodes to hundreds or thousands of such modules in water networks of large cities and megacities, divided in a separate zones with an area of 80-100 km2. The wireless data transmission system (Fig. 7) ensures constant communication between the pumping stations (PS), tanks and DC in the administration building [1, 3, 4].

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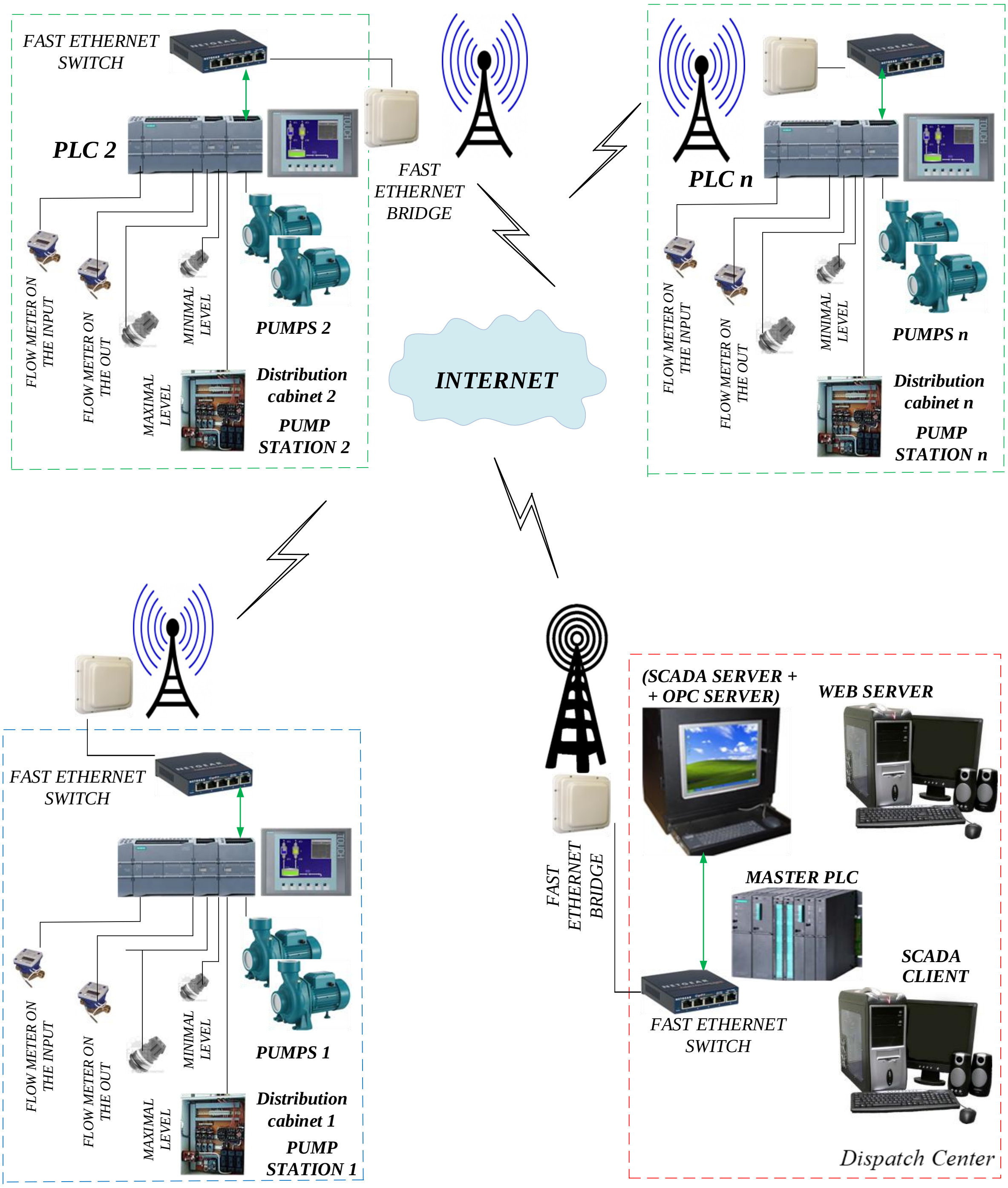

Fig. 7. *Block diagram of the control and supervision system of pumping stations*

Controllable Fast Ethernet L2 switches for connecting equipment, which have Fast Ethernet ports with a speed of 10/100MB/s, are installed in the PS cabinets. The wireless bridge connects the Fast Ethernet switch in PS with the Fast Ethernet switch in DC via a wireless link. The connection between the wireless bridge and the POE (power over ethernet) element in the distribution cabinet PS is made with an STP cable (a twisted pair of shielded conductors). The wireless bridge is connected by an antenna cable to an integrated panel antenna [1, 5].

CONCLUSION

The paper presents the configuration of the control-supervision system of waterwork complex, which enables real-time control, where relevant process variables and parameters are measured, certain controller settings and data transmission are performed. The information system enables the prediction of certain events through the acquisition, processing and analysis of data, which ensures optimal exploitation of the water supply system. The SCADA system enables the detection of faults, information on the working conditions and the state of devices and equipment of remote objects, which gives the possibility to send a signal about the location of the fault and the possible cause, which enables a quick reaction of the operator and the maintenance service in order to solve the problem that has arisen (e.g. cracking pipeline, electrical and/or mechanical failures or major emergency situations). In this way, the downtime in the water supply is reduced. The advantage of using the SCADA system is reflected in the achievement of a certain level of services, especially in relation to the quality of water distributed to clients and the maintenance of constant flow and pressure in the supply network. SCADA also contributes to the optimal dosing of chemicals (aluminum sulfate, chlorine) needed to achieve a certain level of water quality, optimization of pumping plants operation, flow and pressure control-in a word, reliable operation and efficiency of the entire water supply system. Without the application of modern control and monitoring systems, dynamic management and continuous monitoring of water supply systems is impossible. SCADA systems have become a standard in the management, exploitation and optimization of water and sewage systems, whereby installed devices and equipment are monitored in real time as well as the relevant parameters of individual zones. It is possible to inform clients about upcoming interruptions in water supply via SMS messages. SCADA software is based on an open platform and uses standard industry formats such as OPC, HTTP/XML with client server architecture, Web server that enables control and monitoring via the Web.

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THE EXAMINATION OF OPERATIONAL CONDITION THROUGH THE VOLUMETRIC EFFICIENCY OF AN AXIAL PISTON PUMP

Research paper

Borivoj Novaković[1*], Luka Đorđević[2], Ljiljana Radovanović[3], Mihalj Bakator[4], Milan Marković[5], Stefan Ugrinov[6], Mića Đurđev[7]
University of Novi Sad, Technical faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Abstract: The examination of the operational condition of axial piston pumps through the measurement of volumetric efficiency is a key aspect in assessing their performance and reliability. Volumetric efficiency is defined as the ratio of the actual flow rate of the pump to the theoretical flow rate and is directly influenced by internal losses due to leakage and compression. This parameter enables a detailed analysis of the condition of pump components, such as pistons, cylinder block, and valves, and indicates potential defects or the need for maintenance. The paper examines methods for measuring volumetric efficiency, as well as the impact of various operational conditions, including changes in pressure, fluid viscosity, and rotational speed. The aim of the research is to establish standards for assessing pump condition and to propose optimal methods for diagnostics and maintenance, with an emphasis on improving the durability and efficiency of axial piston pumps in various industrial applications.
Key words: Axial piston pumps, volumetric efficiency, diagnostics, hydraulic.

INTRODUCTION

Hydraulic systems are among the most complex systems in industrial applications, characterized by the precision and accuracy required from each component to ensure optimal performance. Any deviation from the ideal functioning of these components directly affects the overall system output. One of the most significant challenges in high-capacity hydraulic systems is leakage. While certain leaks are permissible and accounted for in the design of system components, there are also non-standard leaks that are undesirable and must be prevented. When such leaks occur, it is essential to identify and analyze the underlying causes to mitigate potential issues, [1]. Drive units of large hydraulic systems, such as hydraulic presses, typically consist of a combination of electric motors and various types of pumps, selected based on the capacity of the presses. In applications where higher hydraulic fluid flow rates are required, axial piston pumps are commonly used. Conversely, for lower to medium flow demands, gear or vane pumps are often employed , [2]. Axial piston pumps are extensively utilized in high-power systems due to their capability to deliver a consistent flow and high pressure with exceptional efficiency. These pumps are designed to withstand demanding operational conditions, making them ideal for applications that require precise control and reliability. Their advanced design minimizes energy losses, ensuring optimal performance and contributing to the overall efficiency of hydraulic systems, [3].
The reliability and accuracy of hydraulic pumps, as essential drive units, have been extensively studied in papers [4, 5], where their significance for the proper functioning of supporting system components is highlighted. The occurrence of cavitation due to pump suction issues, along with hydraulic shocks, can severely compromise the integrity of other components, potentially leading to serious damage, increased leakage, and a shortened operational lifespan of the system. These phenomena therefore require careful analysis to ensure the longevity and efficiency of the overall hydraulic system.
in hydraulic systems, the basic parameters for the importance of system operation that are monitored are pressures, flows, temperature, fluid viscosities [6-8].

[1]Corresponding author, borivojnovakovic@tfzr.rs, ORCID: https://orcid.org/0000-0003-2816-3584
[2]luka.djordjevic@tfzr.rs,: ORCID: https://orcid.org/0000-0003-4578-9060
[3]ljiljana.radovanovic@tfzr.rs, ORCID: https://orcid.org/0000-0002-5234-4820
[4]mihalj.bakator@tfzr.rs, ORCID: https://orcid.org/0000-0001-8540-2460
[5]milan.markovic@tfzr.rs, ORCID: https://orcid.org/0009-0007-8130-7467
[6]stefan.ugrinov@tfzr.rs, ORCID: https://orcid.org/0009-0000-7206-655X
[7]mica.djurdjev@tfzr.rs, ORCID: https://orcid.org/0000-0002-1825-2754

MATERIAL AND METHODS

To evaluate the volumetric efficiency of hydraulic axial piston pumps, a flow turbine was used to measure the flow rate over time at specified operating pressures. The testing was conducted using the Parker Service Master Easy, model SCM-340-2-02, which served as the primary measurement device. The operating principle of this device is based on the use of sensors to measure flow, pressure, and temperature of hydraulic fluids in real-time. By utilizing a flow turbine and other sensors, the device records values that allow for the assessment of operational parameters, such as volumetric efficiency, to identify potential anomalies within the system. Measurements are displayed on the device's screen, and the data can be recorded and analyzed for further diagnostic purposes, facilitating a comprehensive evaluation of the system's performance.
The technical characteristics of this device and the measuring range are:

- flow: $8 \div 300\ \frac{l}{min}$,
- operating pressure: $350\ bar$,
- accuracy: $\pm 1\ IR$,
- fluid temperature rate: $-20 \div 90\ ^{\circ}C$.

EVALUATION OF THE VOLUMETRIC EFFICIENCY OF AN AXIAL PISTON PUMP

PQT test

Before commencing the testing procedure, it is essential to ensure that the hydraulic system is functioning correctly and that all connections are securely tightened. The system must be purged of air to avoid measurement errors, thereby stabilizing operating conditions and ensuring precise readings. The Parker Service Master Easy device is connected to the system through appropriate sensors. A flow turbine is installed in the line where the hydraulic fluid flow rate is measured, while pressure and temperature sensors are mounted at designated positions within the system. Proper sensor installation is critical to obtaining accurate data for subsequent analysis. Once all sensors are connected, the device is powered on and calibrated according to the manufacturer's recommendations. The pump is then operated under specified pressures and speeds to simulate various working conditions, allowing realistic testing under different loads that the pump may encounter during operation. The device continuously monitors and records flow, pressure, and temperature values of the hydraulic fluid in real-time. These parameters are crucial for calculating the pump's volumetric efficiency, providing an accurate assessment of the pump's performance under different conditions. Real-time data acquisition ensures a comprehensive evaluation of the pump's behavior. Based on the collected data, the device calculates the volumetric efficiency of the pump as the ratio between actual and theoretical flow rates under varying operating conditions. This calculation enables the identification of internal losses within the system and an evaluation of the component's operational state. All collected data is stored and can be analyzed using the built-in software or exported to a computer for more detailed diagnostics. This analysis helps identify potential anomalies, such as reduced efficiency, leaks, or abnormal operating behavior of the pump. Detailed analysis facilitates early problem detection and optimization of operating parameters. Upon completion of the testing, the results are reviewed and documented in a report that includes an assessment of the pump's condition and recommendations for any necessary maintenance or repairs. The report is crucial for making informed decisions about ongoing maintenance and improving the performance of the hydraulic system. This methodology provides a precise evaluation of the pump's operational parameters, contributing to the optimization of performance and maintenance of the hydraulic system.

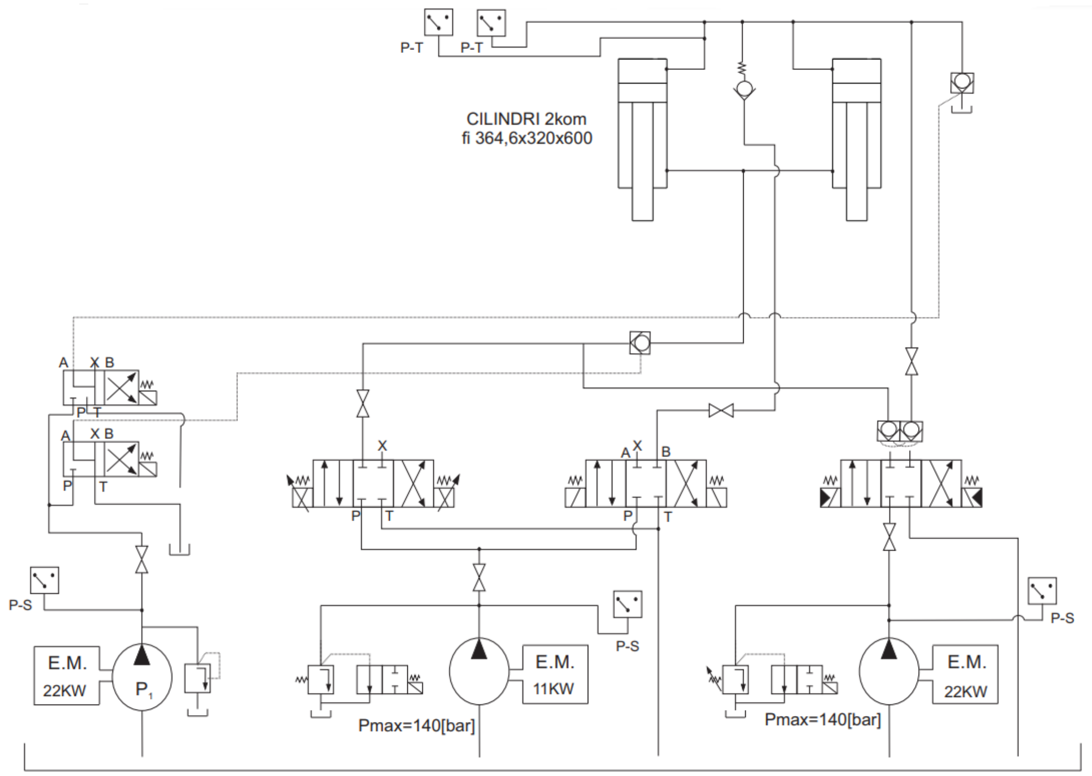

Fig. 1. *Hydraulic scheme of the hydraulic press system*

Figure 2 shows a cross-section of an axial piston hydraulic pump, with all its constituent components displayed.

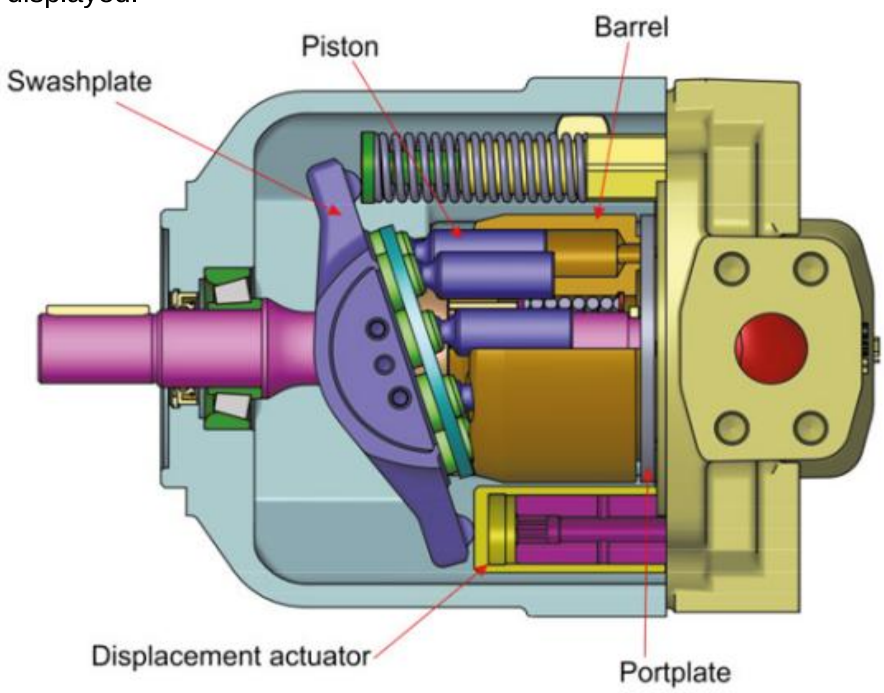

Fig. 2. *Cross-section of an axial piston hydraulic pump [3]*

Figure 3 illustrates the evaluation of the hydraulic axial piston pump through the PQT test.

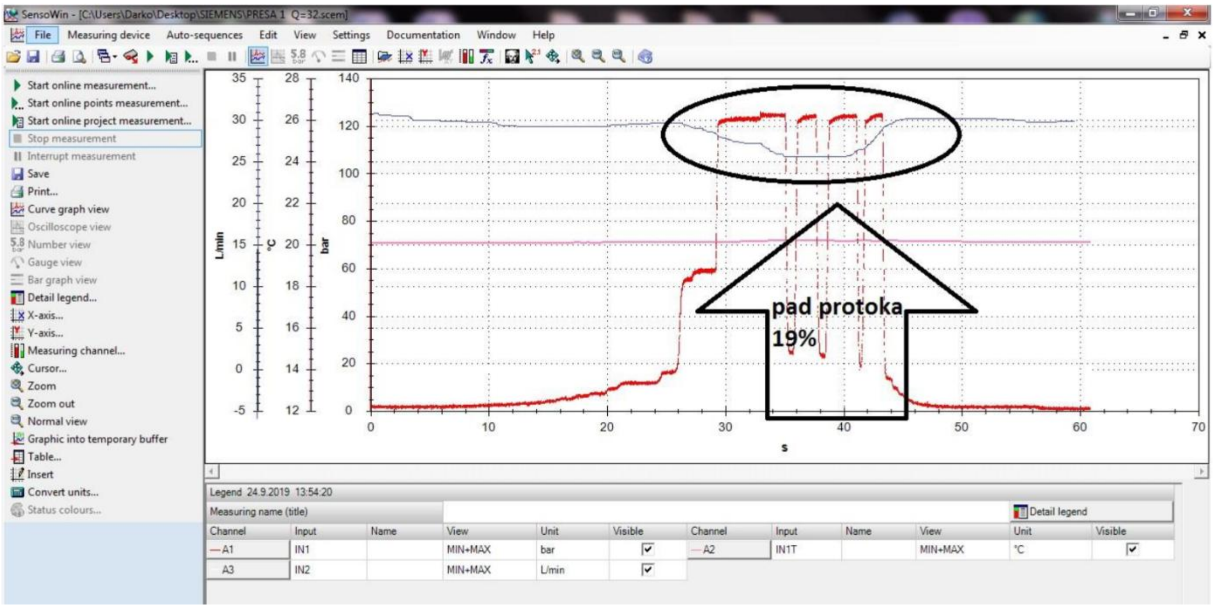

Fig. 3. *PQT diagram*

The diagram presents measurement results of an axial piston pump operating in a hydraulic system, where the y-axis represents the flow rate in liters per minute (L/min), and the x-axis shows time in seconds (s). The red curve indicates variations in flow over time, with clearly observed fluctuations in the middle section of the diagram. A 19% decrease in flow rate, occurring during a pressure increase, is particularly marked. This change indicates a complex interaction between pressure and flow in axial piston pumps.

An increase in system pressure typically leads to additional load on the pump, resulting in a reduction in flow rate. Axial piston pumps are designed to provide a consistent flow, but increased system resistance due to higher pressure can lead to performance degradation. In the diagram, this phenomenon manifests as a 19% drop in flow rate, a significant decrease that underscores the need for a detailed analysis of the underlying causes of these changes.

One possible reason for the flow reduction is a decrease in the volumetric efficiency of the pump at higher pressures. This could be caused by internal fluid leakage within the system or saturation of the pump chambers, leading to a reduced volume of fluid transported per cycle. Additionally, the presence of control mechanisms within the pump may contribute to the flow reduction as a response to the pressure increase, in order to prevent overload or mechanical failure.

Flow fluctuations at several points in the diagram highlight the complexity of the pressure and flow regulation process. These disturbances may be caused by nonlinear system behavior under high loads, necessitating further analysis to identify precise causes and propose measures to improve flow stability. Overall, the diagram illustrates how increased pressure can adversely affect flow in axial piston pumps, emphasizing the need to optimize operational parameters to minimize losses and improve system efficiency.

Table 1. Flow rate dependence on pressure for an axial-piston pump

Time (s)	Pressure (bar)	Flow (l/min)	Flow drop (%)
0	10	32,5	0
10	50	31,74	2,5
20	60	31,23	4
30	80	30,65	6,5
40	120	26,85	17
50	140	26,30	19

The volumetric efficiency of pumps that have been in operation for a certain period tolerates a threshold of 0.92, meaning that an allowable flow rate reduction can be up to 8%. Any decrease beyond this limit would be considered inefficient, which is the case in this example.

The reduction in flow rate in an axial piston pump under increasing pressure is attributed to several factors related to the mechanical loads within the system. Primarily, as the pressure rises, there is increased resistance on the pistons and cylinders, which affects the pump's volumetric efficiency. Higher pressure requires more power to displace the fluid, leading to internal leakage and a decrease in effective flow rate. This leakage, occurring between the pistons and cylinders, reduces the overall amount of fluid passing through the pump, directly impacting system performance.

One of the main reasons for the decrease in flow rate under high pressures is the reduced efficiency of the fluid displacement chambers. The pressure causes deformation and potential saturation of the chambers, thereby reducing the volume of fluid transported per cycle. Additionally, limitations in the pump's suction system can exacerbate the issue, as under high pressures, the pump's suction capacity may become inadequate, leading to cavitation or a significant drop in volumetric efficiency.

To maintain optimal pump functionality and mitigate the risk of reduced flow, special attention must be given to certain components during regular maintenance. Pistons and cylinders, as key elements in the fluid compression process, should be routinely inspected for signs of wear or damage that may lead to leakage. Moreover, seals and gaskets play a critical role in preventing fluid leakage, and their timely replacement is essential for preserving the system's integrity.

In addition, inlet and outlet valves must function properly to ensure unobstructed fluid flow and prevent irregularities in the pump's operation. Lastly, bearings and rotational components, which endure significant loads, must be well-maintained and lubricated to minimize friction and wear. Regular maintenance of these critical parts is essential for ensuring the long-term performance and efficiency of axial piston pumps when operating under high-pressure conditions.

CONCLUSION

The results of this research highlight the crucial role of diagnostics in the maintenance and optimization of axial piston pumps, as well as other hydraulic components. Measuring volumetric efficiency serves as one of the most important indicators of pump condition, enabling a precise analysis of their performance and the timely detection of potential failures. The reduction in flow under high pressure conditions directly points to internal losses caused by fluid leakage and compression within the system, which can significantly impact the performance of the pumps and the overall hydraulic system.

The critical importance of pump diagnostics lies in the ability to detect anomalies early, which, if left unnoticed, could lead to severe failures, such as mechanical damage to pistons, cylinders, and seals, resulting in reduced efficiency and a shortened operational lifespan. Additionally, diagnostics contribute to identifying flow instabilities, such as fluctuations caused by nonlinear behavior under heavy loads. These fluctuations underline the necessity of precise monitoring of pressure and flow, as well as the importance of proper system regulation and maintenance.

Regular monitoring of key operational parameters, such as pressure, temperature, and flow, significantly contributes to optimizing working conditions and ensuring the reliability of hydraulic systems. The inspection of critical components, including pistons, cylinders, seals, and valves, allows for the preventive replacement of damaged parts, thereby preventing potential losses and extending the system's service life. This approach not only enhances pump efficiency but also reduces operational costs and increases safety in industrial applications.

In conclusion, precise diagnostics and adequate maintenance are vital for the long-term operation and stability of hydraulic systems, enabling their optimal performance under varying load conditions and in diverse applications.

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AUTOMATED DECISION SUPPORT SYSTEMS

Review paper

Sondra Preascilla Ioana Vacarescu[1,2], Nicolae Paraschiv[1], Flavius-Maxim Petcuț[3]
[1]Petroleum-Gas University of Ploiesti, Romania
[2]Continental Automotive Romania
[3]Aurel Vlaicu University of Arad, Romania

Abstract: This paper presents an analysis of automated decision support systems (ADSS) that are revolutionizing the landscape of data-driven decision-making across various scientific domains. This article explores the architecture, and applications of ADSS, emphasizing their role in increasing accuracy, efficiency, in numerous complex decision processes. The key algorithms are reviewed, including machine learning and artificial intelligence, that discuss their integration within big data analytics and real-time data processing. Case studies from fields such as automotive, illustrate the transformative potential of ADSS in tackling multifaceted problems. Additionally, challenges are highlighted related to data quality, ethical considerations, and the need for transparency in automated requirements. These findings underscore the importance of interdisciplinary collaboration in advancing ADSS capabilities, ultimately fostering improved outcomes in research and practice. The paper concludes with recommendations for future research directions and the potential evolution of ADSS in a rapidly changing technological landscape.
Key words: automated decisions support systems, artificial intelligence.

INTRODUCTION

Starting in the 1960s, researchers began systematic studies on the use of computer models to facilitate automated planning and decision-making. In 1964, the concept of decision support for interactive management was developed, tested, and implemented by Andre McCosh at Harvard Business School. The study continued, and in 1966, analytical models were examined to assist managers in the decision-making process related to business planning. The system was tested and validated through an experiment involving managers from production and marketing. The experiment utilized a Management Decision System (MDS) to coordinate and plan the production of laundry equipment, as shown in Fig. 1.
By 1980, research highlighted that decision support systems were terms within the realm of generic operations. Following another study involving 56 DSS, these systems were ultimately classified into seven distinct types [1,2,3]:

- File drawer systems with data access.
- Analytical systems that facilitate data processing through computers.
- Analytical systems with access to multiple decision-oriented databases and small models.
- Financial models that estimate the consequences of potential actions.
- Simulation models capable of predicting potential actions.
- Optimization models that provide optimal solutions in accordance with existing constraints.
- Models regarding potential solutions based on logical data processing with the specific goal of providing a specific decision [4].

[1] Corresponding author, sondra-preasilla-ioana@upg-ploiesti.ro, ORCID: https://orcid.org/0009-0000-5450-5272
[2] nparaschiv@upg-ploiesti.ro, https://orcid.org/0000-0002-8923-0966
[3] flavius.petcut@uav.ro, https://orcid.org/0009-0001-6928-4019

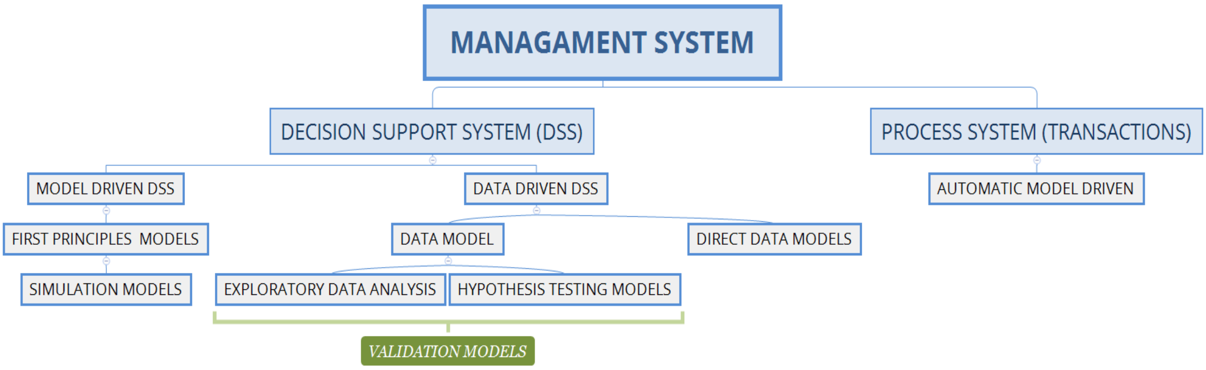

Fig. 1. *Automated Decision Support System*

The automotive industry in the era of Industry 4.0 is experiencing significant technological expansion, leading to the integration of advanced digital technologies and data analytics.
A critical process shaping this sector is the implementation of automated decision support systems (DSS).
These systems leverage artificial intelligence (AI), machine learning, and big data analytics to enhance decision-making processes across various aspects of design and production. The primary goals of automated decision-making systems in the automotive sector are to optimize efficiency, improve quality, and accelerate innovation.
By analyzing real-time data and providing predictive insights, these support systems can offer optimal solutions and reliable actions, helping manufacturers streamline production, reduce downtime, and enhance process performance in both design and manufacturing phases.
Automated decision-making systems play a crucial role in the development of autonomous vehicles, where vast amounts of data from sensors are processed to make decisions in fractions of a second, ensuring safety and efficiency for passengers and end consumers.
Additionally, decision support systems can assist in the supply chain by forecasting demand, managing inventory, and optimizing logistics. The significant advantage of these systems is their ability to enable more agile production that adapts to the dynamic demands of the market and consumer preferences.
As the automotive industry continues to expand, automated decision-making systems are becoming an integral component of technological advancement in vehicle development, manufacturing processes, and operational excellence.

Quality in the Automotive Industry of Industry 4.0

According to the ISO 9000:2015 standard, quality is the ability of a product or service to meet customer requirements and expectations regarding performance, durability, appearance, and usability or purpose. Quality is a critical factor in any organization. Given the dynamics of the automotive industry and the expansion of the market economy, the demands for quality and delivered services must strictly adhere to the requirements of the international quality standard. This includes the following:
Compliance with Specifications refers to the percentage of coverage of the product or service against the specifications and standards imposed by the design center.
Usability Compatibility: This involves assessing the product or service in relation to the needs and expectations of the end user. It aims to observe both the performance of the product or service and their reliability under real-world conditions over time.
Stability: Quality imposes a consistently high level of performance relative to defined evaluation indicators. In mass production, this involves stable processes, controllable costs, and minimal variations regarding disruptions, with minimal changes over time [5].
Customer Satisfaction: Performance indicators for delivered products and services are evaluated monthly in the automotive industry, typically through customer portals. Meeting quality standards and, implicitly, customer requirements is reflected in scorecards.

In conclusion, quality is an overarching characteristic that encompasses adherence to standards, customer satisfaction, stability of processes and delivered services, reliability, and overall performance [6].
With the emergence of advanced technologies in the era of Industry 4.0, the automotive sector has increasingly adopted these technologies to improve the problem-solving process associated with non-quality issues. Artificial intelligence, machine learning, and big data analytics have revolutionized traditional approaches, providing real-time data analysis, necessary predictions, and automated decision-making processes.
The use of automated decision-making systems for handling complaints offers a range of advantages compared to traditional analysis systems (see Fig. 2) [7]:

- Automation: Automated systems can process requests faster than manual systems. The algorithms and associated software can analyze large volumes of complaints, reducing processing time and positively impacting response times in customer portals.
- Error Reduction: Automated systems decrease the likelihood of human error. The algorithms used can identify patterns and discrepancies with high accuracy.
- Manual Systems: Manual processing can lead to errors due to fatigue and subjective judgment. Consistency may vary depending on the individual processor.

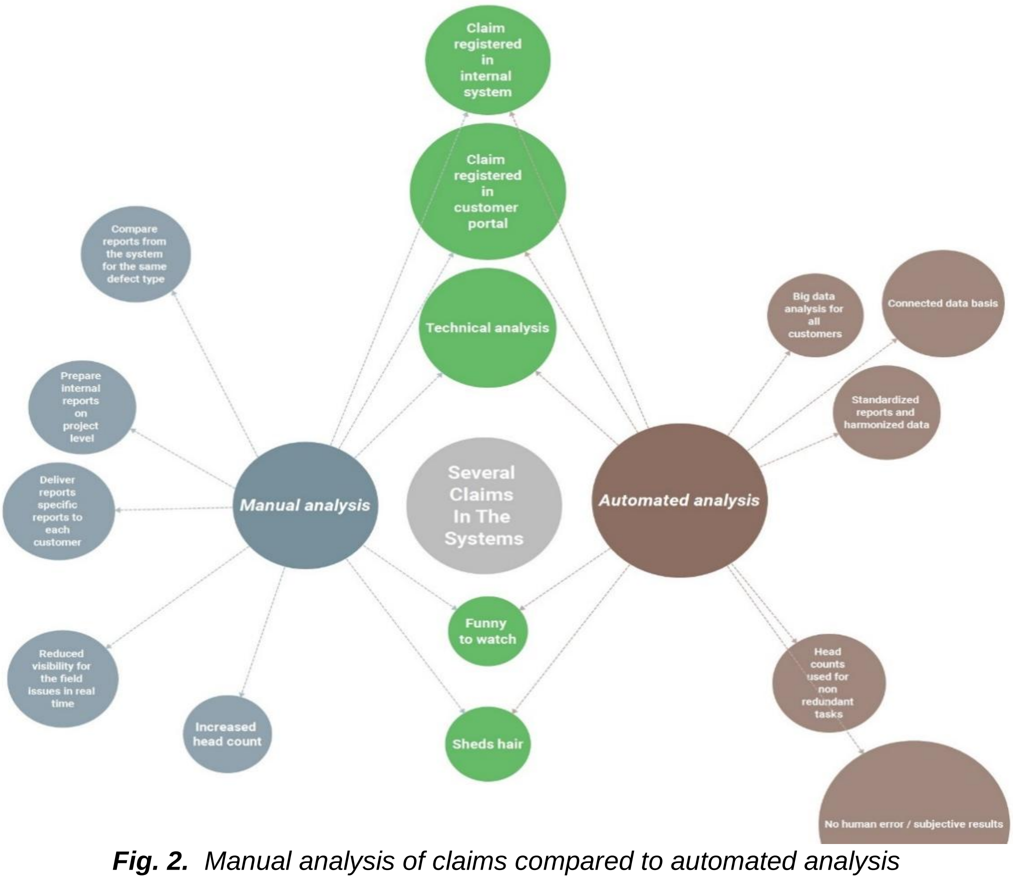

Fig. 2. *Manual analysis of claims compared to automated analysis*

Steps for Quality Assurance in the Implementation of Artificial Intelligence

The study conducted by Haller details the structuring and proactive management of quality assurance through the analysis of the following topics [8]:

- Quality Assurance Stages: These define a structured process in which the order of projects establishes how quality metrics will be calculated based on data. These stages ensure a smooth integration of projects for the implementation of artificial intelligence.
- Monitoring Model: This continuously checks whether the artificial intelligence algorithms provide reasonable quality in predictions and classifications over time after implementation.

- Data Quality: This reflects the significant impact that high-quality data has on the predictions and classifications of trained AI models.
- Integration Testing: This verifies whether the artificial intelligence algorithms interact correctly within the system.

Figure 3 represents the dependencies of these classifications.

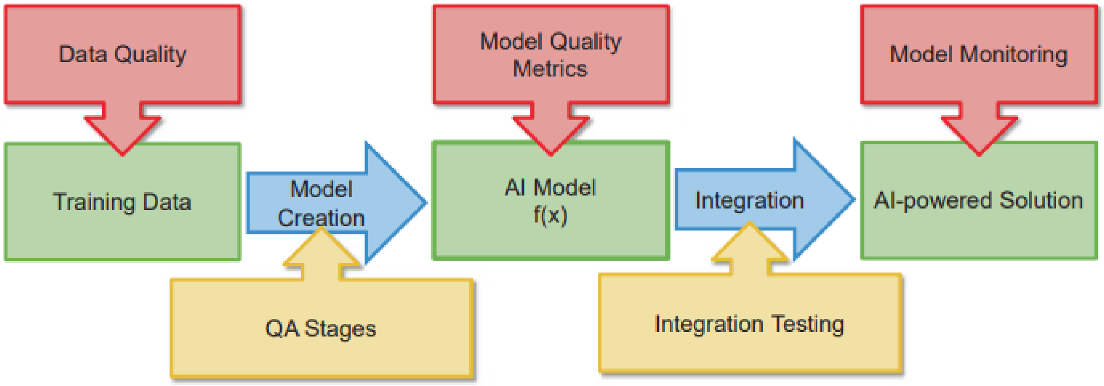

Fig. 3. *Quality Assurance and Artificial Intelligence – An Overview*
https://link.springer.com/chapter/10.1007/978-1-4842-7824-6_3

Figure 3 illustrates a structured quality assurance process for artificial intelligence algorithms. Achieving an optimal algorithm involves starting with multiple classification models. Ultimately, the chosen model goes through testing and validation stages, see Fig. 4.

Fig. 4. *Representation of Quality Assurance in Relation to the Implementation of Artificial Intelligence Algorithms*
https://medium.com/@lilian.swen/data-pipeline-in-production-ml-e83dc1d93328

To achieve the objective regarding my doctoral thesis on Automated Decision Support Systems in Quality within the Automotive Industry, I believe that research must be conducted in several areas to cover the interdisciplinary nature of the developments I will propose in this thesis.
In this context, I consider it necessary to direct the research towards the following fields:

- Automated Systems Engineering
- Classification Algorithms
- Decision Support Systems
- Neural Networks

Automated Systems Engineering:
These systems are designed to perform tasks or processes without continuous human intervention, using specific technologies. The systemic characterization will be based on the definition provided by L. Zadeh of the concept of a system, namely "an abstract object characterized by the connection of pairs of input-output magnitudes" [9].

Classification Algorithms:
The classification algorithms for input magnitudes will be represented in Fig. 5.

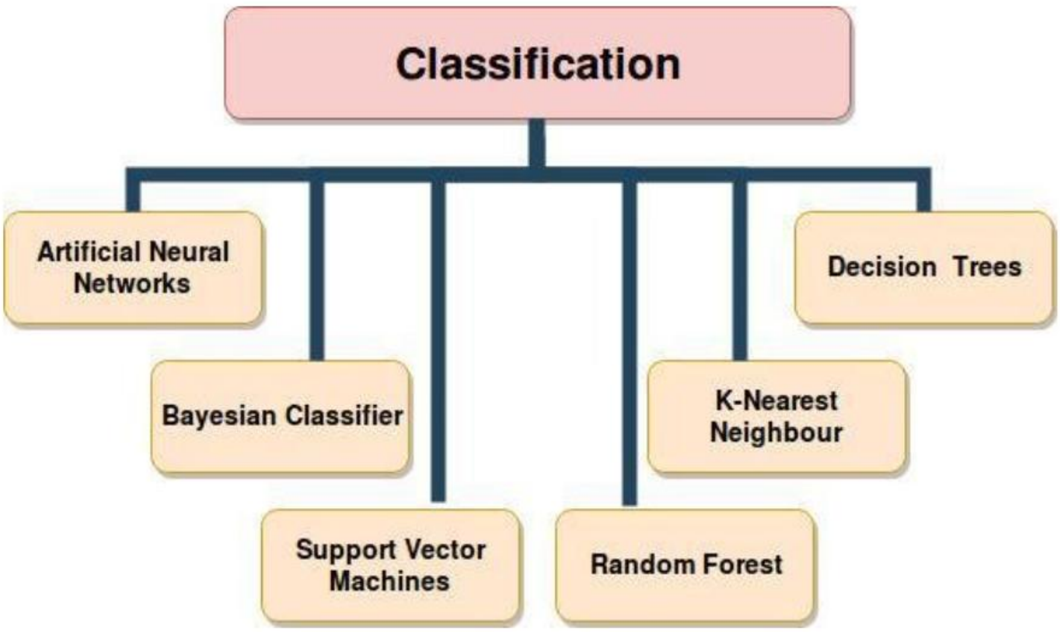

Fig. 5. *Classification Algorithms*
https://www.researchgate.net/figure/Taxonomy-of-Classification-Algorithms_fig3_340314328

Naive Bayes is a classification algorithm based on Bayes' theorem.
It is considered a prompt algorithm that processes both discrete and continuous data, providing real-time predictions.
Decision Trees represent a top-down modeling approach. Decisions provide rules for classifying data.
Support Vector Machine (SVM) uses a binary classification technique that employs training data to predict an optimal hyperplane in an n-dimensional vector space [10,11,12].
Random Forest is a machine learning algorithm based on an ensemble learning approach. The algorithm builds a forest of random decision trees and executes the pruning process with stopping intervals for the expected results. Random Forest algorithms are integrated using the bagging technique for decision-making [10].
K-Nearest Neighbors (KNN): Through the KNN algorithm, an object is assigned to a class based on its neighbors.

Decision Support Systems:
Decision support systems are related to expert systems, Business Intelligence, OLAP, and Executive Information Systems [14].
Types of Decision Support Systems:

- Model-based decision support systems
- Data-based decision support systems
- Document-based decision support systems
- Knowledge-based decision support systems

Decision support systems in industry can be represented in Figure 6 below, where the aforementioned classifications are encountered in daily applications.

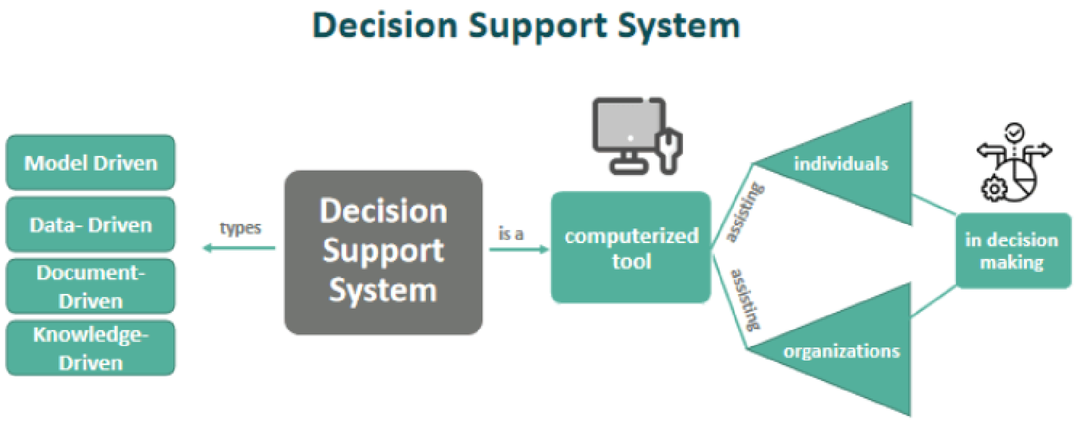

Fig. 6. Decision Support System
https://www.wallstreetmojo.com/decision-support-system/

Neural Networks
Neural networks represent a subclass of machine learning based on the structure and functioning of the human brain. They are primarily found in industry, where they can be used to model and solve complex problems in areas such as image recognition, natural language processing, and prediction.

Types of Neural Networks:

- Convolutional Neural Networks (CNN): Specialized in image processing and visual recognition.
- Recurrent Neural Networks (RNN): Used for sequential data and natural language processing.
- Generative Adversarial Networks (GAN): Used for generating new data similar to the training data.

CONCLUSION

Given the complexity of products and processes—starting from the quotation phase, including the design and development of products, and concluding with industrialization, project launch into series production, and delivery to end customers—we can conclude that the multitude of data does not reside in the same database. This leads to cumbersome analysis, both technically and in terms of costs associated with the technical details of disruptions that may occur during the delivery of products, both in the series phase and as spare parts.
In the field of quality, performance indicators for production processes are monitored, including first pass yield, costs associated with internal rejections, and costs related to complaints from vehicle manufacturers (0 km) and field complaints.
It is noteworthy that these costs are significant in the automotive industry, and the lack of implementation of classification algorithms for data based on the type of defect, the conditions under which defects occurred, geographical area, and correlation with a complete analysis of an 8D report, including root causes and corresponding technical and systemic actions, results in predictions not occurring as promptly as possible.
I aim to develop classification, prediction, and regression algorithms that will analyze data and correlate defects from vehicle manufacturers with internal data, ensuring customer satisfaction is achieved, costs are reduced, and processes are optimized.

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DEVELOPMENT OF SUPPORT VECTOR MACHINE MODEL FOR CHIP FORM CLASSIFICATION IN TURNING OF POM-C

Research paper

Miloš Madić[1*], Milan Trifunović[2], Marko Kovačević[3]
[1,2]University of Niš, Faculty of Mechanical Engineering in Niš, Niš, Serbia
[3]Independent researcher, University of Niš, Niš, Serbia

Abstract: Chip form is considered as important turning process performance measure. It is the prevalent criteria for the evaluation of industrial plastics machinability. Chips of unfavourable forms also create difficulties in production, such as stopping of the machine tool and damage to the machined surface. This factor is influenced by the cutting parameters in turning, which are the depth of cut, feed rate and cutting speed. This study focuses on the development of optimized support vector machine model for binary classification of chip forms in turning of commonly used industrial plastic, unreinforced polyoxymethylene copolymer POM-C.
Key words: turning, chip, form, classification, POM-C, PCD, support vector machine

INTRODUCTION

Turning is considered the oldest and most widespread method of material processing. It is a machining method in which the material is removed from the surface of a rotating workpiece by using a single-point cutting tool. Resulting geometry is determined by the feed trajectory of the cutting tool. Several process performance measures, such as cutting forces, cutting power, surface roughness, part accuracy, tool wear, tool life, chip form, and chip breakability, are commonly associated with machining performance for turning [1]. They are influenced, alone or in interaction, by the main input parameters of the turning process, that include parameters related to the machining process (depth of cut, feed rate and cutting speed), parameters related to the cutting tool geometry (rake angle, tool nose radius and cutting edge angle), cutting tool material, and workpiece material. Therefore, numerous investigations and studies analysed the influence of input parameters on surface roughness [2,3], dimensional accuracy [4,5], cutting forces [6,7], tool wear [8,9], tool life [10,11], cutting power [12], and chip formation [13,14].
Chips of unfavourable forms often create difficulties, such as stopping of the machine tool, cutting tool breakage, and damage to the machined surface. Chip form is the prevalent criteria for the evaluation of industrial plastics machinability [15]. This study focuses on the classification of chip forms generated by turning of unreinforced polyoxymethylene copolymer (POM-C), using a cutting tool made of polycrystalline diamond (PCD). Support vector machine (SVM) model was developed for the classification.

MATERIAL AND METHODS

The material used in the experiment was commonly used industrial plastic, unreinforced polyoxymethylene copolymer POM-C. Longitudinal turning experiment was conducted on a universal lathe machine POTISJE PA-C 30 with the motor power of P_m = 11 kW and spindle speed range of n = 20 – 2400 rpm, in dry machining environment, in accordance with recent trends [16]. Stock was in the form of bar, with a diameter of 100 mm.
The cutting tool was a toolholder Sandvik Coromant SVJBR 3225P 16 with a Walter VCGT160408FS-1 PCD insert. Cutting parameter ranges were selected considering industrial plastics machining recommendations, machine tool characteristics and recommended cutting conditions for the insert. The minimal and maximal depth of cut values were set to 1 and 4 mm, respectively, the minimal and maximal feed rate values were set to 0.049 and 0.392 mm/rev, respectively, while the minimal and maximal selected cutting speed values were set to 188.5

[1] Corresponding author, milos.madic@masfak.ni.ac.rs, ORCID: https://orcid.org/0000-0002-2310-2590
[2] milan.trifunovic@masfak.ni.ac.rs, ORCID: https://orcid.org/0000-0002-4653-6957
[3] marko.kovacevic@iteacake.com, ORCID: https://orcid.org/0009-0000-6190-6664

and 510.5 m/min, respectively. Full factorial design was applied to define experimental hyper-space, wherein depth of cut and feed rate were varied at five levels, while cutting speed was varied at three levels. The total number of different cutting conditions that were realised in the experiment was 75. Chips from each experimental trial were collected and their forms classified as favourable or unfavourable according to ISO 3685-1977 standard.

For the purposes of developing classifier for binary classification (favourable and unfavourable chip form) of experimental data, SVM model was developed. SVM uses supervised training paradigm to determine optimal hyperplane (decision boundary) that maximizes the margin (distance) between data points in different classes. This is achieved by finding the support vectors with the highest distance between the nearest points of each class [17], which ultimately define the position and orientation of the decision boundary. Initially, linear SVM was attempted. However, due to unsatisfactory results, grid search algorithm [18] for SVM optimization of hyper-parameters was performed. All data processing and SVM model development were conducted using the Python language in Visual Studio Code. Experimental data was divided into training (70%) and test (30%) data sets, while the SVM model was trained with different values of hyper-parameters: regularization parameter (C) = [0.1, 1, 10, 100, 1000]; kernel = [linear, poly, rbf, sigmoid]; degree = [2, 3, 4]; γ = [0.001, 0.001, 0.01, 0.1, 1]. SVM model with RBF kernel and model hyperparameters C = 1000 and γ = 0.01 showed best performance for the given data. Due to effective training, SVM model achieved classification accuracy of 96% on entire data set. Although there was limited experimental data, SVM model proved to be able to learn adequately underlying patterns and exhibited high accuracy, which is not uncommon in manufacturing practice [19].

RESULTS AND DISCUSSION

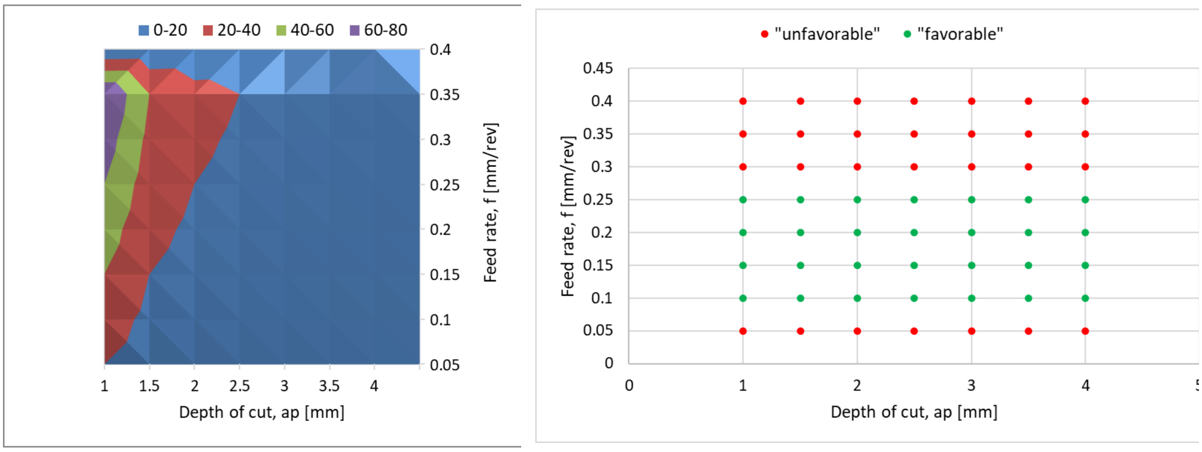
The developed SVM model was trained with two classes of chip (favourable and unfavourable) using experimentally obtained data. By using the grid search algorithm, optimized values of hyper-parameters were determined, resulting in SVM model of very high accuracy. Therefore, the developed machine learning model can be used for engineering analysis and derivation of the corresponding conclusions.

The permutation importance algorithm [20] was performed in order to assess the significance of the input parameters in SVM classifier. The main idea is to monitor the change in model's performance while randomly shuffling (permuting) values of a given input parameter and keeping constant values of all other inputs. In the present study, permutation importance algorithm was performed on training set. The obtained results indicated that the most crucial and informative input parameter was the feed rate, while depth of cut and cutting speed were found to be much less important. The derived observations coincided with observations of Leppert [21] who identified the feed rate as a parameter of greatest influence on the chip form, while the cutting speed and depth of cut had considerable smaller influence on the chip form in turning of carbon steel C45 and austenitic stainless steel X2CrNiMo under different cooling and lubrication conditions. From the conducted experimental trials, it could be observed that with an increase in the chip slenderness ratio (ratio of the depth of cut and feed rate), especially for low feed rates, a strip-like chip (unfavourable) tends to be formed. On the other hand, very low chip slenderness ratio results in small-sized dust-like chips (also unfavourable). Examples of chip forms generated under extreme cutting conditions are given in Fig. 1.

a) b)

Fig. 1. *Chip forms under different conditions: a) slenderness ratio 2.55, b) slenderness ratio 81.63*

Although chip slenderness ratio can be solely used as an indicator of machinability in turning metallic materials, with regards to the resulting chip morphology, in the present study one cannot distinguish favourable and unfavourable chips using only this indicator (Fig. 2 a)). Therefore, for the covered experimental hyper-space, the developed SVM model was used to predict the favourable and unfavourable cutting conditions (Fig. 2 b)).



a) b)

Fig. 2. *Change of: a) chip slenderness ratio, b) chip form*

It has to be noted that Fig. 2 b) was developed for the constant cutting speed of *v* = 188.5 m/min. Very similar patterns, almost identical, were obtained by changing the cutting speed from *v* = 188.5 m/min to *v* = 345.6 m/min, and further to *v* = 510.5 m/min. When the cutting speed was set at the highest level, the process window for obtaining favourable chip forms was somewhat diminished.

CONCLUSION

In the present study optimized SVM model for binary classification of chip forms in turning POM-C was developed. The feature vector consisted of three important cutting parameters, such as the feed rate, depth of cut and cutting speed. Based on obtained results and performed analyses the following conclusions may be drawn:

- RBF-SVM model with optimized hyper-parameters proved to be able to perfectly distinguish two classes of resulting chip forms in turning of POM-C.
- Feed rate is the most important parameter regarding chip form, while the effects of depth of cut and cutting speed are much less pronounced.
- Unlike turning of metallic materials, chip formation cannot be exactly quantified using solely chip slenderness ratio.
- Favourable chip forms can be obtained for all investigated depths of cut (1 to 4 mm) provided that the feed rate varies from 0.1 to 0.25 mm/rev.

The developed SVM model can be used in parallel with other important performance models so as to plan machining processes more effectively.

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RISK ANALYSIS USING THE INTEGRATED FTA AND FMEA MODEL ON THE EXAMPLE OF A BIOGAS PLANT

Review paper

Jovana Radnović[1], Vesna Makitan[2]
[1,2]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: Risk is present everywhere and all organizations have to face the risk. This paper presents the importance of risk as a daily occurrence in project risk management. Using the integrated model of fault tree analysis (FTA) and failure mode and effect analysis (FMEA), a risk analysis was performed on the example of a biogas plant, with risk assessments and adequate treatment of identified main and secondary risks, in order to start the risk management process and thus improve the operation of the biogas plant. First, a system-level FTA is performed, which results in a set of failure modes and proceeds to build a fault tree for the particular system as a whole. Finally, each base event is further analyzed with FMEA to identify the base failure modes for each component, then an RPN value is calculated, to prioritize repairs according to the top event
Key words: failure mode and effect analysis, fault tree analysis, biogas plant

INTRODUCTION

Risk analysis can be defined in many different ways, depending on how risk analysis is related to other concepts. Risk analysis can be broadly defined to include risk assessment, risk characterization, risk communication, risk management and risk-related policy, in the context of risks of interest to individuals, public and private sector organizations, as well as society at local, regional, national or global level. The best approach is to divide risk analysis into two components: risk assessment (identifying, assessing and measuring the likelihood and severity of risk) and risk management (deciding what to do about the risk) [1].
Risk analysis has become an increasingly applied methodology, often providing the basis for plant-level safety activities. [2] Risk analysis usually has three main elements: hazard identification, assessment of emerging risks, and creation of measures that can increase the level of safety. [3]
To prevent accidents, hazards must be systematically recognized, evaluated and minimized. This is the purpose of risk analysis. [4] The tool for performing this analysis is the risk matrix (table 1), which shows the degree of probability that an adverse event will occur (risk) associated with the consequences of that event, in the form of a table.
The categories of probability of an event occurring or having an impact are: rare, unlikely, possible, likely and almost certain. The categories are "judgmental" and statistically verified during the risk assessment. [5]

***Table 1**. Risk matrix*

		Probability				
		I	II	III	IV	V
Consequence	A	IA	IIA	IIIA	IVA	VA
	B	IB	IIB	IIIB	IVB	VB
	C	IC	IIC	IIIC	IVC	VC
	D	ID	IID	IIID	IVD	VD
	E	IE	IIE	IIIE	IVE	VE

Probability:	Consequence:
I Impossible	A Negligible
II Slightly	B Marginal
III Occasional	C Moderate
IV Likely	D Significant
V Frequent	E Critical

Companies and their employees face a wide and varied panorama of risks [6]. In addition to various commercial risks, several specific types can be listed:
• Occupational injuries and health risks.

[1]Corresponding author, jovana.radnovic@tfzr.rs, ORCID:
[2]vesna.makitan@tfzr.rs, ORCID: https://orcid.org/0000-0002-0356-5993

• Fires and explosions.
• Damage to machinery and equipment.
• Transport injuries and related damage.
• Product liability and related damages.
• Damage to the environment resulting from the organization's activities.
• Sabotage.

It is necessary to choose the appropriate method according to the situation, otherwise, the usefulness will be small and maybe even negative.

In order to avoid assumptions and conjectures about the occurrence of risks, it is possible to apply an appropriate combination of methods for determining the reliability of individual system components.

Failure tree and root cause analysis are widely used. Cause of failure analysis is used to discover the cause of failure [7,8]. A classic technique is the fault tree analysis (FTA), while a related technique is failure mode and effect analysis (FMEA) [9,10]. A fault tree translates a physical system into a logical diagram of the various combinations of possible events. The FTA method was created in the 60s of the twentieth century and is suitable for qualitative or quantitative analysis and is one of the most used methods for detecting the cause of failure. Despite all the advantages, this technique is quite time-consuming, but it also fails to use its Boolean logic to express between the states of the components from completely correct to completely incorrect due to knowing only these two states.

MATERIAL AND METHODS

Failure tree analyses (FTA)

FTA is a deductive technique in which the causes of events are derived from the top down. It provides a visual model of how equipment failure, human error, and external factors affect the occurrence of an adverse event. It is a scientifically based and proven technique that models complex system interactions in an easy-to-read visual model [11]

A fault tree provides a framework for qualitative and quantitative evaluation of a peak event. The steps for implementing FTA include defining the top event and system structure, exploring each branch of the tree, solving the fault tree for the combination of events, performing qualitative analysis, and using the results in decision making. [12]. FTA uses Boolean logic to combine a series of lower-level events causing an undesired system state, the technique is static and incapable of examining multiple failures [13]. It is also unintuitive and lacks the ability to properly account for dynamic interactions between components. These and many other shortcomings make FTA limited in the dynamics of modeling complex systems [14].

Failure mode and effect analysis (FMEA)

The FMEA method provides a list of potential system failures as well as possible consequences for the system and the environment [10]. The application ensures that all possible failures and their consequences are taken into account when designing the system. Once there is a system overview of possible errors, it is easier to choose alternatives in the development of systems that have greater security, i.e. less likelihood of cancellation. By predicting possible failures and listing them, ranking them and then solving them, it is possible to reduce the time and costs of developing a new system, maintenance costs, and reduce the time spent in troubleshooting [15].

In this technique, the risk score for each failure mode is obtained by multiplying the individual scores for the three risk factors of severity (S), occurrence (O) and detectability (D). This composite risk is called the "Risk Priority Number (RPN)" and is calculated as follows:

$$RPN = S*O*D \quad (1)$$

To evaluate the parameters of severity, probability and possibility of detection, the scales shown below are used (Tables 2-4). When assessing the risk, the scale given in Table 5 is used.

Table 2. *Scale for evaluating the severity of effects*

Rating	Effect
1-2	Negligible
3–4	Little
5–6	Serious
7–8	Critical
9–10	Catastrophic

Table 3. *Scale for evaluating of failure probability*

Rating	Probability of occurrence
1	Very small
2–3	Small
4–6	Medium
7–8	A big
9	Very big
10	Almost certain

Table 4. *Scale for evaluation of failure detection*

Rating	Noticeability
1–2	Very tall
3–4	Tall
5–6	Medium
7–8	Low
8–9	Very low
10	Inadmissible

Table 5. *Risk assessment scale*

RPN broj	Risk assessment
RPN < 10	The risk is acceptable / no action is required
10 < RPN < 100	The risk is acceptable / the risk can be managed by following the prescribed rules
100 < RPN < 200	The risk is conditionally acceptable / it is necessary to introduce risk control measures, monitoring and follow-up
200 < RPN < 400	Unacceptable risk / shutdown and system redefinition required
RPN > 400	Unacceptable risk / risk cannot be managed

The use of FMEA and FTA methods can be combined for failure analysis so that the advantages of each of these methods can be obtained by using FMEA and FTA approaches separately or by using a combined approach between the two [16]. FTA describes the causes of errors in more detail by indicating the highest event that is not expected to occur, while FMEA provides an overview of where this error occurs and what effects will be caused by the error of the highest event [17]. Compared to using only FTA and FMEA, researchers prefer to use the combination of FMEA and FTA because it is considered to have an advantage in detecting faults [18]. Regarding the second option Shafiee, Enjema, Kolios [19] suggest a mixed approach in which FMEA is guided by FTA. In their proposed approach, the analysis begins with the definition of a system failure event and proceeds with the construction of a fault tree for a particular system as a whole. Finally, each base event is further analyzed with FMEA to identify the base failure modes for each component.

The five categories of biogas system can be treated as five subsystems. Together, these subsystems cover the entire biogas system. Each subsystem can be reduced to a collection of basic events, which will be expressed in a fault tree. Technical problems identified in the field of the study are summarized. Each problem represents an underlying event.
Failure of a biogas system occurs due to events occurring in one or more of the five subsystems (structural components, biogas utilization equipment, piping system, biogas production, and effluent disposal system). As such, any malfunction in the subsystem can lead to abnormal operation of the biogas system.
Identification of factors causing failure using the Fault Tree Analysis shown in Figure 1 – 4 [20].

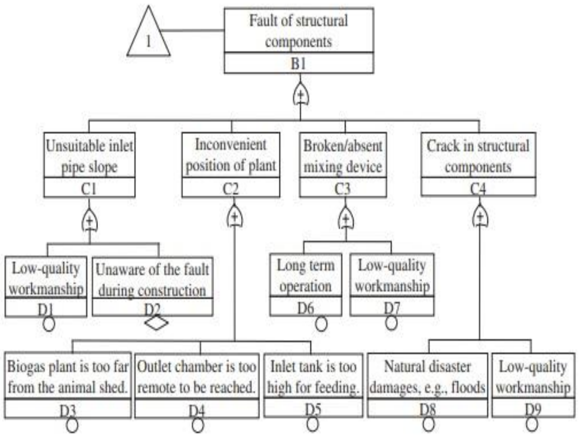

Fig. 1.. Fault tree of structural components — **Fig. 1.**

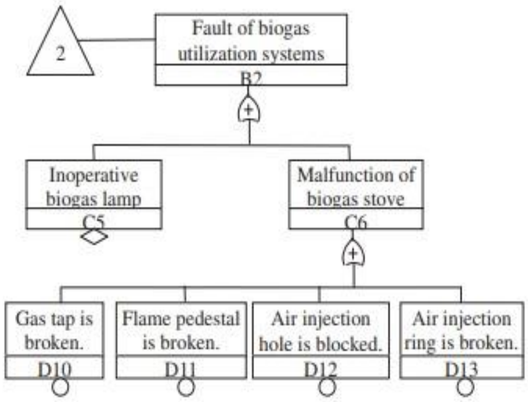

***Fig. 2.** Fault tree of biogas utilization systems*

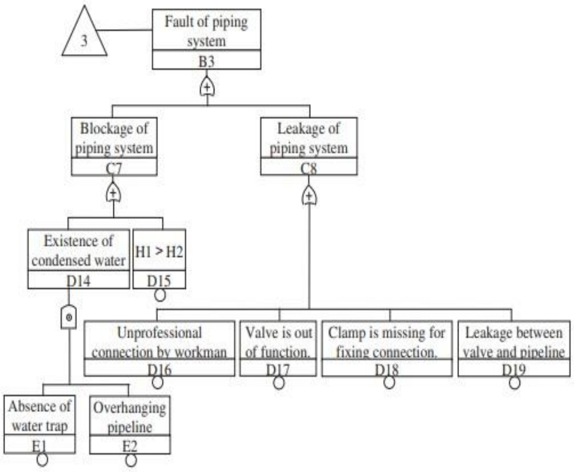

***Fig. 3.** Fault tree of the piping system*

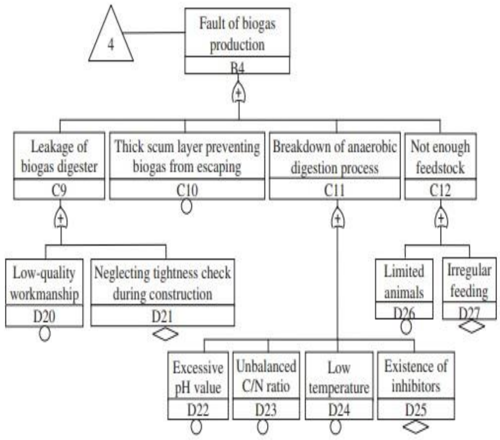

***Fig. 4.** Fault tree of biogas production*

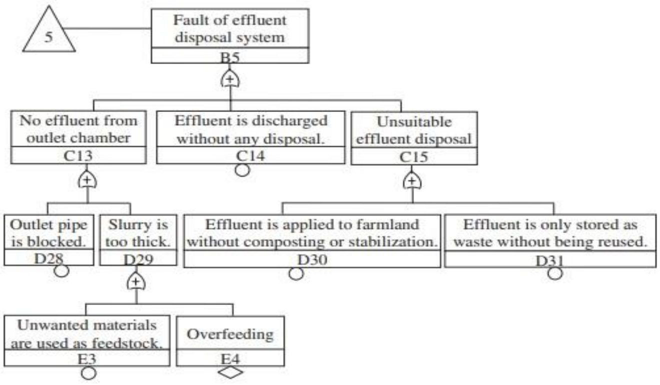

Fig 5. *Fault tree of the effluent disposal system*

Figure 6 shows the total number of failures, and Figure 7 shows the total number of failures in the studied systems categorized by failure type:

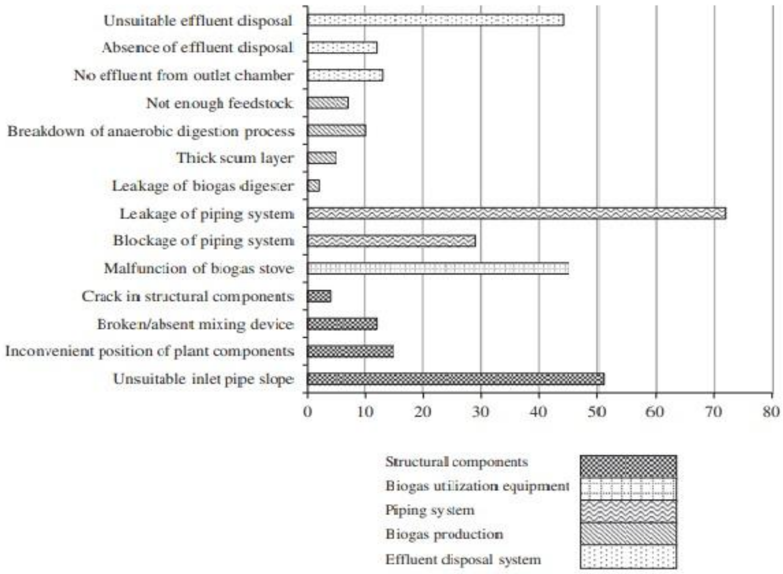

Fig. *6. Total number of failures in the studied systems categorized by failure type*

After knowing the failure mode and its possible causes on the biogas system, the next step is to evaluate the scale of severity, probability and failure detection. Determining the severity rating scale is used to find out how serious the consequences are if an error occurs. After rating the severity on the scale, the next step is rating the probability of failure recurrence scale. Determining failure probability scales is done to find out how often failure occurs by observing existing failure modes. This assessment is made on the basis of the data available in the failure mode. A failure detection rating scale is implemented to predict how often failures occur. This assessment is based on the potential causes obtained by the FTA method. After the assessment of the severity level, the assessment of the probability of failure occurrence and the assessment of failure detection, the value of the RPN (Risk Priority Number) is calculated. Calculation of RPN values is performed to prioritize repairs according to the peak event. The highest RPN values are sorted so that it can be seen which improvements must be undertaken first. The FMEA results are shown in Table 6 which presents the above RPN value as a reference for improvement.

Table 6. *Results of the FMEA method*

Function / Process	Potential Failure Mode	Potential Failure Effects	Potential Causes	Potential Detection	Severituy (S)	Occurrene (O)	Detection (D)	RPN
Failure of the biogas plant	Structural component errors	Inconvenient location of the plant	The biogas plant is too far	During construction	3	5	8	120
			The outlet chamber is remote				8	120
			The inlet tank is high for feeding				8	120
		A crack in the structure	Natural disaster				5	75
		Broken mixer	Low build quality				7	105
	Errors in using the biogas system	Malfunction of biogas stoves	The gas tap is broken	During the operation of the biogas system	3	4	5	60
			The base of the gas torch is broken				6	72
			The air injection hole is blocked.				6	72
			The air injection ring is broken				5	60
	Piping system errors	Blockage of the pipeline system	Absence of water regulation	On occasion equipment testing	8	5	4	160
			The pipe is too high				2	80
		Piping system leak	Unprofessional workers				5	200
			The valve has no function				6	240
			Clamps for fixing the connection are missing				6	240
			Leakage between valve and piping				6	240
	Biogas production errors	Biogas digester leakage	Low build quality	In the event of a disturbance at the biogas plant, the telephone device is turned on and information is sent to the official	9	4	2	72
		Breakdown of the anaerobic digestion process	Too high pH value				3	108
			Unbalanced C/N ratio				3	108
			Low temperature				4	144
			Existence of inhibitors				4	144
		Not enough raw materials	Not enough animals				2	72
			Improper feeding				2	72
	Delay system errors	The procrastination problem	Waste water is discharged without control	During the operation of the biogas system	5	7	5	175
		Non-spills of surrounding water from the outlet chambers	The drain pipe is blocked				4	140
			Unwanted materials are used as raw materials				5	175
			Overfeeding				4	140
		Improper disposal of waste water	The wastewater is used for agricultural land without composting or stabilization				5	175
			Waste water is stored only as waste without reuse				4	140

RESULTS AND DISCUSSION

In this paper we confirm that the methods are coherently complementary and allow to be used together. They do not exclude each other, on the contrary, they complement the necessary data for analysis. The FTA method focuses on detailed analysis of process or product nonconformities from the point of view of detailed causes. The FMEA method is often used to identify failure modes, to assess the consequences of specific failures, and to subjectively conclude the risk and priority number. The application of these two complementary methods provides deeper information than the separate application of the methods.

The main causes of breakdowns in biogas plants are people/workers, machines and tools used during the production process. These three factors are the main factors that cause failure. Based on the results obtained from the FMEA method, we see that the main priority for repair is the valve of the pipeline system with the value of RPN 240 with the cause of workers or people who are less focused. This implies that the risk is conditionally acceptable and that it is necessary to introduce risk control measures. The lowest RPN value is the breakage on the air injection ring and on the gas valve with a value of 60 which is caused by the absence of replacement of worn parts during regular inspection which implies that the risk is acceptable and that the risk can be managed by following the prescribed measures. Based on the FMEA table, we observe that the errors of the structural components in the highest RPN value amount to 120, which in the risk assessment scale means that the risk is conditionally acceptable and it is necessary to introduce risk control measures, monitoring and follow-up. Which also means that for errors of biogas production and errors of the disposal system whose RPN is $100 < RPN < 200$, the lowest value of RPN has the errors of using the biogas system $10 < RPN < 100$, which means that the risk is acceptable and that the risk can be managed by complying with the regulations regulations. The highest value of RPN has errors of the piping system $200 < RPN < 400$, which means that it is an unacceptable risk and requires the interruption of work and the redefinition of the system. After the determined values and the insight into the risks, the improvement of failures follows according to the priority of improvement from the highest to the lowest RPN value. Some suggestions for improvement that can be increasing supervision by the manager of the biogas plant, provision of additional training for workers, more frequent control of the system, more frequent replacement of worn parts, valve repair and control of digester operation are foreseen.

CONCLUSION

It has been confirmed that two techniques, FMEA and FTA, are of great importance for the assessment of potential system failures. They encourage objective analysis of the project to justify changes, analyze common work failures and indicate the need to comply with safety requirements. They are complementary techniques and it is recommended that both be used for a more complete reliability study.

According to the results of the research that was carried out, it is concluded that the results of the FTA (Fault Tree Analysis) identification are known, that the factors that cause failure in the operation of the biogas plant
include the people, machines and tools used. According to the results of the RPN values obtained in the process of creating the FMEA, the given suggestions include:

1. They represent a systematic tool for providing information about process failures;
2. They provide better knowledge about problems in the processes;
3. Influence improvement actions in the process project based on proper data monitoring;
4. Reduction of costs through the prevention of failures;
5. Attitude of cooperation and maintenance of the biogas plant.

The analysis done using FTA and FMEA must lead to the development of an action plan for the execution of the recommended corrective or preventive maintenance action. Adequate improvements proposed in this case can be planned in the direction of reducing the failures of the pipeline system and biogas production, so that this failure mode will not be presented as critical by the FTA.

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LOCALIZED STATES OF BASIC ELEMENTARY CHARGES IN ULTRATHIN CRYSTALLINE FILM-STRUCTURES

Research paper

Nikola R. Vojnović[1], Dušan I. Ilić[2], Jovan P. Šetrajčić[3]

[1,2]University of Novi Sad, Faculty of Technical Sciences, Trg D.Obradovića 6, 21.000 Novi Sad, Vojvodina – Serbia;

[2]Academy of Sciences and Arts of the Republic of Srpska, Bana dr T.Lazarevića 1, 78.000 Banja Luka, Republic of Srpska, B&H

Abstract: The dispersion law of basic elementary charges (electrons or holes, in the following text: charges) in contemporary nanodimension crystalline film-structures (ultrathin film-structures) was evaluated by the method of two-time temperature dependent Green's functions. In variance from unbounded structures, the energy spectrum of charges in film posses the top and bottom gap and the band of charge energies is narrower and strictly discrete. The conditions for the appearance and existence of the localized charge states were found and analized as a function of the size (i.e. value) of the boundary parameters.

Key words: Crystals, film-structures, elementary charges, Green´s functions, energy states

INTRODUCTION

The fundamental physical properties of quasi two-dimensional charge systems derive primarily from their spatial limitation (boundness), as well as from special perturbative conditions occurring on and within their surface layers [1–3]. The aim of this work is to analyze the effects of the finite dimensions of the crystalline ultrathin film along one direction, then the existence of changed values of the energy parameters at two boundaries, as well as the influence of changing the boundary conditions on the energy spectrum of the charge with a special interest in the possibility of the appearance of localized states of charge.

We based our analysis on the standard Hamiltonian of the gas of free charges of the ultrathin crystalline film-structure model in the nearest neighbors approximation [4–6]:

$$H = \sum_{m_x m_y m_z} a^{+}_{m_x m_y m_z} \Big\{ \big[1 + \varepsilon\big(\delta_{m_z,0} + \delta_{m_z,N_z}\big)\big] \Delta a_{m_x m_y m_z} - \\ -\big[1 + w\big(\delta_{m_z,1} + \delta_{m_z,N_z-1}\big)\big] W \Big(a_{m_x+1,m_y m_z} + a_{m_x-1,m_y m_z} + \\ + a_{m_x m_y+1,m_z} + a_{m_x m_y-1,m_z} + a_{m_x m_y m_z+1} + a_{m_x m_y m_z-1} \Big) \Big\}, \tag{1}$$

where $\Delta \equiv \Delta_{n_x n_y n_z}$ is the energy of an charge localized at the site $\vec{n} \equiv (n_x, n_y, n_z)$, and $W \equiv W_{n_x n_y n_z, m_x m_y m_z}$ is the energy of the charge transfer from the site $\vec{n}$ to the site $\vec{m}$. The parameter ε defines the change of the charge energy at the surface layers of the film, while w defines the change of the transfer energy within the surface layers. The fact that the film is of finite dimension along all z-directions (orthogonal to the film boundary surfaces) is expressed in terms of the conditions $n_z = 0, 1, 2, \cdots, N_z,\ N_z \sim 10;\quad n_\alpha \in [-\frac{N_\alpha}{2}, +\frac{N_\alpha}{2}],\quad N_\alpha \sim 10^8,\quad \alpha = (x, y).$

RESEARCH METHOD

The dispersion law for the charges will be looked for by one of the most suitable theoretical treatments of the quantum solid state physics - Green's functions method [7–9]. For that purpose, we study single-charge, two-time anticommutator Green's function:

[1]Corresponding author, nikola.vojnovic@uns.ac.rs , ORCID: https://orcid.org/0000-0001-8361-2085
[2]dusilic69@gmail.com ORCID: https://orcid.org/0000-0002-3644-1268
[3]jovan.setrajcic@gmail.com, ORCID: https://orcid.org/0000-0002-6903-2882

$$G_{n_x n_y n_z; m_x m_y m_z}(t) = \Theta(t) \, \langle \, \left\{ a_{n_x n_y n_z}(t), \; a^{+}_{m_x m_y m_z}(0) \right\} \rangle \tag{2}$$

Following the standard procedure [5–7], using equations of motion for the Green’s function and performing the temporal and partial spatial (XY) Fourier-transformation (defined in [8,9]) we obtain the system of $N_z + 1$ nonhomogeneous algebraic-diference equations:

$$\left[1 + w\left(\delta_{n_z,1} + \delta_{n_z,N_z}\right)\right] G_{n_z-1} + \left[\varrho - \varepsilon\left(\delta_{n_z,0} + \delta_{n_z,N_z}\right)\right] G_{n_z} + \\ + \left[1 + w\left(\delta_{n_z,0} + \delta_{m_z,N_z-1}\right)\right] G_{n_z+1} = K_{n_z}, \tag{3}$$

where: $G_{n_z} \equiv G_{n_z;m_z}(k_x k_y, \omega)$; $K_{n_z} \equiv \frac{i\hbar}{2\pi W} \; \delta_{n_z,m_z}$ and

$$\varrho = \hbar \frac{\omega}{W} - \frac{\Delta}{W} + 2\left(\cos a k_x + \cos a k_y\right). \tag{4}$$

The determination of Green’s function poles, which define the spectrum of possible charge energies, turns into the calculation of the roots of the determinant of the system of equations (3), i.e. to condition:

$$D_{N_z+1}(\varrho) \equiv (\varrho - \frac{\Delta}{W}\varepsilon)^2 \; C_{N_z-1} - 2(1+w)^2(\varrho - \frac{\Delta}{W}\varepsilon) \; C_{N_z-2}(\varrho) + (1+w)^4 \; C_{N_z-3}(\varrho) = 0, \tag{5}$$

where C_n are the characteristic Chebishev’s polynomials: $C_{n-1} = \varrho C_n - C_{n+1}$ [10,11].

ENERGY SPECTRA OF CHARGES IN ULTRATHIN FILMS

In the general case, this equation is not anallytically solvable (anallytically solvable case arises for $\varepsilon = w = 0$ [3,12]), so numerical methods must be applied. For given numerical values of the parameters N_z, ε and w, one can obtain the numerical values for ϱ_ν, $\nu = 1,2,3,\cdots, N_z + 1$ from the equation (5). Their substitution into (4) leads to the charge dispersion law in the following form:

$$E_{xy}(\nu) \equiv \frac{\hbar \; \omega_{xy}(\nu)}{4 \; W} = F_{xy} + G_\nu \; ; \qquad F_{xy} \equiv \sin^2 \frac{a_x k_x}{2} + \sin^2 \frac{a_y k_y}{2} \; ; \quad G_\nu \equiv \frac{\varrho_\nu + 2}{4}. \tag{6}$$

The study of the influence of the surface parameters of the studied film onto the energy spectrum was performed for $N_z \in \{3, 5, 10, 20\}$ and $(\varepsilon, w) \in \{-1{,}0, -0{,}8, -0;5, -0{,}2, 0{,}0, 0{,}2, 0{,}5, 0{,}8, 1{,}0\}$. Figure 1 shows the case of occurrence of localized states on both boundary surfaces: one on the upper one, and two on the lower one. Then the film parameters had the following values: $N_z = 5$, $\varepsilon = 0{,}2$ and $w = 0{,}5$.

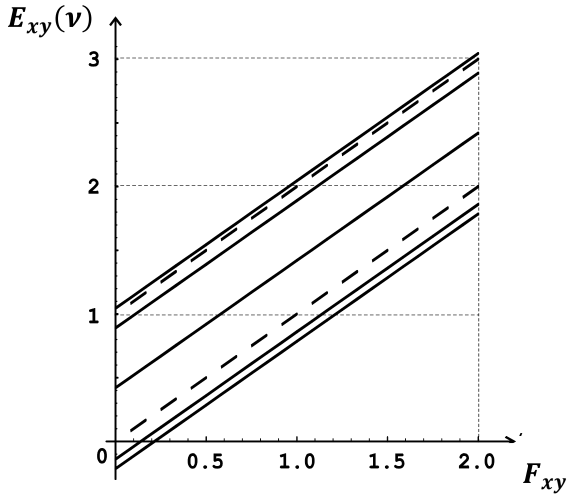

Fig. 1. *The energy spectra of chargse in ultrathin film (appearance of localized sublevels outside the beam boundaries - indicated by dashed lines)*

In addition, similar to the case of an ideal crystal film [9], by analyzing the dispersion law - expression (6), it is easy to conclude that the charge energy spectra are discrete with a finite number of energy levels ($N_z + 1$) and that they have an upper and lower energy gap:

$$b \equiv G_{\nu}^{\min} = G_{\nu=1}(\varepsilon, w); \qquad t \equiv 1 - G_{\nu}^{\max} = 1 - G_{\nu=N_z+1}(\varepsilon, w), \tag{7}$$

which depend on the thickness of the film, but also on the value of the boundary parameters ε and w, which is shown in Figure 2.

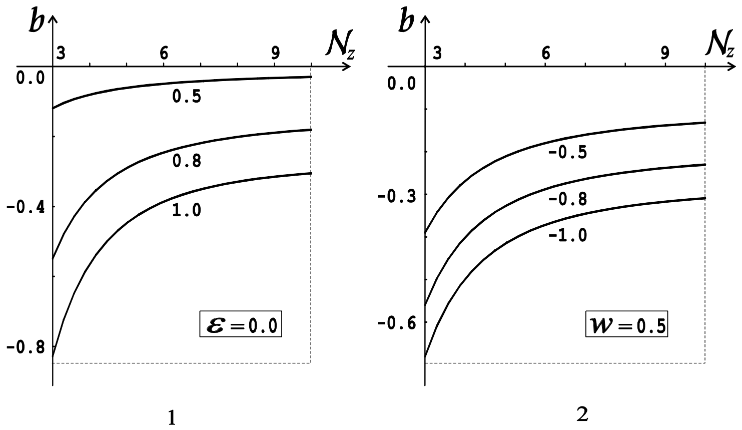

Fig. 2. *Dependence of the size of the lower energy gap on the film thickness:*
1) $\varepsilon = 0{,}0;\ w = +0{,}5; +0{,}8; +1.0$ 2) $w = 0{,}5;\ \frac{\Delta}{W}\varepsilon = -0{,}5;\ -0{,}8;\ -1{,}0.$

Analyzing the energy gap dependence on the film thickness and boundary parameters ε and w, one can register the appearance of the surface localized states of charges for some values of parameters: $b < 0$, $t < 0$, i.e. $E_{\min}^{\mathrm{F}} < E_{\min}^{\mathrm{B}} = 0$, $E_{\max}^{\mathrm{F}} > E_{\max}^{\mathrm{B}} = 1$ for $k_x = k_y = 0$. At the same time, the indexes F and B correspond to film and bulk respectively.

Energy levels out of the continuum band of the allowed energies of an infinite crystal correspond to the complex values of quasimomentum, i.e. there arise the localized charge states at the surface film layers (Figure 1). The conditions for the appearance of the localized states are determined from the equation (5) by substituting: $\omega_{\min} < 0$, where $\varrho < -2$ and $D_n = (-1)^n(n+1)$ or $\omega_{\max} > \frac{4W}{\hbar}$, with $\varrho > 2$ and $D_n = n + 1$ and in both cases for: $k_x = k_y = 0$. It is interesting to note that in this case we obtain the conditions:

$$\frac{\Delta}{W}\varepsilon < (1+w)^2 - 2; \quad \omega_{\min} < 0;$$
$$\frac{\Delta}{W}\varepsilon > 2 - (1+w)^2; \quad \omega_{\max} > \frac{4W}{\hbar},$$

which do not include the dependence on the number of layers, i.e. on the film width.

It is also noticeable that with the increase in the width of the film, the energies of the localized states approach the limits of the bulk range, so in the limiting case ($N_z \to \infty$) they coincide with them.

Bottom energy gap dependence on boundary parameters in the case of the appearance of localized states is studied, because low energy states have the main influence onto the thermodynamics and transport properties of thin films. The boundary charge localization increases with the increase of the parameter w and the decrease of the parameter ε. These results have physical explanation. With decreasing ε, the charge localization for crystal sites becomes smaller, and for greater w, the charge transport from inner sites to boundaries increases. The charge energies can become negative (for imaginary values of quasimomentum), so the Fermi level in the crystalline film has to be redefined.

DISCUSSION OF RESULTS AND CONCLUDING CONSIDERATIONS

In this paper, which presents the results of the analysis of the law of electron dispersion in perturbed crystal film-structures and the study of the dependence of the lower energy gap on the boundary parameters in the case of the occurrence of localized states, because low-energy states have the main influence on the thermodynamics and transport properties of thin films. The localization of the boundary charge increases with increasing parameter w and decreasing parameter ε. These results have a solid physical explanation. With decreasing ε, charge localization for crystal sites becomes smaller, and for larger w, charge transport from internal sites to boundaries increases. The charge energies can become negative (for imaginary values of the quasimomentum), so the Fermi level in the crystalline film must be redefined.

Results of these analyses confirm the essential differences in dispersion law of charges in film structures in comparison with unbounded ones, which is as an exclusive consequence of boundaries existence.

1) Energy spectrum of charges in the crystalline film is a discrete one with the finite number of possible energy levels equal to the number of atomic planes in the film along z -direction.
2) The consequence of the spectrum discreteness is the existence of the top and bottom energy gap which decrease with the increase of the film width.
3) Increase of the charge energy at the boundary surfaces induces the shift of the spectrum towards higher energies (the increase of the bottom gap and the decrease of the top gap), while for the increase of the transfer energy of charges at the surfaces, the spectrum broadens (the decrease of both bottom and top gap).
4) Depending on the values of the parameters of surface interactions, certain energy levels can lie outside the energy band of the ideal crystal, so there appear the surface localized states of charges.
5) Increasing the film width, the energy of the localized states shifts towards the bulk band boundaries, coinciding with them for $N_z \to \infty$. In this limit the localized states, as well as the energy gaps vanish, while the spectrum turns in the quasicontinual spectrum of the ideal infinite crystal.
6) The position of the Fermi level in the film differs from its bulk position and depends strongly on the boundary parameters and the film thickness.

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APPLICATION OF STATISTICAL METHODS IN ORDER TO DETERMINE THE LEVEL OF ENERGY EFFICIENCY

Research paper

Čugalj Jovana[1*], Pekez Jasmina[2], Stojanov Jelena[3], Ašonja Aleksandar[4]
[1,2,3] University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia
[4] University Business Academy in Novi Sad, Faculty of Economics and Engineering Management in Novi Sad,

Abstract: The study explores the state of energy efficiency in residential buildings in the city of Zrenjanin through an analysis of a survey conducted among 662 respondents. The results indicate a prevalent issue of the inability for collective investment in the energy efficiency of communal residential buildings compared to single-family homes. By using the Chi-square test of independence, a statistically significant relationship between the type of residential property and the presence of external thermal insulation was discovered. Additionally, a moderate dependence between the age of the heating system and the need for additional heating was identified. The research's conclusion suggests the need for subsidies to improve the energy efficiency of residential buildings, especially multi-family complexes, to achieve sustainability and reduce energy consumption in the urban environment of Zrenjanin.
Key words: energy efficiency, external thermal insulation, statistics

INTRODUCTION

The relationship between humans and the environment significantly differs before and after the technological revolution, while in pre-industrial society, humans tried to adapt to nature in their life within it, post-industrial society strives to adapt nature to human needs. The greatest problem is the ruthless depletion of natural resources and inappropriate construction methods. All of this has contributed to the deterioration and pollution of the environment. Efficient energy use has become one of the most significant measures of building quality. The goal is for the amount of energy used by a building to be minimized, with investment in energy efficiency being a priority. Investments in energy efficiency through thermal insulation and the utilization of renewable energy sources increase the value of the building and ensure a quick return on investment. Energy efficiency entails reducing energy consumption in the production of goods or provision of services compared to energy consumption in existing systems [1]. Energy efficiency defines the quality of energy use. Measures of energy efficiency involve actions taken to reduce energy consumption and loss, which can be implemented by producers in production but also by users in energy consumption [2].

Building energy efficiency involves implementing measures aimed at reducing energy needs and introducing new, environmentally friendly technologies and energy sources [3]. An energy-efficient building consumes minimal energy while providing necessary comfort conditions in accordance with regulations and with minimal environmental pollution. It consumes less energy than a standard building, meaning it is less energy-dependent while still being comfortable and pleasant to inhabit. Windows and skylights are often the weakest parts of a building's envelope, causing heat energy losses, which means that heat passes through them more easily than through walls or the ceiling. The heat gain during summer is also significant and cannot be ignored. However, windows can also be a source of much-needed heat gains during winter, late autumn, or early spring [4,5].

The energy efficiency of buildings is crucial for reducing global energy consumption and achieving climate goals. Key strategies include improving insulation, window replacement,

[1]Corresponding author, jovana.cugalj@tfzr.rs, ORCID: https://orcid.org/0009-0002-7257-7936
[2]jasmina.pekez@tfzr.rs, ORCID: https://orcid.org/0000-0003-0454-5326
[3]jelena.stojanov@uns.ac.rs, ORCID: https://orcid.org/0000-0002-2237-8026
[4]aleksandar.asonja@gmail.com, ORCID: https://orcid.org/0000-0001-6667-1024

and upgrading heating, ventilation, and air conditioning (HVAC) systems. Modern technologies such as smart energy management and renewable energy integration play an essential role in further lowering energy demand. Optimizing heating, cooling, and lighting systems, alongside enhancing building insulation, helps reduce both carbon emissions and operational costs. By adopting these measures, building energy efficiency significantly contributes to lowering long-term expenses and supporting environmental sustainability [6,7].

MATERIAL AND METHODS

In order to assess the energy efficiency status in the homes of Zrenjanin residents, an online survey consisting of 23 questions was conducted. A total of 662 respondents were surveyed within the territory of the city of Zrenjanin. The survey was distributed via social media platforms. For the purpose of processing the survey on the energy efficiency of residential buildings in Zrenjanin, descriptive statistics are applied (with the primary aim of determining the mean and standard deviation). Furthermore, within the framework of inferential statistics, the interrelation of different elements of energy efficiency is considered.
The elements of energy efficiency covered by this research (and survey) correspond to categorical (nominal) variables. This means that respondents are categorized into different groups based on their responses to specific questions. It is interesting to analyze whether the choices of responses by respondents to different questions are interrelated. In other words, whether there is a pattern where the majority of respondents who have a certain attitude towards one/some element(s) of energy efficiency belong to the same category when it comes to other elements of energy efficiency. And of course, the question is how reliably can it be claimed that the attitudes of respondents can be generalized to all residents of Zrenjanin (the population).
The chi-square test (χ^2-test) is used to determine whether there is an association between categorical variables. In order to use the chi-square test, the data must meet several conditions:

- There are two categorical variables,
- There are two or more categories for each variable,
- Independence of observations (no relationship between subjects in each group and categorical variables are not "paired" in any way),
- The sample size is relatively large (where the expected frequencies for each cell are at least 1, and they should be at least 5 for 80% of cells) [8].

In the same sample, two variables are observed, and their interrelation is considered throughout the correlation. The null hypothesis (H0) and alternative hypothesis (H1) of the Chi-Square Test of Independence are:

- H0: the variables are independent
- H1: the variables are not independent [8].

For the calculated value of the chi-square statistic, the corresponding p-value is computed, which is then compared to the significance threshold (the highest acceptable probability of rejecting the true null hypothesis ($\alpha=0.05$)), and a conclusion is drawn as follows:

- If the p-value $\leq \alpha$, it is considered that there is empirical evidence to reject the null hypothesis in favor of the alternative hypothesis,
- If the p-value $> \alpha$, the null hypothesis is accepted, indicating that there is not enough evidence to reject it [9].

After establishing the dependency between variables, Cramer's V coefficient is used as a measure of this dependency, whose value is interpreted from Table 2 based on the degrees of freedom (df) value (table 1) [10].

***Table 1**. Display of the interpretation of Cramer's V coefficient values*

df	Negligible dependence	Minor dependence	Moderate dependence	Significant dependence
1	0 < 0,1	0,1 < 0,3	0,3 < 0,5	0,5 or more
2	0 < 0,07	0,07 < 0,21	0,21 < 0,35	0,35 or more
3	0 < 0,06	0,06 < 0,17	0,17 < 0,29	0,29 or more
4	0 < 0,05	0,05 < 0,15	0,15 < 0,25	0,25 or more
5	0 < 0,04	0,04 < 0,13	0,13 < 0,22	0,22 or more
6	0 < 0,04	0,04 < 0,12	0,12 < 0,20	0,20 or more
7	0 < 0,04	0,04 < 0,11	0,11 < 0,19	0,19 or more
8	0 < 0,04	0,04 < 0,11	0,11 < 0,18	0,18 or more

All the aforementioned statistical values of the data are obtained using the software tool The Statistical Package for the Social Sciences (SPSS).

RESULTS AND DISCUSSION

The results of the survey indicate that out of the total number of surveyed citizens (662), 396 (59.8%) reside in single-family homes, 183 (27.6%) in residential buildings for communal living, and 83 (12.5%) in row houses. The survey also revealed that 380 respondents (57.4%) live in buildings constructed between 1960 and 1990. Furthermore, 107 respondents (16.2%) reside in buildings built between 1990 and 2010, while 37 respondents (5.6%) live in buildings constructed after 2010. Only 21 respondents (3.2%) live in buildings built before 1920. Over the past decade, 582 respondents (87.9%) have invested in their homes, while 80 respondents (12.1%) have not. Regarding thermal insulation, 339 respondents (51.2%) have it installed in their residential buildings, while 323 respondents (48.8%) do not. The survey results suggest a significant potential for enhancing energy efficiency by installing thermal insulation in residential buildings in Zrenjanin.

In terms of window sealing, 412 respondents (62.2%) reported good window sealing, while 250 respondents (37.8%) indicated poor sealing. Effective window sealing is crucial for preventing heat loss. Similarly, door sealing is essential, with 418 respondents (62.2%) reporting good door sealing and 244 respondents (36.9%) reporting poor sealing. These findings highlight the potential for improving energy efficiency by addressing sealing issues.

Regarding heating systems, the majority of respondents (34.9%) use a gas heating system, followed by district heating (25.7%), solid fuel (21.5%), individual electric heaters (6.9%), gas heaters (5.4%), heat pumps (3.5%), and other heating sources (2%). Only one respondent (0.2%) uses oil. While individual heaters represent the least economical heating method, heat pumps are the most efficient and environmentally friendly, used by only 3.5% of respondents (figure 1). Notably, heating accounts for 42.2% of total energy consumption in households during the winter season [8]. Therefore, selecting energy-efficient heating systems is crucial.

The advantages of using heat pumps for heating and cooling are significant. Over 70% of the energy required for space heating is sourced for free from groundwater throughout the pump's lifetime. The most cost-effective application of heat pumps is in combination with underfloor heating and cooling systems. Optimal energy efficiency is achieved when the pump is activated at the beginning of the heating season and deactivated at the end, following the same principle for cooling. Lowering the room temperature by just 1°C can result in energy savings of 5-6%. Additionally, a single investment in a heat pump covers both heating and cooling needs. During heating, minimal air circulation is achieved through even heat distribution, reducing the presence of dust in the air and alleviating allergy symptoms [11].

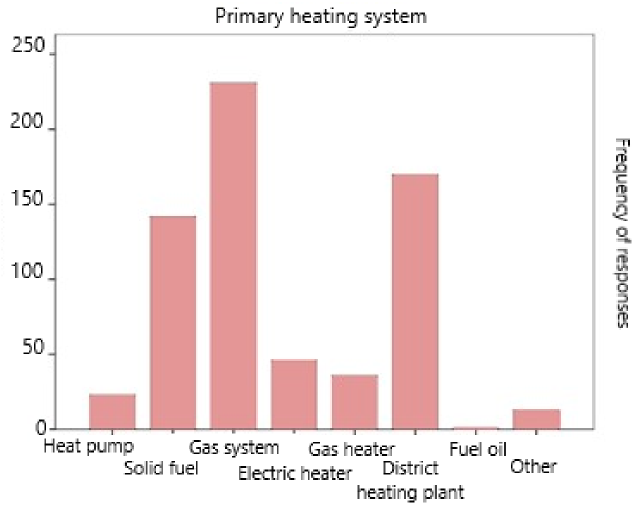

Fig. 1. *Presentation of research results by primary heating system*

Based on the research results, 509 respondents (76.9%) do not require additional heating of their premises during the heating season. The need for additional heating of the space, in addition to the primary heating source, is felt by 153 respondents, or 23.1% of the total number of respondents. According to the research findings, the most common system for heating technical water is an electric boiler, used by 423 respondents (65.3%). A gas instant water heater is used by 119 respondents (18%), while an electric instant water heater is used by 71 respondents (10.7%). A boiler connected to the heating system is used by 33 respondents (5%), and a district heating system for supplying hot technical water is used by 4 respondents (0.6%). A boiler connected to a solar collector system is used by 3 respondents (0.5%). Heating technical water with an electric boiler represents the least economical way of water heating, as well as the least energy-efficient. An electric boiler consumes a significantly larger amount of electricity to heat water compared to, for example, an electric instant water heater. In addition, the widespread use of electric boilers (65.3% according to the research results) leads to a greater demand for electricity, emitting significant amounts of greenhouse gases for its generation, making this method of water heating environmentally unacceptable. The city of Zrenjanin is located in an area with the fewest hours of sunshine in December, 42.5, and the most in July, 314, with a total of 2000 to 2200 sunshine hours per year. The annual amount of solar radiation on a larger surface area of the city is 1500 kWh/m2 per year, which represents an exceptional potential for using solar energy for heating domestic water through a solar collector system. Initial investments require significant financial resources, but the benefits of using this water heating system are manifold. The research showed that out of the total number of respondents, 365 respondents (55.1%) would invest in improving the energy efficiency of their home if they were able to do so in the next 5 years. 271 respondents (40.9%) would invest in their home only if there were subsidies from the state, while 26 respondents (3.9%) would not invest in improving the energy efficiency of their home (or have already taken all measures to improve energy efficiency). Most citizens are willing to invest in their homes to achieve energy efficiency. There is a high probability that 40.9% of respondents will not invest in improving the energy efficiency of their home if there are no subsidies from the state in the next 5 years.

The analysis of research results obtained through the application of the Chi-square test of independence and the SPSS software package.
In Figure 2, the number of buildings with external thermal insulation is shown relative to the type of residential building.

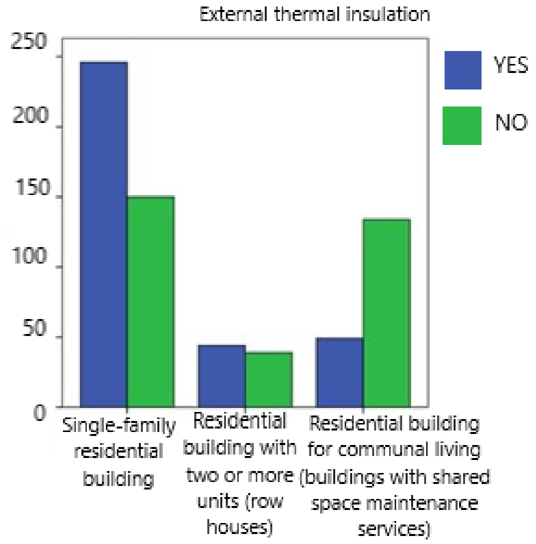

***Fig. 2**. The number of buildings with external thermal insulation, relative to the type of residential building.*

The obtained data can be explained as the inability of some residents living in collective housing to install external thermal insulation on their buildings. Out of 183 respondents living in apartment buildings, only 49 (26.78%) have external thermal insulation on their buildings. To carry out the mentioned investment in improving energy efficiency, all tenants of the building need to agree and invest significant financial resources, which are the main obstacles when it comes to insulating residential buildings. Regarding single-family houses, 246 (62.12%) of the buildings have external thermal insulation. Residents living in single-family houses have complete freedom to decide whether to install thermal insulation on their buildings or not, depending on their financial capabilities. Based on the chi-square test of independence (Table 10), the null hypothesis of independence between the variables is rejected ($\chi^2$2, N=662) = 62.705, $p < 0.05$), indicating a statistically significant association between the presence of external thermal insulation and the type of residential building.

***Table 2**. Application of the Chi-square Test for Data on the Type of Residential Building and External Thermal Insulation*

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	62,705[a]	**2**	**,000**
N of Valid Cases	662		

a. 0 cells **(0,0%)** have expected count less than 5. The minimum expected count is 40,50.

The dependence between the existence of external thermal insulation and the type of residential building, based on the degree of freedom and Cramer's V value (Table 3), falls into the category of significant dependence.

***Table 3**. Intensity of Dependence between the Type of Residential Building and External Thermal Insulation*

		Value	Approx. Sig.
Nominal by Nominal	Cramer's V	**,308**	,000
N of Valid Cases		662	

Table 4 illustrates the number of households requiring additional heating for their rooms relative to the age of the heating system. When these data are converted into percentages, a clear increase in the need for additional heating as the heating system ages can be observed (Figure 3). Although 26.11% of respondents express a need for additional heating during the winter period, this need increases with the age of the heating system. Only 5.23% of respondents require additional heating with a heating system aged up to 5 years, while with a heating system aged from 5 to 10 years, 16.34% of respondents express this need, and 78.43% of respondents require additional heating with a heating system aged over 10 years.

Table 4. *Data on Heating System Age and Need for Additional Heating*

		Additional heating		Total
		Yes	No	
Heating System Age	Up to 5 years	8	140	148
	5-10 years	25	96	121
	Over 10 years	120	273	393
Total		153	509	662

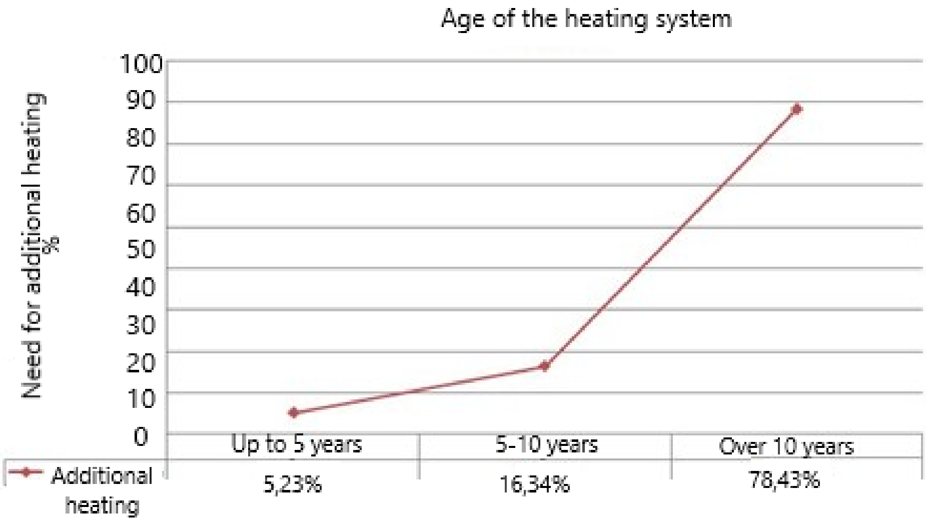

Fig. 3. *Graphical Representation of Increased Need for Additional Heating with Heating System Age (Percentage)*

The condition for applying the chi-square test of independence is met, hence by applying the test (Table 5), the null hypothesis of independence between the variables is rejected.

Table 5. *Application of the Chi-square Test for Data on Heating System Age and Need for Additional Heating* [a]

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38,705[a]	**2**	**,000**
N of Valid Cases	662		

a. 0 cells **(0,0%)** have expected count less than 5. The minimum expected count is 27,97.

The dependency between the age of the heating system and the need for additional heating is of moderate intensity, based on the value of Cramer's V (Table 6) and the degrees of freedom (df=2), compared to the categorization from Table 1.

Table 6*. Intensity of Dependency between Heating System Age and*

Need for Additional Heating

		Value	Approx. Sig.
Nominal by Nominal	Cramer's V	**,242**	,000
N of Valid Cases		662	

CONCLUSION

The research on energy efficiency in residential buildings in Zrenjanin showed that the majority of respondents (57.4%) live in buildings constructed between 1960 and 1990, with heat losses ranging from 200 to 250 kWh/m², while newer buildings have much lower losses, around 150 kWh/m². Additionally, only 26.78% of residential buildings have external thermal insulation, compared to 62.12% of detached houses, underscoring the difficulty in achieving collective agreements on energy efficiency improvements in communal living environments. The need for additional heating is most prevalent in buildings without proper insulation, poorly sealed windows, and outdated heating systems. From the survey, just 9.37% of respondents live in fully energy-efficient homes, revealing the widespread need for improvement, particularly in multi-family residential buildings, which are in worse condition than detached houses. Addressing these challenges will require subsidies for energy efficiency upgrades, especially for multi-family buildings. It is also essential to raise public awareness about energy efficiency and promote it through widespread education. By integrating energy efficiency concepts into the educational system, future generations will be better equipped to tackle environmental issues and contribute to cleaner air, water, and soil.

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ANALYSIS OF A RESIDENTIAL PHOTOVOLTAIC SYSTEM

Review paper

Anca-Adriana Petcuț-Lasc[1], Valentina-Emilia Bălaș[2], Flavius-Maxim Petcuț[3]
[1,2,3]Aurel Vlaicu University of Arad, Romania
[1,2]Petroleum-Gas University of Ploiesti, Romania

Abstract: This paper presents an analysis of residential photovoltaic (PV) panel systems, focusing on their environmental, economic and technological impact for homeowners. The study evaluates the financial viability of solar installations by examining energy savings and net metering. In addition, the environmental benefits of installing a residential PV, such as reduced carbon emissions and decreased reliance on non-renewable energy sources, are explored. The paper also assesses the technological advancements in solar panel efficiency, including monocrystalline, polycrystalline, and emerging bifacial and PERC technologies, to provide a detailed comparison of their performance in residential settings. Further, the integration of energy storage solutions and their potential to enhance energy independence and grid stability is discussed. Through a combination of the studied PV system this analysis points out the long-term advantages of the residential PV systems.
Keywords: PV, grid, green deal, residential photovoltaic panel

INTRODUCTION

The European Green Deal, adopted by the European Union in 2019, is a comprehensive strategy having the scope of making Europe the first climate-neutral continent by the year 2050. Solar energy, particularly solar photovoltaic (PV) panels, plays a crucial role in this transition, contributing to the decarbonisation of the energy sector, increasing renewable energy use, and driving economic growth through innovation and job creation. While the European Green Deal is a policy framework specific to the European Union (EU), its impact and principles are influencing climate action and green transitions beyond the EU's borders. Many countries, regions and organisations outside the EU are adopting similar strategies, often in alignment with the EU's Green Deal, given its prominence in the global climate change discourse.[1]

RESIDENTIAL ELECTRIC GREEN ENERGY USING PHOTOVOLTAIC PANEL

To obtain electric green energy you need to use a lot of components presented in Fig. 1.

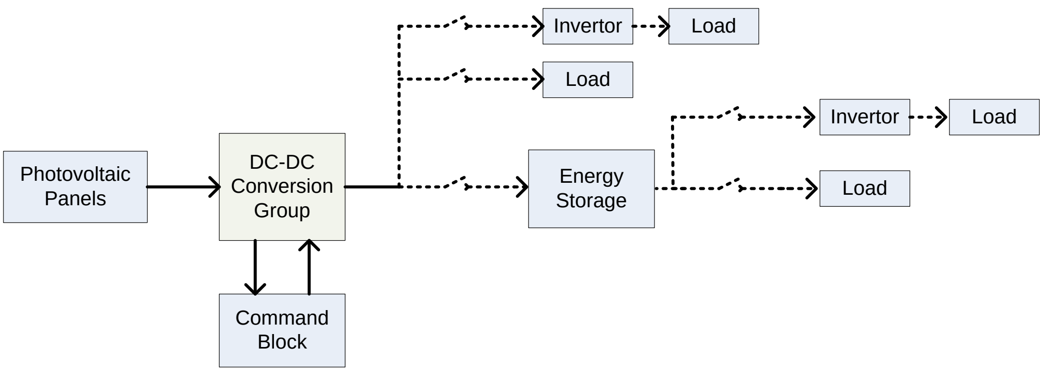

Fig. 1. *Electric green energy production*

On the left of Fig. 1 we see the group of photovoltaic panels [2]. The ongoing research and development in materials, efficiency, and cost reduction aim to make solar energy more accessible, efficient, and sustainable. Based on these we presented the advantages and disadvantages of multiple solar panel type.

[1] Corresponding author, anca.petcut@uav.ro, ORCID: https://orcid.org/0009-0000-5450-5272
[2] balas@drbalas.ro, ORCID: https://orcid.org/0000-0003-0885-1283
[3] flavius.petcut@uav.ro, ORCID: https://orcid.org/0009-0001-6928-4019

Table 1. *Solar Panels advantages and disadvantages*

Type of Solar Panel	**Description**	**Advantages**	**Disadvantages**
Monocrystalline Silicon Solar Panels	These are the most efficient type of commercially available solar panels. They are made from a single, continuous crystal structure of silicon.	Higher efficiency, longer lifespan and better performance in low-light conditions.	More expensive than other types of panels.
Polycrystalline Silicon Solar Panels	Made from silicon crystals that are melted together. These panels are less efficient than monocrystalline ones but are cheaper to produce.	Lower cost, decent performance in sunlight.	Lower efficiency and reduced performance in low-light conditions.
Thin-Film Solar Panels	This type of panel is made from materials such as cadmium telluride (CdTe), copper indium gallium selenide (CIGS) or amorphous silicon (a-Si). Thin-film panels are flexible and lightweight.	Lightweight, flexible, performs better in high temperatures and diffused light.	Much lower efficiency, requires more space for the same power output.
Bifacial Solar Panels	These panels can capture sunlight from both sides: the back and the front sides. This increases the energy production.	Higher overall energy output by capturing reflected sunlight from the ground.	Higher cost, requires specific installation environments to fully benefit.
PERC Solar Panels (Passivated Emitter and Rear Cell)	PERC panels are an enhancement of polycrystalline or monocrystalline panels, with an additional layer to reflect unabsorbed sunlight back into the panel, increasing efficiency.	Higher efficiency than standard monocrystalline and polycrystalline panels.	Costs more than traditional panels.
Concentrated Photovoltaic Panels (CPV)	Uses lenses or mirrors to concentrate sunlight onto a high-efficiency solar cell.	Extremely high efficiency.	Expensive, requires direct sunlight and solar tracking systems, sensitive to temperature changes.

Solar panels efficiency is referring to the percentage of sunlight that a solar panel is able to convert into usable electricity. It's a critical measure of how effectively a solar panel can generate power [3]. The efficiency depends on several factors, including the type of solar cell technology used, environmental conditions and the quality of manufacturing [3]. The solar panels efficiency is presented in Table 2.

Table 2. *Solar Panels efficiency comparison*

Type of Solar Panel	Efficiency Range	Cost	Common Usage
Monocrystalline	17%-23%	High	Residential, Commercial
Polycrystalline	15%-17%	Medium	Residential, Commercial
Thin-Film	10%-12%	Low	Large-scale, Special Application
Bifacial	18%-24%	High	Commercial, Utility
PERC	18%-22%	Medium-High	Residential, Commercial
Concentrated Photovoltaic	40%-45%	Very High	Utility-scale

PHOTOVOLTAIC PANEL USED

The analyzed site, located in Arad, Romania, 46°10'25.8"N 21°21'40.0"E, has installed 10 block of photovoltaic panel model monocrystalline Canadian Solar 410W [4] as we can see on the Fig. 2. The connection between the photovoltaic panels is a serial connection.

Fig. 2. *Photovoltaic monocrystalline Canadian Solar 410W panel.*

Table 3. *The analyzed PV electrical characteristics under standard test conditions*

ELECTRICAL DATA	**STC***
CS6R	410MS
Nominal Max. Power (Pmax)	410 W
Opt. Operating Voltage (Vmp) 31.2 V	
Opt. Operating Current (Imp)	13.15 A
Open Circuit Voltage (Voc)	37.2 V
Short Circuit Current (Isc)	14.01 A
Module Efficiency	21.0%
Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500V (IEC/UL) or 1000V (IEC/UL)
Module Fire Performance	TYPE 1 (UL 61730 1500V) or TYPE 2 (UL 61730 1000V) or CLASS C (IEC 61730)
Max. Series Fuse Rating	25 A
Application Classification	Class A

Power Tolerance
* Under Standard Test Conditions (STC) of irradiance of 1000 W/m2, spectrum AM 1.5 and cell temperature of 25°C [4]

Table 4. *The analyzed PV electrical characteristics under Nominal Module Operating Temperature*

ELECTRICAL DATA	**NMOT***
CS6R	410MS
Nominal Max. Power (Pmax)	307W
Optimal Operating Voltage (Vmp)	29.20V
Optimal Operating Current (Imp)	10.52A
Open Circuit Voltage (Voc)	35.10V
Short Circuit Current (Isc)	11.28A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m2, spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s [4]

Table 5. *The analyzed PV mechanical characteristics*

MECHANICAL DATA	
Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	108 [2 X (9 X 6)]
Dimensions	1722 x 1134 x 30 mm (67.8 x 44.6 x 1.18 in)
Weight	21.3 kg (47.0 lbs.)
Front Cover	3.20 mm tempered glass with antireflective coating
Frame	Anodized aluminum alloy,
J-Box IP68,	3 bypass diodes
Cable	4 mm2 (IEC), 12 AWG (UL)
Connector	MC4 or MC4-EVO2
Cable Length (Including Connector)	Portrait: 410.0 mm (16.1 in) (+) / 290.0 mm (11.4 in) (-); landscape: 1100.0 mm (43.3 in)*
Per Pallet	35 pieces
Per Container (40' HQ)	910 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives [4]

Table 6. *Temperature characteristics*

Specification of Temperature	Data
Coefficient (Pmax)	-0.34 % / °C
Coefficient (Voc)	-0.26 % / °C
Coefficient (Isc)	0.05 % / °C
Nominal Module Operating	41 ± 3°C

The inverter used is presented on Fig. 3.

Fig. 3. *Huawei Solar SUN2000-450W inverter*

The Huawei solar inverter used by our PV plant is a smart inverter. Its active protection against current arcs is up to 30% higher efficiency thanks to the SUN2000-450W-P optimizers with which it is provided. It came equipped with artificial intelligence and has WLAN connection. The inverter's power is 5000W and the efficiency it has is a of 98.4%. This inverter can quick start-up using the application offered by to Huawei and can be configured with a single click, being extremely easy to install. [5]

This generation of inverter is a smart one that can combine the stored energy together with the energy generated by the photovoltaic field. This improvement provides all the energy a residential home needs. The housing is rated with the IP65 protection index, which gives the inverter outstanding protection against potential hazards. This inverter is approved by the Romanian National Energy Regulatory Authority (ANRE) [5,6].

THE POWER FEED INTO THE GRID

The power feed into the network is metered with a smart meter that transmits both the energy produced and the energy consumed via the Internet [7]. Every 3 months, the consumption is regularized and if you produced more energy than you consumed you can recover the money owed by the distributor. The used meter is presented in Fig. 4.

Fig. 4. *Power meter*

Below we present the power obtained and the feed power into the grid for September 2024.

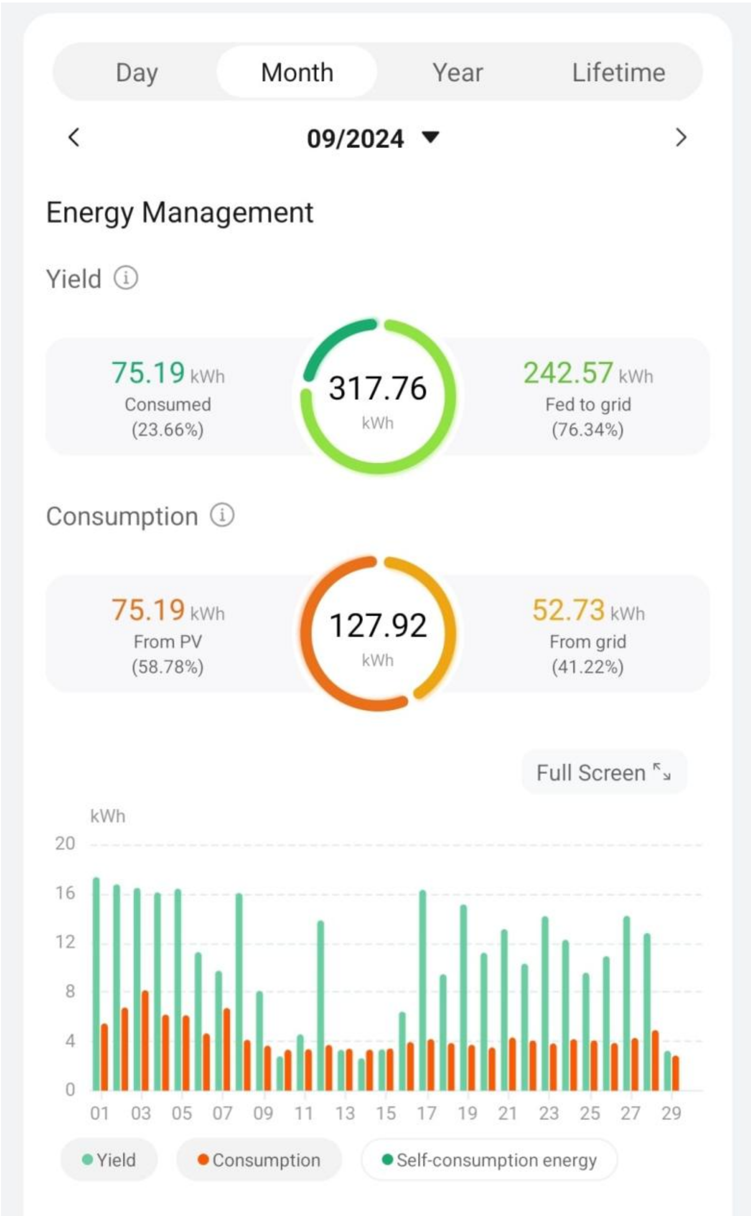

Fig. 5. *September statistics for the residential photovoltaic*

Table 7. *Residential PV production and consumption of power in September 2024*

day	Yield produced [KWh]	Feed to grid [KWh]	Consumed from PV [KWh]	Consumption from grid [KWh]	Total consumption [KWh]
1	17.34	13.76	3.58	1.88	5.46
2	16.76	11.98	4.78	1.97	6.75
3	16.46	10.77	5.69	2.46	8.15
4	16.10	11.93	4.17	2.00	6.17
5	16.40	12.03	4.37	1.75	6.12
6	11.25	8.35	2.90	1.75	4.65
7	9.74	5.15	4.59	2.12	6.71
8	16.05	13.75	2.30	1.82	4.12
9	8.10	6.18	1.92	1.73	3.65
10	2.79	1.34	1.45	1.87	3.32
11	4.57	2.86	1.71	1.65	3.36
12	13.83	11.68	2.15	1.56	3.71
13	3.31	1.64	1.67	1.73	3.40
14	2.63	1.38	1.25	2.08	3.33
15	3.35	1.97	1.38	2.04	3.42
16	6.41	4.20	2.21	1.73	3.94
17	16.31	13.81	2.50	1.68	4.18
18	9.46	7.22	2.24	1.63	3.87
19	15.12	13.05	2.07	1.65	3.72
20	11.20	9.42	1.78	1.73	3.51
21	13.12	10.72	2.40	1.91	4.31
22	10.31	8.11	2.20	1.87	4.07
23	14.17	12.17	2.00	1.83	3.83
24	12.25	9.84	2.41	1.77	4.18
25	9.58	7.35	2.23	1.85	4.08
26	10.92	8.84	2.08	1.79	3.87
27	14.19	11.73	2.46	1.82	4.28
28	12.80	9.72	3.08	1.83	4.91
29	3.24	1.62	1.62	1.23	2.85
Total	317.76	242.57	75.19	52.73	127.92

According to the study carried out, for a residential home from Arad, in September 2024, 300KWh were produced. Of these, 230KWh were injected into the grid. The power consumed from the grid was 50KWh while from the own PV system the location used 70KWh.

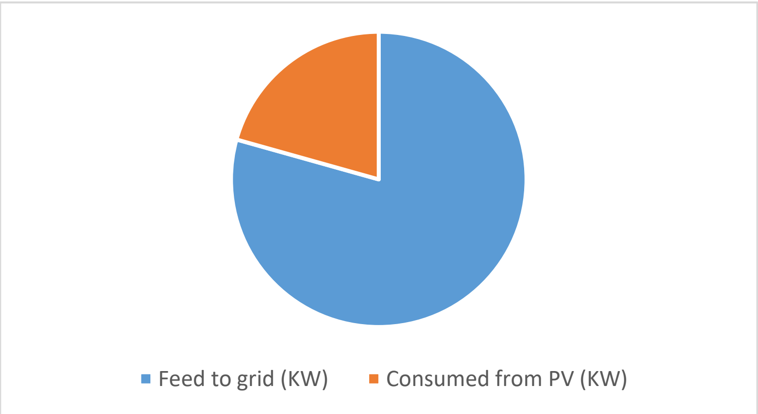

Fig. 6. *Produced KW by the PV system in September 2024*

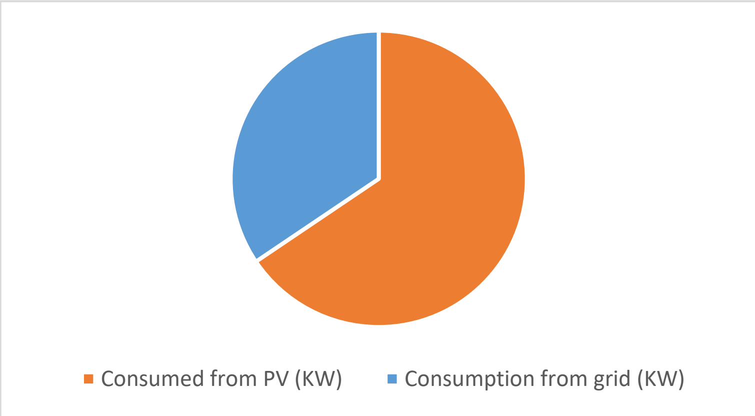

Fig. 7. *Consumed KW by the residential home in September 2024*

The amount of kilowatts consumed by the residential home from the grid, as shown in Fig. 6, is less than half of the kilowatts fed into the grid in September 2024, as depicted in Fig. 7.

CONCLUSION

The studied residential photovoltaic (PV) system offers several key benefits for the homeowners, making it an attractive investment.
The primary benefit is it generates the own electricity from sunlight, it reduces significantly or even eliminate the monthly electricity bills, while any excess energy is sold back to the grid through net metering.
Other benefits are: increase the property value, increase the energy independence, offers you real-time tracking and greater control over energy use, has environmental benefits such as reduced carbon footprint and promote of clean energy.
In summary, the residential PV system provides homeowners with significant financial, environmental and lifestyle benefits, making it a smart investment both for immediate savings and long-term sustainability.

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Session 3

Designing and Maintenance

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PRELIMINARY STUDY ON DRIVER POSTURE THROUGH NEW METHOD OF ANALYSIS

Research paper

Anca - Ioana SABĂU[1], Mihaela POPA[2], Gabriela STOIA[3], Timotei Bogdan BACOȘ[4], Adrian Eugen CIOABLĂ[5*]

[1,3,4,5]Faculty of Mechanical Engineering, University Politehnica Timisoara, Timisoara, Romania
[2]Faculty of Engineering Hunedoara, University Politehnica Timisoara, Hunedoara, Romania

Abstract
The driver position and posture during long activity hours can become a problem affecting overall health for speciffic activities relative to different jobs connected with driver applications. Current methods approach this aspect relative to obtaining results in different scenarios with applications on optimisation for driver posturality and overall short and long term benefits through added value of driver seat, activity and overall comfort. In this regard, the current paper aims to determine initial methods of analysis for driver posture in order to better determine solutions for optimising the overall ergonomic and confort aspects for drivers during long hour schedule.
Key words: posture, ergonomics, comfort, modern technology.

INTRODUCTION

In recent decades, contemporary society has witnessed a significant increase in sedentary lifestyle. This phenomenon is largely attributed to technological advances and social changes that have led to a reduction in daily physical activity. People spend more and more time in front of screens - whether it's computers, televisions, or mobile phones - and less time engaging in physical activities. The decrease in physical activity is partially due to inactivity in leisure time and sedentary behavior at work and at home. Additionally, an increase in the use of "passive" modes of transportation also contributes to insufficient physical activity [1,14].
A significant percentage of drivers suffer from back pain, and this pain is often associated with incorrect posture while driving. Education and awareness regarding correct posture can significantly reduce these problems, thus improving the comfort and safety of drivers

Fig 1. *Correct / Incorrect driver posture [2]*

Therefore, evaluating and monitoring the posture of drivers becomes essential to address and prevent health problems associated with this activity. This thesis aims to explore in detail the

[1] anca.sabau98@gmail.com
[2] mihaela.popa@upt.ro, ORCID: https://orcid.org/0000-0002-1435-645X
[3] gabrielastoia30@gmail.com
[4] bacost@yahoo.com
[5] Corresponding author, adrian.cioabla@upt.ro, ORCID: https://orcid.org/0000-0001-6261-0064

issue of driver posture, using modern motion sensor technologies to better evaluate and understand the factors that influence posture at the wheel. The posture that drivers adopt while driving is influenced by a series of factors that can vary from the individual characteristics of the driver to the ergonomic aspects of the vehicle. Understanding these factors is essential to develop efficient strategies for improving posture and reducing the risks associated with incorrect posture [15].
The design and ergonomics of the car seat play a crucial role in maintaining a correct posture [3]. Seats that do not provide adequate lumbar support, are not adjustable, or do not allow for a uniform distribution of body weight can contribute to adopting an incorrect posture. A well-designed seat should allow for adjustment in height and depth, provide support for the lumbar area, and ensure a comfortable position for the legs and arms, thus the trend analysis has shown that the equipment aspect is the most important factor influencing driving posture and that the main component is the driver's hip height [4].

Fig. 2. *Driver posture monitoring [5]*

The positioning of the steering wheel and pedals directly influences the posture of the driver [6]. The steering wheel should be positioned so that the driver can keep their arms slightly bent at an angle of approximately 120 degrees, avoiding excessive stretching or excessive bending of the arms. Additionally, the pedals should be placed so that the feet can operate comfortably and effortlessly. The optimal positioning of the pedals can prevent excessive stretching of the ankles and knees, contributing to a better distribution of pressure and reducing muscle fatigue [10].
Incorrect posture of the driver at the wheel can lead to a series of musculoskeletal conditions, influenced by the position adopted over long periods of time. These conditions include lower back pain, neck pain, carpal tunnel syndrome, and tendonitis [11-12].

POSTURE MONITORING TECHNOLOGIES

Monitoring the posture of drivers is essential to identify and correct postural problems, thus ensuring increased comfort and safety at the wheel. Modern technologies offer advanced solutions for evaluating and analyzing posture, allowing for the collection of precise and detailed data [13, 16, 17].

Triaxial Motion Sensors (TMS)

Triaxial motion sensors (TMS) are widely used for posture monitoring due to their ability to measure movements in three directions [7]. These sensors are mounted on the bodies of drivers and record data regarding their position and movements while driving. They can record movements in real-time, allowing for continuous monitoring and dynamic evaluation of posture under different driving conditions.

Electrogoniometric Technology

Electrogoniometers are devices used to measure the flexion and extension angles of joints during movement [3]. These devices are useful for monitoring posture at the wheel, as they can detect incorrect joint positions, such as incorrect angles of the knees and elbows, which can contribute to discomfort and musculoskeletal problems.

Pressure Analysis Systems

Pressure analysis systems use pressure sensors placed on seats and backrests to measure the distribution of body weight and the pressure exerted on different parts of the body [6]. These systems are essential for identifying areas of excessive pressure, which can cause discomfort and pain. The data obtained can be used to adjust the seat design and develop more ergonomic seats.

Motion Capture Technology

Motion capture technology involves using cameras and sensors to record the movements of drivers in real-time [3]. This technology provides a detailed visualization of posture and movements, allowing for the analysis of body dynamics and the identification of repetitive or incorrect

Analysis and Visualization Software

Analysis and visualization software, such as CAPTIV, are used to interpret data collected from various sensors [6]. These programs allow for a detailed analysis of movements and posture, providing graphs and reports that help identify postural problems.

Virtual Reality Technology (VR)

Virtual reality is used to simulate different driving scenarios and evaluate the posture of drivers in controlled environments [8]. VR allows for the recreation of various road and traffic conditions, offering the opportunity to study the reactions and postural adjustments of drivers in specific situations.

Applicability in Various Fields

These sensors are used in a wide range of applications, from ergonomics and medical rehabilitation to sports performance analysis and scientific research. Their versatility makes them an essential tool for professionals in various fields.

RESULTS AND DISCUSSION

The subject of the experiment is a person of medium stature, and the study will analyze this person's posture in various configurations of steering wheel, mirrors, and seat adjustments, simulating driving in different positions. The experiment aims to evaluate the posture of the driver using T-sens Motion sensors and to identify ergonomic configurations that offer optimal comfort and reduce the risk of musculoskeletal conditions [9]. Specific objectives include analyzing the impact of different steering wheel, mirror, and seat adjustments on the driver's posture and evaluating the effects of these positions on comfort and safety while driving.

Data analysis

The raw data collected from the sensors will be processed and organized using the CAPTIV software. Statistical analysis will evaluate the impact of different configurations on posture, and descriptive analysis will identify movement and posture patterns. The data will be used to identify incorrect positions and repetitive movements that can cause discomfort, correlating this information with ergonomic configurations. The results obtained will be interpreted to confirm or refute the initial hypotheses and to discuss the implications on the health and safety of the driver. Based on these results, recommendations will be developed to improve posture and vehicle ergonomics, including ergonomic adjustments and educational interventions for drivers. The recommendations will be tested in real conditions to evaluate their effectiveness, and participant feedback will be essential for adjusting and refining the recommendations.

Fig. 3. *Charging process for the used sensors*

To ensure accurate and efficient monitoring of movements and posture, the T-Sens Motion sensors must be correctly mounted on the participant's body using elastic bands (Figure 4) or other comfortable fastening devices, ensuring a firm attachment without limiting movements.

Fig. 4. *Elastic bands used for attaching sensors to the driver*

The elastic bands allow positioning of sensors in different scenarios and are versatile and easy to work with by the user.

Data interpretation

After initial preparation of experimental setup, the software allows configuring of data through means of a virtual avatar which will embody the studied driver through all the experiment.

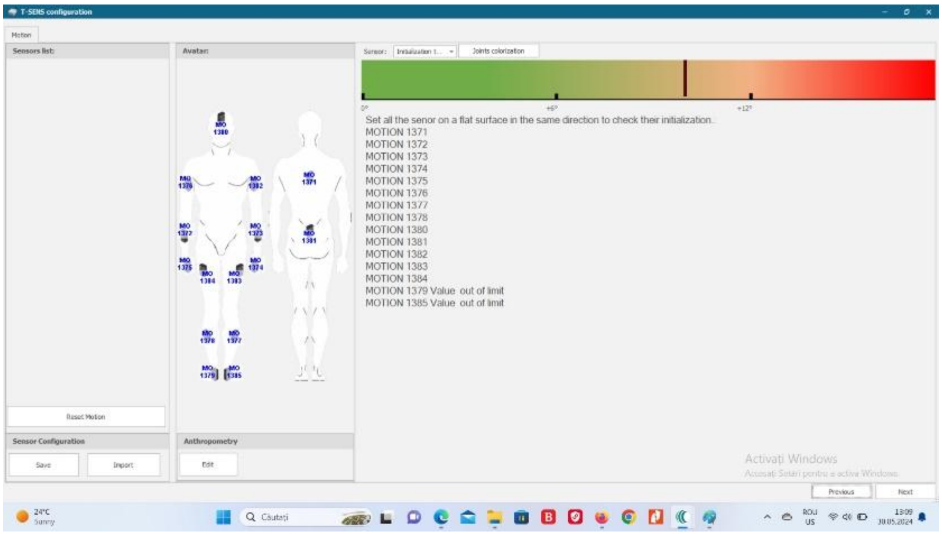

Fig. 5. *Virtual positioning of sensors on the driver [9]*

As it can be observed, the physical sensors are identifired and synchronized with the software in order to create the avatar of the test driver.

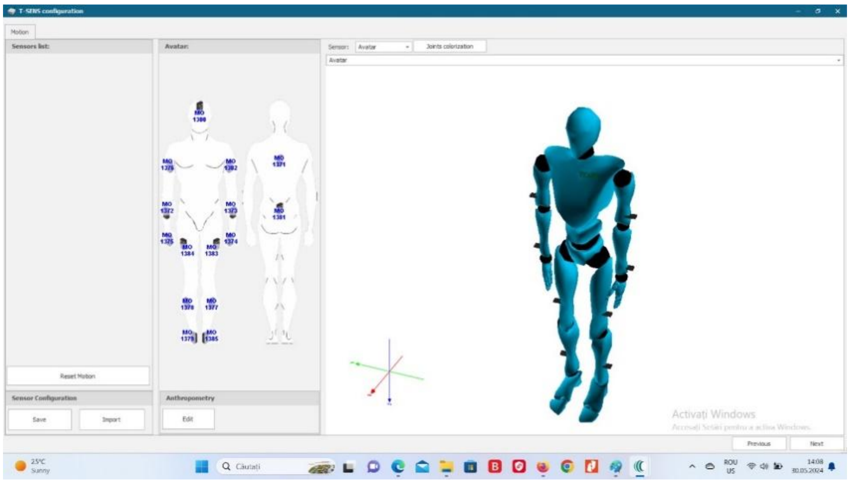

Fig. 6. *Virtual avatar [9]*

After the creation of the avatar, the experiments will be carried on and preliminary results relative to the overall status of the test driver will be monitored, stored and interpreted in order to determine the overall muscular tensions, and other physical stress parameters that can be later used for improving the driver posture, chair positioning and the overall ergonomic and comfort status and possibilities for improvement.

CONCLUSION

The present paper represents only the preliminary study of the current developing status for different technologies used nowadays for monitoring and improvement of driver ergonomics and overall posturality influence on the short and long term effects on human health. Further studies will be developed for improving the current level of research, using different scenarios for drivers and driving conditions.
The overall conclusion is that the current technology has a great impact on the research factors in the field of ergonomics and human health and can be further improved by connecting it with

different applicative scenarios personalized for different types of drivers, vehicles and driving conditions.

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PROJECT MANAGEMENT AND MAINTENANCE OPTIMIZATION IN INDUSTRIAL TECHNICAL SYSTEMS

Review paper

Peko Lakatuš[1]
[1]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: This paper explores the integration of AI-driven project management and predictive maintenance strategies within industrial technical systems. It discusses the adaptation of methodologies like Agile, Lean, and Waterfall to the specific demands of industrial environments, emphasizing the need for tailored approaches to optimize efficiency and reliability. The paper also examines the implementation of AI in predictive maintenance, highlighting the importance of data quality, sensor technology, and machine learning in preventing equipment failures and reducing downtime. The balance between cost and efficiency in maintenance practices is analyzed, with insights drawn from case studies in manufacturing and energy sectors. Additionally, the paper suggests strategies for governments, enterprises, and individuals to foster the development of integrative AI systems, including investments in research, cross-sector collaboration, and workforce training. The research questions focus on effective methodology adaptation and the important factors influencing AI-driven maintenance success, providing a roadmap for achieving seamless industrial automation.
Keywords: Project Management, Maintenance Optimization, Industrial Technical Systems, Predictive Maintenance, AI Integration, Agile Methodology, Lean Management, Industrial Automation.

INTRODUCTION

The integration of project management principles within industrial settings is a key factor in ensuring the success of technical systems. In environments where efficiency, precision, and safety are of utmost importance, traditional project management methodologies, such as Agile, Lean, or Waterfall, must be carefully adapted to meet the specific needs of industrial applications. These methodologies provide structured frameworks that guide the planning, execution, and monitoring of projects. However, the complexity of industrial systems, often characterized by large-scale operations, intricate workflows, and stringent regulatory requirements, presents unique challenges. To navigate these challenges, project management practices must be tailored to accommodate the distinct operational dynamics of industries such as manufacturing, energy production, and transportation [1]. This adaptation often involves a blend of multiple methodologies or the development of hybrid approaches that can address both the technical and organizational aspects of industrial projects. Understanding the impact of these methodologies on project outcomes and how they contribute to the overall optimization of technical systems is significant for achieving project success in these sectors

Another significant area of focus in industrial technical systems is the implementation of predictive maintenance strategies. These strategies are becoming increasingly important as industries seek to improve system reliability while reducing operational costs. Predictive maintenance involves the use of advanced technologies, such as IoT sensors, data analytics, and machine learning algorithms, to monitor the condition of equipment in real time and predict potential failures before they occur. This approach allows for maintenance activities to be scheduled based on actual equipment needs rather than fixed intervals, leading to more efficient use of resources and minimizing unplanned downtime. The adoption of predictive maintenance is particularly relevant in industries where equipment failure can result in significant financial losses, safety risks, or environmental impact. However, the integration of predictive maintenance into existing systems is not without challenges [2]. It requires significant investment in technology, data management, and skill development. Additionally, the accuracy of predictive models is dependent on the quality of data collected, making it essential to have robust data collection and analysis processes in place. The

[1] Corresponding author, peko.lakatus@gmail.com

exploration of predictive maintenance strategies in industrial systems provides valuable insights into how technology can be leveraged to improve system reliability and operational efficiency.

Balancing cost and efficiency is another important aspect of maintenance optimization in industrial technical systems. Maintenance activities are essential for ensuring the long-term performance and reliability of industrial equipment, but they also represent a significant portion of operational costs. The challenge lies in finding the optimal balance between reducing costs and maintaining high levels of efficiency and reliability. Different maintenance approaches, such as preventive, corrective, and condition-based maintenance, offer various cost-benefit trade-offs. Preventive maintenance, for example, involves regular inspections and servicing of equipment to prevent failures, but it can lead to unnecessary maintenance activities if not carefully managed. Corrective maintenance, on the other hand, involves repairing equipment after a failure has occurred, which can result in higher costs due to unplanned downtime and potential damage to other system components. Condition-based maintenance aims to optimize maintenance activities by monitoring equipment condition and performing maintenance only when necessary, thus reducing unnecessary work while preventing unexpected failures. Each of these approaches has its advantages and limitations, and the choice of strategy depends on factors such as the of the equipment, the cost of downtime, and the availability of resources. Understanding these trade-offs and developing strategies to optimize maintenance activities is essential for improving the cost-efficiency of industrial technical systems [3].

The practical application of these concepts can be illustrated through case studies of successful maintenance optimization in industrial technical systems. These case studies provide concrete examples of how different industries have approached the challenge of optimizing maintenance and project management practices to achieve better outcomes. For instance, companies in the manufacturing sector have implemented predictive maintenance systems that have significantly reduced downtime and maintenance costs, while energy companies have adopted integrated project management approaches to streamline operations and improve project delivery timelines. These examples not only highlight the potential benefits of maintenance optimization but also provide valuable lessons and best practices that can be applied across different industries. The analysis of these case studies offers a deeper understanding of how maintenance optimization can be achieved in practice and underscores the importance of a holistic approach that considers both technical and organizational factors.

PROJECT MANAGEMENT PRINCIPLES AND PREDICTIVE MAINTENANCE FOR SYSTEM RELIABILITY

The application of project management principles in industrial settings demands a nuanced understanding of both the methodologies themselves and the unique environments in which they are implemented. Industrial technical systems, which often encompass large-scale operations such as manufacturing plants, power generation facilities, and complex transportation networks, require a structured approach to project management that can accommodate their intricacies. Traditional project management methodologies like Agile, Lean, and Waterfall have proven effective across various industries, yet their direct application in industrial contexts often necessitates adaptation to meet specific operational requirements. In industrial environments, the scale and complexity of projects can be daunting. These projects typically involve the coordination of numerous teams, the integration of advanced technologies, and the adherence to stringent safety and regulatory standards. For instance, in the manufacturing sector, project management is significant in overseeing the development and deployment of production lines, ensuring that all components are delivered on time, installed correctly, and function as expected. Agile methodologies, known for their flexibility and iterative nature, can be particularly useful in managing such projects by allowing teams to adapt to changes quickly [4]. However, Agile's emphasis on short development cycles and frequent revisions might need to be balanced with the long lead times and high precision required in industrial projects. This can be achieved through hybrid approaches that incorporate the adaptability of Agile with the more rigid planning and documentation processes characteristic of Waterfall or Lean methodologies. Lean project management, with its focus on waste reduction and efficiency, is another methodology that aligns well with the objectives of industrial technical systems. Lean principles can be applied to streamline processes, reduce unnecessary steps, and improve the overall efficiency of project execution. For example, in the energy sector, Lean methodologies can help optimize the construction and maintenance of power plants by minimizing downtime and maximizing resource utilization. However, implementing Lean in industrial settings requires careful consideration of the specific processes involved and the potential risks of cutting too much, which could compromise safety or quality. The challenge lies in finding the right balance between efficiency and the thoroughness required in such important operations [6].

Waterfall methodology, known for its linear and sequential approach, can be beneficial in projects where clear and well-defined stages are necessary, such as the construction of infrastructure or the development of large-scale industrial systems. The clarity and structure provided by Waterfall can help ensure that each phase of the project is completed before moving on to the next, reducing the likelihood of costly errors or delays. However, the rigidity of Waterfall can also be a limitation in industrial projects where flexibility and adaptability are needed to respond to unexpected challenges or changes in scope. As a result, many industrial projects now employ a combination of Waterfall and Agile methodologies, allowing for a more structured approach while retaining the ability to adapt to changes as they arise. While the integration of project management methodologies in industrial settings is important for ensuring the success of technical systems, the adoption of predictive maintenance strategies plays an equally important role in enhancing system reliability and efficiency. Predictive maintenance represents a shift from traditional maintenance practices, which often rely on fixed schedules or reactive repairs, to a more proactive approach that uses data-driven insights to predict and prevent equipment failures. This approach is particularly valuable in industrial environments, where unplanned downtime can have significant financial and operational consequences.

Predictive maintenance involves the continuous monitoring of equipment using sensors and data analytics to detect signs of wear or impending failure. The data collected from these sensors is analyzed in real-time, allowing maintenance teams to identify potential issues before they escalate into major problems. For example, in the manufacturing industry, predictive maintenance can be used to monitor the condition of important machinery, such as conveyor belts or robotic arms, ensuring that any anomalies are detected early and addressed before they lead to production halts. Similarly, in the energy sector, predictive maintenance can help prevent outages by monitoring the health of key infrastructure components, such as turbines or transformers, and scheduling maintenance at optimal times to avoid disruptions in service. Implementing predictive maintenance in industrial technical systems requires significant investment in technology and infrastructure, including the deployment of IoT devices, the development of robust data management systems, and the training of personnel in data analysis and interpretation. Moreover, the success of predictive maintenance depends on the quality and accuracy of the data collected. Poor data quality can lead to incorrect predictions, resulting in either unnecessary maintenance or, worse, missed opportunities to prevent failures. Therefore, it is essential to establish strong data governance practices, including regular calibration of sensors, validation of data, and the use of advanced analytics tools to process and interpret the data effectively [7].

The benefits of predictive maintenance extend beyond just preventing equipment failures. It also contributes to optimizing maintenance schedules, reducing overall maintenance costs, and extending the lifespan of equipment. In industries where equipment downtime directly impacts revenue, such as in manufacturing or energy production, the ability to predict and prevent failures can provide a significant competitive advantage. Additionally, predictive maintenance can improve safety by identifying and mitigating potential hazards before they result in accidents or injuries. This is particularly important in industries with high safety risks, such as chemical processing or mining, where equipment failures can have catastrophic consequences. The adoption of predictive maintenance represents a key component of the broader trend toward digitalization and the use of big data in industrial operations. As more industries embrace these technologies, the ability to effectively predict and prevent equipment failures will become increasingly important for maintaining competitiveness and ensuring the reliability of industrial technical systems.

BALANCING COST AND EFFICIENCY IN MAINTENANCE OPTIMIZATION AND APPLICATION IN PRACTICE

Maintenance optimization in industrial technical systems is a multifaceted challenge that requires careful consideration of both cost and efficiency. Maintenance activities are integral to ensuring the reliability and longevity of equipment, but they also represent a significant financial investment. The complexity of industrial systems, with their diverse range of machinery and operational requirements, means that finding the right balance between cost-effective maintenance and high operational efficiency is not straightforward. Different maintenance approaches, such as preventive, corrective, and condition-based maintenance, each offer unique advantages and drawbacks, making the decision of which approach to implement a important one. Preventive maintenance is a widely used strategy that involves regularly scheduled inspections and servicing of equipment, regardless of its current condition. This approach is based on the assumption that regular maintenance can prevent unexpected failures and extend the life of the equipment. In industrial settings, preventive maintenance can be particularly effective for important machinery that is essential to continuous operations, such as turbines in power plants or assembly lines in manufacturing facilities. However, preventive maintenance can also lead to inefficiencies if not carefully managed. Over-maintenance, where equipment is serviced more frequently than necessary, can result in unnecessary downtime and increased operational costs. Additionally, preventive maintenance does not eliminate the risk of sudden failures between scheduled maintenance intervals, which can still disrupt operations and incur additional costs [8].

Corrective maintenance, in contrast, involves performing repairs after equipment has failed. While this approach can be more cost-effective in the short term by avoiding the costs associated with regular maintenance, it carries significant risks. Unplanned downtime resulting from equipment failure can be costly, particularly in industries where continuous operation is important. Furthermore, the cost of repairing or replacing damaged equipment after a failure can far exceed the costs of preventive maintenance. Corrective maintenance is often used for non-important equipment, where the financial impact of downtime is minimal, or when resources are limited and cannot support a more proactive maintenance strategy. However, relying too heavily on corrective maintenance can lead to a reactive rather than proactive maintenance culture, which can be detrimental to overall operational efficiency. Condition-based maintenance offers a more balanced approach by monitoring the actual condition of equipment and performing maintenance only when necessary. This strategy leverages data collected from sensors and other monitoring devices to assess the health of machinery in real time. Maintenance is then scheduled based on the actual wear and tear of the equipment, rather than on a predetermined schedule. This approach can significantly reduce maintenance costs by eliminating unnecessary work and minimizing the risk of unexpected failures. In industrial settings, condition-based maintenance is particularly valuable for important equipment, where early detection of potential issues can prevent costly downtime and extend the life of the machinery. However, implementing condition-based maintenance requires significant investment in technology and data analysis capabilities. Additionally, the success of this approach depends on the accuracy and reliability of the data collected, as well as the ability of maintenance teams to interpret this data and respond appropriately [9].

To better understand the practical implications of these maintenance strategies, it is instructive to examine case studies of successful maintenance optimization in industrial technical systems. These case studies provide real-world examples of how different

industries have approached the challenge of balancing cost and efficiency in maintenance activities. For instance, in the manufacturing industry, companies have successfully implemented condition-based maintenance strategies that have reduced downtime and maintenance costs while improving overall equipment effectiveness. These strategies often involve the integration of advanced technologies, such as IoT sensors and machine learning algorithms, to monitor equipment in real time and predict potential failures. The data-driven insights gained from these technologies allow maintenance teams to prioritize their efforts and focus on the areas where they can have the greatest impact. Another example can be found in the energy sector, where companies have adopted a combination of preventive and condition-based maintenance strategies to optimize the performance of important infrastructure, such as power plants and distribution networks. These companies have invested in sophisticated monitoring systems that provide continuous feedback on the condition of their equipment, enabling them to schedule maintenance activities more effectively and avoid costly outages. The use of predictive analytics has also played a key role in these efforts, allowing companies to anticipate potential issues and address them before they lead to failures. This proactive approach to maintenance has not only improved the reliability of energy systems but also reduced operational costs and improved safety [10].
In addition to these technological advancements, successful maintenance optimization also depends on the effective management of human resources. Maintenance teams must be well-trained and equipped to handle the complexities of modern industrial systems. This includes not only technical skills but also the ability to interpret data, make informed decisions, and collaborate with other teams across the organization. In some cases, companies have restructured their maintenance departments to create more cross-functional teams that can respond more quickly to emerging issues and work more efficiently. This organizational flexibility, combined with advanced maintenance strategies, has enabled these companies to achieve significant improvements in both cost-efficiency and system reliability.
The lessons learned from these case studies underscore the importance of adopting a holistic approach to maintenance optimization, one that considers not only the technical aspects of maintenance but also the organizational and human factors that contribute to its success. By examining the experiences of companies that have successfully optimized their maintenance practices, other organizations can gain valuable insights into how to approach their own maintenance challenges and improve the performance of their industrial technical systems.

SUGGESTIONS AND GUIDELINES FOR IMPROVING PROJECT MANAGEMENT AND MAINTENANCE OPTIMIZATION

To further enhance the effectiveness of AI integration in project management and maintenance, it is crucial to establish a strategic framework that guides the adoption and implementation of these technologies. By addressing key areas of investment, collaboration, and standardization, stakeholders can ensure a smoother transition and more successful outcomes in optimizing industrial processes.

- Governments and enterprises should prioritize funding for AI technologies that improve project management within industrial sectors. This investment will drive innovation, enabling the development of tools that improve planning, execution, and monitoring of complex industrial projects.
- Encouraging partnerships between these sectors can accelerate the development of specialized project management and maintenance solutions. Such collaborations can combine theoretical research with practical industry applications, leading to more effective and customized approaches.
- Establishing clear guidelines for incorporating AI into existing maintenance frameworks can help ensure consistency and reliability across industries. Standardized protocols will make it easier to adopt new technologies and maintain compatibility with existing systems.

- Enterprises should invest in upskilling their workforce to handle AI-powered tools and strategies effectively. Training programs focused on data analysis, machine learning, and system management will empower employees to maximize the benefits of these technologies.
- Ensuring high-quality data is essential for the success of AI-driven project management and maintenance optimization. Governments and enterprises should establish robust data governance policies to maintain accuracy, security, and reliability in AI applications.
- Enterprises should integrate AI-driven predictive maintenance into their operations to improve equipment reliability and minimize downtime. These technologies allow for proactive identification of potential issues, optimizing maintenance schedules and reducing costs.
- Setting up specialized research labs focused on AI in industrial contexts can drive continuous innovation in project management and maintenance. These labs can serve as experimental hubs where new technologies are tested and refined before wider implementation.
- Governments and enterprises should work together to develop and enforce ethical standards for AI use in project management and maintenance. These guidelines will ensure that AI technologies are applied responsibly, with considerations for privacy, security, and fairness.

DISCUSSION

The integration of AI systems into industrial technical environments offers transformative potential for both project management and maintenance optimization. As industries shift towards increased automation, adapting project management methodologies such as Agile, Lean, and Waterfall to these complex environments becomes crucial. Each methodology’s principles must be tailored to address the unique challenges posed by industrial systems to maintain efficiency, mitigate risks, and ensure timely project completion within budget constraints. When effectively combined with AI technologies, these methodologies can significantly streamline operations, enhance decision-making, and optimize resource allocation.

Predictive maintenance, supported by AI, represents a notable advancement in improving system reliability and operational efficiency. By leveraging real-time data and advanced machine learning algorithms, industries can proactively address equipment failures and schedule maintenance more strategically. This approach not only minimizes downtime and maintenance costs but also prolongs the lifespan of critical assets. However, the efficacy of predictive maintenance hinges on the quality of data, accuracy of predictive models, and the seamless integration of these systems into existing operations.

The challenge of balancing cost and efficiency in maintenance practices is central to industrial operations. The exploration of preventive, corrective, and condition-based maintenance approaches reveals that a one-size-fits-all solution does not exist. A tailored approach that considers specific industrial system needs and constraints is essential. The case studies discussed demonstrate how companies have successfully utilized AI and advanced technologies to optimize maintenance strategies, leading to notable improvements in performance and cost management.

Additionally, the development of AI systems for industrial automation necessitates a collaborative effort among governments, enterprises, and academic institutions. Investments in AI research, cross-sector partnerships, and standardized frameworks are critical for accelerating the adoption of AI-driven technologies. Workforce training and ethical guidelines are also vital to ensuring responsible and effective implementation.

As industries continue to integrate AI and automation, insights from successful implementations provide valuable lessons in best practices and potential challenges. The ongoing evolution of AI technologies and their application in industrial settings promise further advancements in efficiency, reliability, and overall system performance.

CONCLUSION

This study highlights the significant opportunities that AI integration offers in enhancing project management and maintenance optimization in industrial environments. By adapting project management methodologies to the complexities of industrial systems and leveraging predictive maintenance strategies, industries can achieve improved efficiency, reduced downtime, and extended asset lifespans. The successful integration of AI technologies into these processes demonstrates their potential to streamline operations, optimize resource allocation, and enhance decision-making.

The findings underscore the importance of a tailored approach to maintenance practices and the need for collaborative efforts in developing and implementing AI systems. The lessons learned from this study provide a roadmap for harnessing AI's potential to drive industrial automation, ultimately contributing to more resilient and competitive industrial systems. As AI technologies continue to evolve, they hold the promise of further advancements in operational performance and system reliability.

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OPTIMIZATION OF OIL PRODUCTION ON THE EXAMPLE OF LIBYA

Review paper

Branislava Radišić[1], Snežana Komatina[2], Slavica Prvulović[3], Snežana Filip[4], Dragana Kovač[5]
[1,2,3,4,5]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Abstract: In this paper we are studying the problems of oil manufasturing and methods for solving them on the oil field in Amal. Problems on the oil field in Amal are: deposition of paraffin, occurrence of stratified sand, inefficient operation of the gas-lift system, salt deposition, inefficient oil desalination, and environmental problems. Without taking additional measures and activities, production problems may worsen, causing an even greater reduction in oil production.
Key words: oil production in Libya, Amal oil field, production problems, solution to production problems

INTRODUCTION

Libya is a country rich in oil and natural resources and as such has become one of the world's energy producers. Improving and achieving optimal production in the oil sector is crucial for Libya's economic development and stability. Oil exploration in Libya began in 1955, and the first oil fields in Amal and Zelten were discovered in 1959. Today, the most significant oil and gas fields are: Amal, El Sharara, Mellitah, Brega, Zueitina, Sirtica, Es Sider, Abu Attifel, Amna, Sarir, Mesla, Bouri, Al Jurf, and others [1]. The leading Libyan National Oil Company is "The National Oil Corporation" (NOC), which covers about 70% of oil production. According to data from the website [2], Libya ranks ninth in the world in terms of oil reserves, a position it has held for the past decade. However, on its continent, Africa, it possesses almost the largest oil reserves [3].
Unfortunately, there are very important factors that affect oil and gas production and their export, namely: political instability, conflicts, technical problems, and lack of investment. These are the main limiting factors for achieving optimal oil production [4].
The focus of this research is primarily on technical problems at the Amal oil field, whose location is shown in Figure 1.

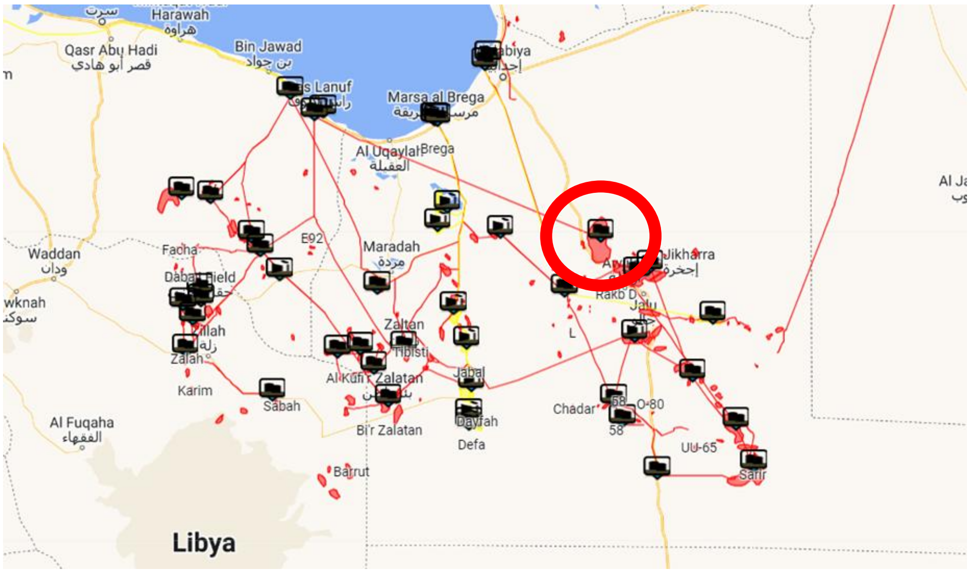


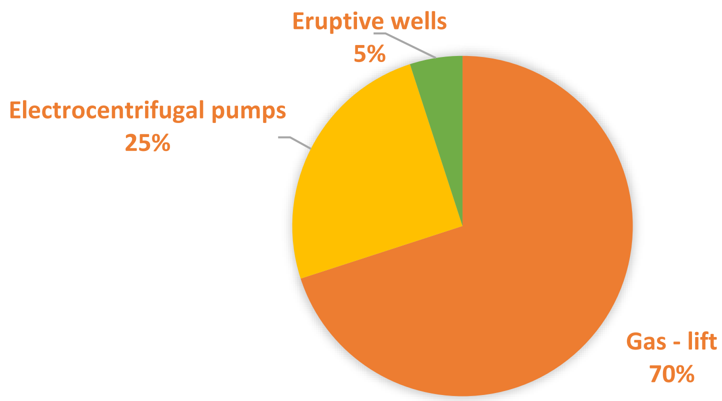
***Fig. 1**. Location of the Amal oil field [5]*

[1]Corresponding author. branislava.radisic999@gmail.com, ORCID: https://orcid.org/0009-0007-3664-2012
[2]komsne@yahoo.com, ORCID: https://orcid.org/0000-0002-2770-9306
[3]prvulovicslavica@yahoo.com, ORCID: https://orcid.org/0000-0001-6353-7145
[4]filipsnezana@gmail.com, ORCID: https://orcid.org/0000-0003-4113-9247
[5]milosavljevd@yahoo.com, ORCID https://orcid.org/0000-0002-5421-4376

MATERIAL AND METHODS

Amal Oil Field

The Amal oil field was discovered in 1959. It covers an area of over 100,000 hectares, where around 230 wells have been drilled. Of these, about 130 wells are in production, while around 60 are periodically inactive. Approximately 105 wells have been shut down, as they have been inactive for an extended period due to low production. It has been determined that oil production in this field is declining, and for this reason, in recent years, the focus has been on its intensive development. Various methods are being undertaken to mitigate or completely eradicate the problem of declining oil production from the Amal field [6].
Oil production at this field is carried out using mechanical extraction methods such as gas-lift (continuous) and electrocentrifugal pumps. Very few wells are operating through natural flow. Graph 1 shows the prevalence of extraction methods at the Amal field.



Graph *1. Exploitation Methods at the Amal oil field*

At Amal, both collection and preparation of produced fluids, i.e., the preparation of oil, water, and gas for further transport, are carried out. There are more than 10 gathering stations where oil, gas, and formation water are separated. The produced fluid is separated in three-phase separators, and before entering them, it is treated with demulsifiers. After that, the separated oil goes to degasser units where the remaining gas is extracted from the oil at atmospheric pressure. It is then directed to the dehydrator tank, where the formation water is separated. Afterward, desalination of the oil is performed, i.e., the removal of salt from the oil. Following this, the oil is directed to storage tanks. The oil from the Amal field contains paraffins, meaning it needs to be heated for further transport. There is no refinery on this oil field, but there is one on a neighboring field where the processing is done [7]

RESULTS AND DISCUSSION

Production Problems and Their Solutions at the Amal Oil Field

In general, production problems need to be solved on a daily basis. As already mentioned, oil production at the Amal field has been reduced. The key problems encountered during production are:

- paraffin deposition,
- the occurrence of formation sand,
- operation of the gas-lift system,
- salt deposition and oil desalination, and
- environmental problems.

The following sections will discuss each problem individually.

Paraffin Deposition

Paraffin deposition occurs in the upper part of the well and in the oil pipeline. Paraffin deposition in the oil pipeline is shown in Figure 2. During the production process, due to a decrease in temperature and pressure in the well and the oil pipeline, paraffins tend to precipitate from the oil. This problem is solved by mechanical removal and the application of chemical methods. At the Amal field, the intensity of deposition is high, requiring its rapid removal, as it can damage production equipment. Another reason why it is important to remove deposited paraffin quickly is to minimize well downtime. Due to the high intensity of deposition, the application of mechanical removal of paraffin is not efficient enough. All of this leads to a reduction in oil production [8].

***Fig** 2. Paraffin in the Oil Pipeline [8]*

To successfully resolve the problem of paraffin deposition, the following information is needed:

- *deposition intensity* – determined based on the established mass of deposited paraffin,
- *well temperature* – measured in the well, and
- *deposition rate* – allows for determining the type of crystallization and the nature of the problem.

The crystallization rate directly affects the shape (type) of paraffin crystals, which can be needle-like, irregular, plate-like, or microcrystals, and their appearance is shown in Figure 3.

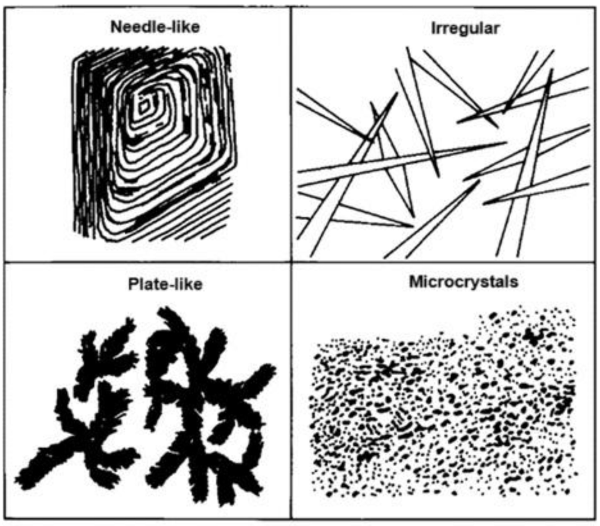


***Fig** 3. Types of Paraffin Crystals [9]*

The solution to the problem of paraffin deposition depends on the location of the deposition, as presented in Table 1.

Table 1. Methods for Solving Paraffin Deposition

Paraffin Deposition Problem	
Location	**Methods**
Perforations	Chemical methods
Well	Chemical methods
	Thermal methods
Oil pipeline	Chemical methods
	Thermal methods

The application of chemical methods for solving paraffin deposition has proven successful in the well and oil pipeline. It is necessary to pay attention to the dosing of additives that would prevent deposition. Thermal methods involve heating the well and oil pipeline using heating cables or electro-induction heating of the oil pipeline.

Occurrence of Formation Sand

Numerous problems at the Amal oil field are caused by the production of formation sand. Sand deposition can occur in the well and surface equipment. Deposition in the well occurs when the velocity of the produced fluid is not high enough to carry the formation sand to the surface. Its deposition causes a reduction in production, which can lead to a complete production stoppage. Additionally, its removal requires well shutdown, i.e., production interruption. Sand deposition in surface equipment occurs when the fluid velocities are high enough to carry the formation sand to the surface, which causes either a reduction in capacity or damage to the equipment [10]. This occurrence can also cause erosion of well and surface equipment, as well as the collapse of the formation in the near-wellbore zone. Erosion of surface equipment is shown in Figure 4.

***Fig** 4. Erosion Caused by Sand in the Valve [11]*

As far as is known, the problem of formation sand production at this oil field has not been addressed. However, the application of the "Gravel Pack" method would solve the problem of formation sand entering the well. To successfully implement this method, the following data are required:

- collection of formation sand samples: through coring, deep from the well, or on the well surface,
- conducting granulometric analysis of formation sand,
- determining the uniformity of formation sand,
- determining the optimal granulation of gravel and
- determining the optimal clearance of the filter.

The filter consists of three levels, as shown in Figure 5. The base of the filter is a perforated pipe with the tubing diameter, on which the first level of the filter is placed. The second level is the fill between the first and third layers of the filter, and it serves as a safety layer that prevents the penetration of formation sand. The third (outermost) level of the filter is made of trapezoidal wire, which also prevents the penetration of formation sand into the filter construction.

***Fig** 5. Cross-Section of the Filter [9]*

The Gravel pack fills the installed filter in the well, thereby preventing direct contact between the formation sand and the filter, which is crucial as it prevents damage to the filter.

Problems in Gas-Lift Operations

Problems in gas-lift operations may include:

- improper distribution of injected gas quantities,
- inadequate maintenance of compressor stations (compressors) – which prevents providing enough gas for well injection,
- improper gas-lift operational parameters,
- cooling of the well due to gas injection – which causes paraffin deposition,
- increased production of formation water.

In the case of well cooling due to gas injection, it is recommended to inject a smaller amount of gas at lower pressure or to dose an inhibitor to prevent paraffin deposition. In the case of increased formation water production, it is suggested to close existing perforations and open new ones above the water-oil contact or increase the amount of gas for injection. The most significant problems are improper distribution of injected gas quantities and improper gas-lift operational parameters. The distribution of injected gas quantities per well directly depends on their dynamic characteristics [12].

Salt Deposition and Oil Desalination

Crude oil at the Amal oil field contains salts in the form of sodium chloride, magnesium chloride, and calcium chloride. The cause of salt deposit formation in the well or the formation of so-called salt bridges is the occurrence of salts. Salt deposition leads to a reduction in oil production. The salt deposit in the well is removed mechanically, while the formation of salt bridges can be prevented by injecting fresh water along with the injected gas, so that the water keeps the salt in solution when it comes into contact with the produced fluid [13].

The problem of oil desalination at the Amal field can be solved by introducing crude oil into mixers with chokes as it passes through heaters. Immediately upon entering the crude oil heater, chemicals are injected. Fresh water is also introduced into the mixers with multiple chokes after passing through the heater. The mixers with chokes are used to increase the degree of mixing, as shown in Figure 6.

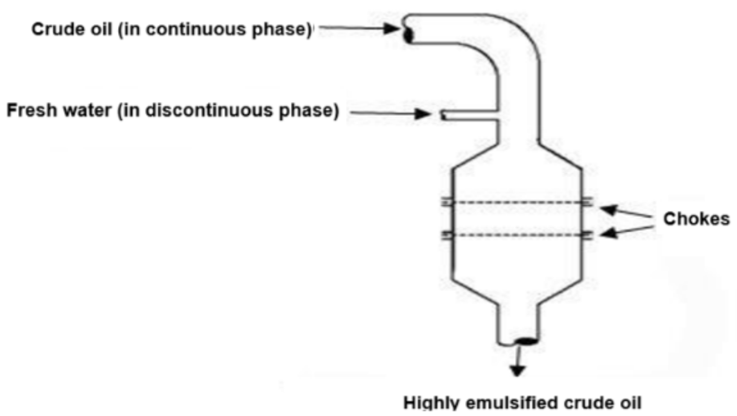


***Fig** 6. Mixer with chokes [9]*

After that, the emulsified crude oil is directed from the mixer with mufflers to the hydrocyclone, where the separation of water-soluble salts from the crude oil occurs. After this process, crude oil with a very small amount of salt is obtained at the top of the hydrocyclone, while a solution with a high salt concentration is separated at the bottom of the hydrocyclone. The hydrocyclone is shown in Figure 7.

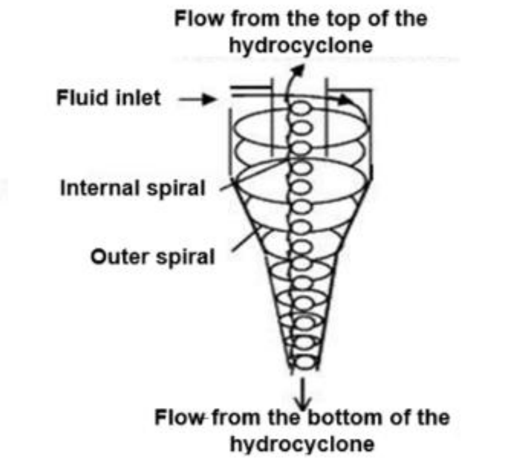


***Fig** 7. Hydrocyclone [9]*

Environmental Issues

Formation water and gas containing acidic components are the causes of environmental problems at the Amal field. Formation water is a byproduct of the oil and gas production process, and as such, it is discharged into the environment. There is a significant risk of environmental pollution, as it can penetrate underground and surface waters. The solution is quite complicated because there is no facility for the treatment of formation water at this field.

At certain wells, natural gas containing acidic components is produced. After processing, part of the gas is released into the atmosphere or burned off at flares, during which these harmful substances are also released. These harmful components can lead to an increase in the greenhouse effect and/or acid rain and soil contamination. The problem can be solved by redirecting the gas into a purification system before further use or combustion [14].

CONCLUSION

Conflicts and political instability often lead to disruptions in oil production and hinder investments. For the long-term development of the oil industry in this country, it is necessary to achieve a stable political environment. As the world's major powers increasingly care about sustainability and environmental protection, the Libyan oil industry must also address these issues. The use of environmentally friendly technologies and proper oil exploitation is key to the long-term success of the industry and environmental protection.

The application of advanced technologies such as horizontal drilling, hydraulic fracturing, and process monitoring with smart sensors can significantly improve the efficiency of oil extraction in Libya. These technological advancements enable access to harder-to-reach oil fields and increase the percentage of oil recovery from existing fields.

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POSSIBILITIES OF PURIFICATION OF OIL CONTAMINATED WATER USING PERLITE

Research paper

Danijela Jašin[1], Milana Drašković[1], Milada Novaković[1]
[1]Technical College of Applied Studies, Zrenjanin, Serbia

Abstract: It is known that oil is an extremely important resource for a whole range of industries, but spilt oil can pollute oceans, seas, rivers and, if it soaks through the soil and, groundwater.
This work presents the results of the use of fractions of expanded ground perlite of the industrial designation Perfit PF-220 GG, PF-220 and PF-245, obtained by the domestic producer Termika D.O.O. from Zrenjanin, in the purification of oil-contaminated water.
Key words: perlite, filtration, water purification

INTRODUCTION

Contamination of water with oil and oil derivatives is a significant environmental problem due to the harmful effects of these pollutants on human health and the environment. Oil and its derivatives, such as gasoline, diesel, and various lubricants, often enter waterways through industrial accidents, transportation, waste disposal, and other human activities. Due to their toxicity and ability to bioaccumulate, these pollutants can cause long-term environmental consequences, which requires effective methods for their removal and treatment [1].
Contaminated water purification methods can be divided into physical-chemical, chemical and biological methods, each of which has its own specific advantages and limitations [2]. The latest studies indicate the possibility of oil sorption by expanded perlite [3].
Perlite is an aluminosilicate material of volcanic origin. Raw perlite is found in nature in the form of rock. Depending on the site, the chemical composition of perlite also differs [4,5]. Raw perlite contains 2-5% crystal water. After grinding the ore, perlite is exposed to a temperature of about 1000°C [4,6]. At such a high temperature, pearlite expands and increases in volume 20-40 times [7]. The bound water evaporates and creates innumerable bubbles that provide the exceptional characteristics of perlite: porous structure, light weight and white color that distinguish perlite from other volcanic rocks. The chemical composition of raw perlite differs depending on the location (Greece, Hungary, Bulgaria and Turkey).
Features of perlite that make it irreplaceable in application:

- ecologically clean;
- chemically inactive;
- pH neutral.

Perlite used in this work includes ground expanded ground Perfit (PF-220 GG, PF-220, PF-245). Each of these types has specific characteristics that affect their effectiveness in the water purification process.
The physicochemical characteristics of perlite, such as granulation, density, porosity, and chemical composition, play a key role in its ability to adsorb and filter contaminants from water. These properties directly affect the interactions between perlite and contaminants. The physico-chemical characteristics of perlite are crucial for the evaluation of its filtration and adsorptive capacity.
The aim of the work is to examine the effectiveness of perlite in the purification of oil-contaminated water. The results of this research can have a significant contribution in the field of environmental engineering and environmental protection. By using perlite as a treatment agent for oil-contaminated water, it is possible to develop sustainable and efficient

[1] Corresponding author, danijelajasin@gmail.com

methods that will help conserve water resources and reduce the environmental footprint of oil.

MATERIAL AND METHODS

A solution of water and oil was used as the material. For the purposes of this research, a solution containing 5 liters (5l) of tap water and 5 milliliters (5ml) of processed oil was prepared. This specific ratio was chosen to adequately simulate the conditions of water pollution with oil, allowing for the precise effectiveness of perlite as a treatment agent.
In addition, ground expanded perlite, Perfit PF-220 GG, PF-220, PF-245, which was taken from the production plant of Termika doo from Zrenjanin, was used in order to test the filtration and adsorptive capacity of purifying oil-contaminated water. These pearlite types were thoroughly tested and characterized before the start of the experiment to ensure consistency of results. The characteristics of the product Perfit PF-245 obtained by grinding and cyclone separation of expanded perlite, chemical composition, physical - chemical characteristics, granulometric analysis, were taken from the manufacturer Termika D.O.O. Zrenjanin. The equipment used was a Turbidimeter (Eutech TN-100) and a vacuum pump with a 1000 ml vacuum bottle, as shown in Figure 1.

a) ***b)***

Figure 1. *a) Turbidimeter and b) Vacuum pump with vacuum bottle*

The method of determining the turbidity of the filtrate after the formation of the cake

After the procedure for determining the rate of filtration of the cake made from the sample of Perfit according to the "Instructions for determining the rate of filtration perlite" (TR-UPL-03-011), the turbidity of the filtrate is determined in accordance with the "Instructions for calibration and use of the turbidimeter" (TR-UPL-03-003), "Method for determining turbidity of filtrate after cake formation", internal method for quality control of ground expanded perlite "Termike D.O.O" Zrenjanin [8].

Formation of the filter cake

In a laboratory beaker, mix 300 ml of water and 140 ml of Perfit, this way you will get a 20 mm thick cake. Form a cake in a funnel with a mesh. Determine the NTU of the water to be used for recirculation. Recirculate water through the cake and measure the NTU (Nephelometric Turbidity unit) of the filtered water, until the turbidity level of the filtered water is the same as before filtration. Measure in measuring cups 3 x per 100 ml sample of water contaminated with oil. Pass these three samples through the formed cake and determine the degree of turbidity of the obtained filtrates.

RESULTS AND DISCUSSION

The physicochemical characteristics of perlite, such as granulation, density, porosity, and chemical composition, play a key role in its ability to adsorb and filter contaminants from water. These properties directly affect the interactions between perlite and contaminants. The chemical composition of perlite, physico-chemical properties and typical distribution of particle sizes by volume are shown in Tables 1, 2, and 3. The physico-chemical characteristics of perlite are crucial for the evaluation of its filtration and adsorptive capacity.

***Table 1**. Chemical composition of raw Greece'perlite and expanded perlite [8, 9]*

Content	**Row Greece' perlit (%)**	**Expanded perlite (%)**
SiO_2	74 - 76	68 - 75
Al_2O_3	13 - 14,5	10 - 12
Fe_2O_3	1,0 - 1,3	1 - 2,5
Mg_2O	0,25 - 0,45	0,2 - 1,5
CaO	1,4 - 1,8	1,5 - 2
Na_2O	4,5 - 5,5	2,8 - 4,5
K_2O	3,5 - 5	3,2 - 4,5
Loss on ignition	2,6 - 3,2	1,6 - 1,9

From Table 1, it can be seen that silicon (SiO_2) dominates the chemical composition of raw and expanded perlite with (74 to 76) % and (68 to 75) %. The results of this chemical composition show that there are no significant changes in the chemical composition of raw and expanded perlite.Typical values of the most important physical properties of raw Greek perlite and expanded perlite are given in Table 2.

***Table 2.** Physical properties of raw perlite and expanded perlite [8]*

Property	**Value**
Color	Light gray color (unexpanded) White color (expanded)
pH	6,5-7,5 (unexpanded) 8,1-8,2 (expanded)
Specific Gravity (raw perlit)	2,2 g/cm^3-2,4 g/cm^3
Bulk Density	Raw perlit: 1100 kg/m^3-1200 kg/m^3 Expanded: 105 kg/m^3
Melting point (raw perlit)	1250 °C-1350 °C

Similar results were obtained by [11, 12] when it comes to the chemical and physical properties of raw perlite and expanded perlite. The distribution of particle sizes by volume is shown in Table 3. The granulometric characteristics of PF-245 show that 90% of the particles are smaller than 47 μm.

***Table 3**. Particle size Perfit PF-245, PF-220 GG and PF-220*

Parameter	Specific surface area (m^2/g)	d 0,1%-10% of particles pass through a sieve of: (μm)	d 0,5%-50% of particles pass through a sieve of: (μm)	d 0,9%-90% of particles pass through a sieve of: (μm)
Perfit PF-245	0,90	3	15	47
Perfit PF-220 GG	0,37	8	31	322
Perfit PF-220	0,59	5	21	85

The results of testing the effectiveness of perlite in the purification of oil-contaminated water include turbidity measurements. The results after filtration of oil-contaminated water through PF-220 GG, PF-220, and PF-245 cakes are given in Table 4 and Figure 2.

***Table 4.** The results after filtration of oil-contaminated water through PF-220 GG, PF-220, and PF-245 cakes*

	After filtration through PF-220 GG, PF-220 and PF-245 cakes		
	PF-220 GG	PF-220	PF-245
	NTU	NTU	NTU
Sample 1	8.48	10.35	22.60
Sample 2	7.61	11.16	22,00
Sample 3	7.28	11.56	22.30
Mean value	7.79	11.02	22.30

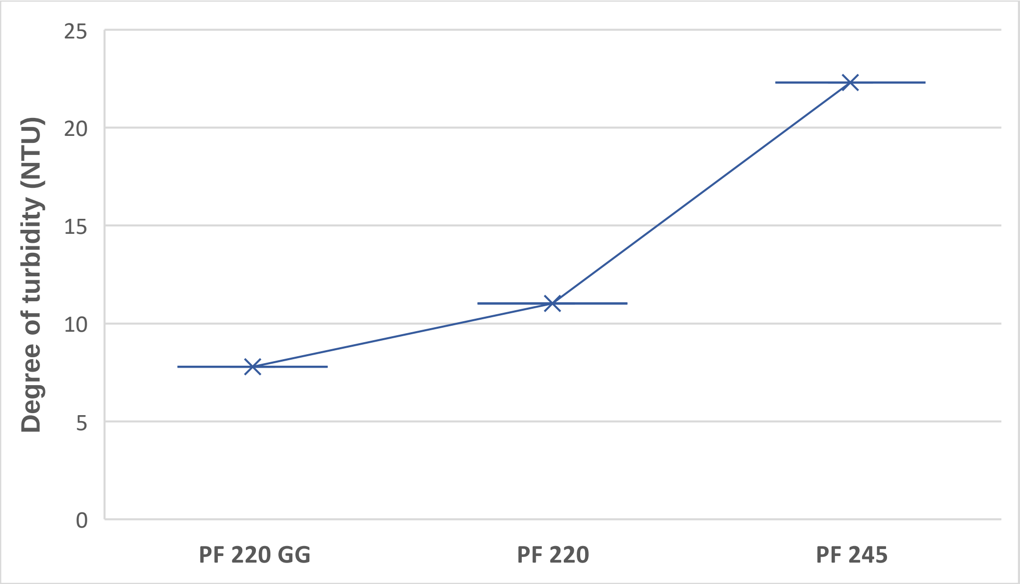

***Figure 2.** Graphic representation of results after filtration of oil-contaminated water through PF-220 GG, PF-220, and PF-245 cakes*

From the results, it can be concluded that the cake made of ground expanded perlite, PF-220 GG, proved to be the most effective for the filtration of oil-contaminated water, while the cake made of Perfit PF-245 is not adequate for the filtration of oil-contaminated water. During filtration, PF-245 particles passed through the vacuum filter mesh and entered the solution, which caused poor measurement results.

The effectiveness of the oil-contaminated water purification method can be assessed as acceptable based on the results obtained. Although complete removal of contaminants has not been achieved, significant reductions in pollutant concentrations have been achieved. The percentage reduction varies, but in all cases there is a certain reduction of contaminants, which is an indication of the effectiveness of the method.

Today, a combination of physical, chemical and biological methods, including the use of perlite, are used to treat oil-contaminated water. Each of these methods has its own advantages and challenges. Physical methods are fast and effective, but do not always remove dissolved petroleum products. Chemical methods can be expensive and sometimes create additional pollutants. Biological methods are sustainable and environmentally friendly, but require specific conditions and a longer time to achieve results. Perlite, thanks to its porous structure and high adsorption capacity, can effectively remove oil pollutants, contributing to a more comprehensive purification.

CONCLUSION

Treatment of oil-contaminated water is a key challenge that requires innovative and integrated approaches. Oil and its derivatives can cause serious environmental damage, endangering aquatic ecosystems and the health of living beings. Effective treatment methods are therefore necessary to preserve water resources and protect the environment.
The purification method used in this experiment showed significant potential for reducing oil contamination of water. Considering the results achieved, it can be considered that this purification method is acceptable and effective, although further research could help to optimize the process in order to achieve an even greater reduction of contaminants.

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ANALYSIS OF TEMPERATURE DROP AND HEAT LOSSES OF CRUDE OIL ALONG THE MAIN OIL PIPELINE

Research paper

Jasna Tolmač[1*], Slavica Prvulović[1], Saša Jovanović[2], Uroš Šarenac[1], Branislava Radišič[1]
[1]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin
[2]University of Pristina, Faculty of Technical Sciences, Kosovska Mitrovica, 38220, Kosovo

Abstract: The paper describes an analysis of the temperature drop and heat losses of crude oil along the l = 91000 m main oil pipeline. The analysis was performed for domestic paraffin oil with an average paraffin content of 15% and a pour point of 26 °C, when the initial heating temperature is t_1 = 40 °C. Such oils have high flow temperatures and unfavorable characteristics for pipeline transport. When transporting heated crude oil through pipelines, the temperature of the oil at the end of the pipeline must not be lower than the pour point. During the transportation of heated crude oil, there is an exchange of heat with the surrounding soil. This is how the oil temperature drops in the direction of its flow. The following parameters have the most influence on the temperature drop along the oil pipeline: mass flow m (kg/s), heat capacity of transported crude oil c_n (J/kgK), heat conduction coefficient kD_m (W/mK), pipeline length l (m). Determining the optimal heating temperature before introduction into the pipeline is information that is necessary when designing an oil pipeline.
Key words: paraffin, pipeline, flow, temperature, heat losses

INTRODUCTION

Each oil field produces oil of certain characteristics, density and viscosity. It is difficult to find two oils of the same composition in nature. Based on that, for each type of crude oil, the flow properties are determined and suitable solutions for transportation are found, [1].
The paraffin content is a key parameter that is analyzed when determining the fluidity of oil. Domestic oils are paraffin-type oils, from the oil fields of Vojvodina - Serbia. The average paraffin content of domestic oils is 15%, and the pour point is 26 °C. Such oils have high flow temperatures and unfavorable characteristics for pipeline transport. When transporting heated crude oil through pipelines, the temperature of the oil at the end of the pipeline must not be lower than the pour point.
If there is an interruption in the flow and cooling of the oil in the pipeline below the flow temperature, the paraffins will crystallize, causing gelation of the oil mass in the pipeline and problems with the operation of the pump, especially in winter. Under such conditions, re-establishment of flow will require significantly higher pressure. Wax deposits in pipelines cannot be easily removed due to its hardening over time. For these reasons, losses occur in transport and production.
The goal of the work is to determine the information that is necessary for the design of the oil pipeline, such as the optimal heating temperature of the transported oil t_1, along with the analysis of the temperature drop Δt and heat losses, along the main oil pipeline.

ANALYSIS OF TEMPERATURE DROP AND HEAT LOSSES OF CRUDE OIL ALONG THE MAIN OIL PIPELINE l = 91000 m

The case was considered when the paraffinic crude oil is heated to the starting temperature t_1 = 40 °C, before being introduced into the main oil pipeline with a diameter of D_{ca} = 457 mm. The oil pipeline is isolated with polyurethane foam, and the thickness of the isolation is s = 100 mm.

[1]Corresponding author, jasna.tolmac@tfzr.rs, https://orcid.org/0000-0003-3860-2034
[2]slavica.prvulovic@tfzr.rs, https://orcid.org/ 0000-0001-6353-7145
[3]sasa.m.jovanovic@pr.ac.rs, https://orcid.org/ 0009-0006-9728-0695
[4]uros.sarenac@tfzr.rs, https://orcid.org/ 0009-0007-6619-6076
[5] branislava.radisic@tfzr.rs, https://orcid.org/0009-0007-3664-2012

Crude oil is pre-heated in a tank with a volume of V = 15000 m^3. Heating is done with superheated steam of pressure p = 4 bar, and temperature t = 160 ^oC, using a heat exchanger - heater, thermal power of 9 MW. The density of oil is approximately 875 kg/m^3.
The oil pipeline is digg into the ground at a depth of h = 1 m. During the transportation of heated crude oil, there is an exchange of heat with the surrounding soil. This is how the oil temperature drops in the direction of its flow. The following parameters have the most influence on the temperature drop along the oil pipeline: mass flow m (kg/s), heat capacity of transported crude oil c_n (J/kgK), heat conduction coefficient kD_m (W/mK), pipeline length l (m).
The temperature drop along the pipeline is determined based on the well-known equation (1) which shows the exponential dependence between the starting and ending temperatures of crude oil, [2].
Based on the following equations, the results for the temperature drop along the oil pipeline were determined and are given in Table 1.

$$t_2 = t_1 e^{-al} \tag{1}$$

$$al = \frac{kD_m \pi l}{mc_n} \tag{2}$$

The results are given for paraffinic crude oil with a pour point of max. 26 ^oC. The oil is heated to the starting temperature t_1 = 40 ^oC.
In Table 1, the values of the temperature drop along the main oil pipeline, at a length of l = 91000 m, for different flow values are determined.

Table 1. *Temperature drop along the pipeline (outer diameter D_{ca} = 457 mm, length l = 91000 m)*

1	Flow - transport capacity G (t/h)	486	525	558	612
2	Mass flow m (kg/s)	135	146	155	170
3	Heat conduction coefficient kD_m (W/mK)	0,32	0,32	0,32	0,32
4	Temperature t_2 (^oC) on lenght l = 0 (m)	40	40	40	40
5	Temperature t_2 (^oC) on lenght l = 22750 (m)	36,56	36,81	36,98	37,24
6	Temperature t_2 (^oC) on lenght l = 45500 (m)	33,44	33,87	34,22	34,70
7	Temperature t_2 (^oC) on lenght l = 68250 (m)	30,56	31,21	31,65	32,33
8	Temperature t_2 (^oC) on lenght l = 91000 (m)	27,95	28,72	29,27	30,07

After being introduced into the main oil pipeline during transportation, the oil cools down and releases its heat to the surrounding environment. Heat losses on the entire length of the oil pipeline for different time intervals during oil transport are given in Tables 2 to 5, for different transport capacities: (486, 525, 558, 612) t/h.

Table 2. *Heat losses during non-isothermal flow of crude oil through a digg into pipeline, at transport capacity G = 486 t/h*

	Heat losses Q_g (MJ/h)	Specific heat losses q_m (kJ/mh)	Thermal power losses q_w (W/m)	The length of the pipeline section l (m)	Time interval during oil transportation τ (h)
1	675	139	38,61	4860	1,00

2	3151	138	38,33	22750	5,85
3	6009	132	36,70	45500	11,70
4	8648	127	35,27	68250	17,55
5	11039	121	33,61	91000	23,40

Table 3. *Heat losses during non-isothermal flow of crude oil through a digg into pipeline, at transport capacity G = 525 t/h*

	Heat losses Q_g (MJ/h)	Specific heat losses q_m (kJ/mh)	Thermal power losses q_w (W/m)	The length of the pipeline section l (m)	Time interval during oil transportation τ (h)
1	680	140	38,88	4860	1,00
2	3156	139	38,61	22750	5,44
3	6067	133	36,94	45500	10,90
4	8698	127	35,27	68250	16,40
5	11162	123	34,16	91000	21,80

Table 4. *Heat losses during non-isothermal flow of crude oil through a digg into pipeline, at transport capacity G = 558 t/h*

	Heat losses Q_g (MJ/h)	Specific heat losses q_m (kJ/mh)	Thermal power losses q_w (W/m)	The length of the pipeline section l (m)	Time interval during oil transportation τ (h)
1	714	147	40,83	4860	1,00
2	3176	140	38,88	22750	5,14
3	6079	134	37,22	45500	10,27
4	8782	129	35,83	68250	15,47
5	11286	124	34,44	91000	20,55

Table 5. *Heat losses during non-isothermal flow of crude oil through a digg into pipeline, at transport capacity G = 612 t/h*

	Heat losses Q_g (MJ/h) (MW)	Specific heat losses q_m (kJ/mh)	Thermal power losses q_w (W/m)	The length of the pipeline section l (m)	Time interval during oil transportation τ (h)
1	150 0,04	150	41,70	1000	0,20
2	719 0,19	148	41,11	4860	1,00
3	3183 0,88	140	39,00	22750	4,68
4	6114 1,70	134	37,22	45500	9,36
5	8848 2,45	129	35,83	68250	14,40
6	11455 3,18	126	35,00	91000	18,00

TEMPERATURE DROP RESEARCH RESULTS AND DISCUSSION

At the transport capacity G = 612 t/h, the oil temperature at the end of the main oil pipeline is t_2 = 30,07 ^oC, Table 1. The pour point of paraffinic crude oil is 26 ^oC, so the temperature difference is +4,07 ^oC, which means that solid paraffin particles will not appear, i.e. there will be no solidification of crude oil at maximum transport capacity. Results are given for paraffinic

crude oil, pour point max. 26 °C. At the same time, the oil is heated to the initial temperature t_1 = 40 °C, which is also the optimal temperature.
At the transport capacity *G* = 486 t/h, the oil temperature at the end of the main pipeline is t_2 = 27,95 °C, Table 1. The pour point of paraffinic crude oil is 26 °C, so the difference in temperature is +1,95 °C, which means that there will be no solidification of crude oil even with minimum transport capacity. By heating the crude oil before introducing it into the pipeline, the level of transport reliability is increased.
The mean value of heat losses is q_m = 138 kJ/mh (38 W/m), Tables 2 to 5, at stationary thermal and hydraulic mode of transport. During transportation, the oil cools down and releases its heat to the environment. This is about the flow of heat between the system (pipeline) and the environment (surrounding soil). The heat from the pipeline with a higher temperature is transferred to the surrounding ground with a lower temperature.
At the beginning of pumping, the specific heat losses are higher since the surrounding environment is unheated. How the pumping time ie. transport increases, specific heat losses decrease, due to the heating of the soil around the pipeline and the reduction of the temperature difference between the pipeline and the environment.
For example, at the maximum transport capacity, after 4,68 h from the start of pumping - transport, heat losses amount to 140 kJ/mh, (39 W/m), and after 18 h, from the start of transport, heat losses amount to 126 kJ/mh, (35 W/m), Table 5. Based on the research, a model was obtained that enables the calculation of heat losses along the entire length of the pipeline, for different time intervals during oil transportation.
Based on the results given in Table 5, Figure 1 is given, which shows specific heat losses on the entire length of the oil pipeline.

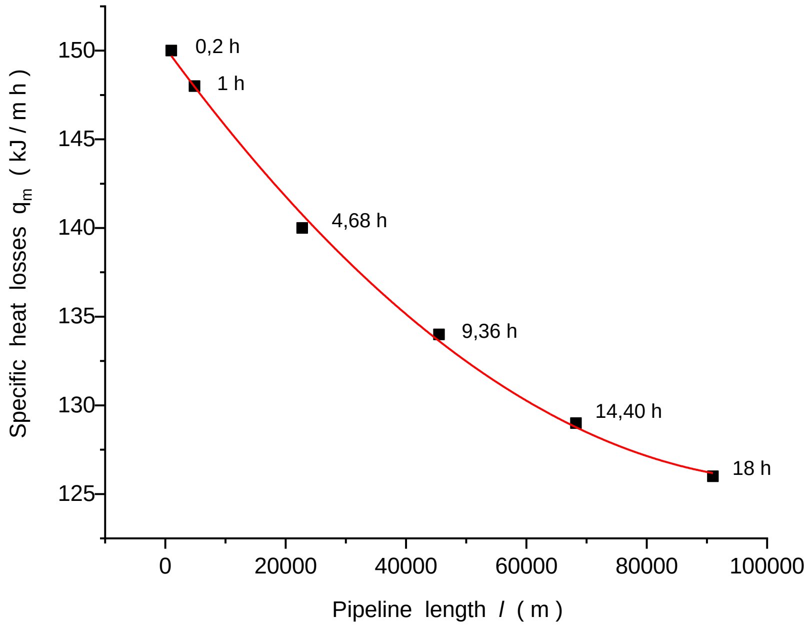

Fig. 1. *Specific heat losses along the oil pipeline*

Heat losses depend on the heat transfer coefficient, the diameter and length of the pipeline and the oil temperature at the beginning and end of the pipeline. The values of heat losses through the pipeline are calculated based on the well-known formula (3), which takes into account the mass flow of crude oil, the specific heat capacity of oil and the difference in temperature of crude oil at the beginning and end of the pipeline.
The optimal heating temperature of crude oil, before introduction into the pipeline, is influenced by the paraffin content, the flow temperature and the concrete operating conditions of the pipeline [3, 4].
During the transportation of heated crude oil, there is an exchange of heat with the environment. This is how the oil temperature drops in the direction of its flow. From the

transported crude oil, heat is transferred to the pipeline and is represented by the following equation [1], [5,6]:

$$Q = mc_n \left(t_1 - t_x\right) \quad (3)$$

where is:
m (kg/s) – mass flow,
t_1 (°C) i t_x (°C) – middle temperatures per section at the beginning and at the distance x (m), from the beginning of the pipeline,
c_n (J/kgK) – specific heat capacity.
The average value of the specific heat capacity of oil at standard conditions amounts to
c_n = 1885 J/kgK, [2].

In Figure 2, the research results are given, which show the dependence of the temperature change along the main oil pipeline, for different mass flows. For higher oil flow, a smaller temperature drop along the pipeline is obtained, and for lower oil flow values, larger temperature drops are obtained along the pipeline.

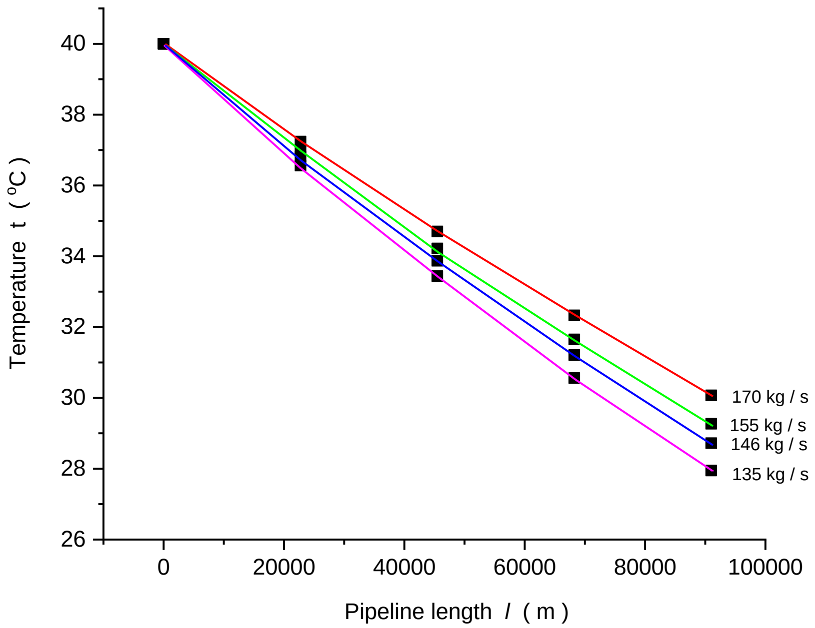

Fig. 2. *Temperature drop along the oil pipeline for different flows when the initial oil temperature is* t_1= *40 °C*

Depending on the transport capacity, the oil temperature t_2 at the end of the pipeline ranged from 27,95 to 30,07 °C. The pour point of crude oil is max. 26 °C. Based on that, the temperature of crude oil at the end of the pipeline is higher than the pour point by 1,95 to 4,07 °C, which enables a safe process of transporting crude oil, i.e. there will be no appearance of paraffin in the pipeline and solidification of crude oil in the pipeline, considering that paraffins are in a liquid state at temperatures higher than 26 °C. Based on this, the heating temperature of crude oil is t_1 = 40 °C, the optimal temperature.
For the operating regime of the flow in the range m = 135 – 170 kg/s (486 – 612 t/h), at the initial oil temperature of t_1 = 40 °C, the temperature values at the end of the oil pipeline were obtained in the range of t_2 = 28 – 30 °C, i.e. the temperature drop along the entire route of the oil pipeline was Δt = 10 –12 °C, [7].
If the flow is interrupted and the oil in the pipeline cools down below the flow temperature, the paraffins will crystallize, causing the gelation of oil mass in the pipeline [8]. For these reasons, the operating conditions of the oil pipeline are designed so that the temperature of the oil is always above the flow temperature.

If there is a stoppage during the transportation of oil at the flow temperature (pour point), the oil gelation occurs in the pipeline. In such conditions, re-establishment of the flow will require significantly higher pressure [9, 10].

CONCLUSION

Improving the technique of transporting oil by pipelines aims to increase the efficiency and economy of these transport systems, i.e. reduction of energy and investment costs. Therefore, further research in this area is necessary in order to find optimal models and numerical values of relevant parameters of the transport process that would correspond as realistically as possible to real systems. For these reasons, the paper presents theoretical and experimental research in determining the temperature drop and heat losses along the main oil pipeline with a length of l = 91000 m.

The optimal heating temperature of crude oil before introduction into the pipeline depends on the physical characteristics of the oil and its pour point. When transporting domestic paraffin oil with 15% paraffin and a pour point of 26 ^{o}C, the heating temperature was t_1 = 40 ^{o}C, while, depending on the transport capacity, the oil temperature at the end of the pipeline was in the interval t_2 = 28-30 ^{o}C.

Preheated crude oil to initial temperature t_1 = 40 ^{o}C cools down during flow through the pipeline and transfers its heat to the surrounding environment. Cooling of heated crude oil is carried out to a temperature above the pour point, i.e. up to max. 26 ^{o}C. The temperature to which the crude oil is cooled is of great practical importance, considering that at a lower temperature the fluidity of the oil decreases and paraffin appears in the pipeline.

The characteristic of oil pipeline changes with changes in oil temperature and viscosity. In order for the operating point of the pumping station to always be in a narrow area and to be as close as possible to the point for which the pumping station was designed, the characteristic of the pipeline must also be kept approximately constant. This is achieved by heating the crude oil to the optimal temperature. When transporting crude oil through pipelines, the temperature of the oil at the end of the pipeline must not be lower than the pour point.

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THE IMPORTANCE OF BUSINESS INCUBATORS FOR THE IMPLEMENTATION OF ENERGY MANAGEMENT

Review paper

Vladimir Milošev[1*], Rade Dragović[2], Igor Kostovski[3]
[1,2,3]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: This paper explains the key role of business incubators in advancing energy management initiatives in entrepreneurial ecosystems. It indicates that by providing basic resources, mentoring and networking opportunities, incubators empower startups to develop innovative solutions that improve energy efficiency and sustainability, and thus receive support that facilitates the creation of new business models and technologies that address pressing energy challenges. Through collaborative efforts, incubators foster partnerships among entrepreneurs, investors and industry experts, fostering the growth of sustainable practices. Ultimately, business incubators serve as vital catalysts for promoting efficient energy management strategies, contributing to a greener and more resilient economy.
Key words: business incubators, energy management, entrepreneurial ecosystems.

INTRODUCTION

The business incubator (BI) is the smallest, i.e. micro-initiator of entrepreneurial ecosystems, since one incubator includes many participants, e.g. entrepreneurs, mentors, service staff and investors, who share contextual conditions such as basic infrastructure, local economy and government policies, which comprise an ecosystem with clear boundaries and goals. The concept of business incubators began in the 1950s, and its popularity has continued throughout the world in the development of entrepreneurship. BI is an organization that helps new startup companies grow by providing support services such as office space, management training and professional staff support. Current studies are more interested in technology-focused BI because the fastest growing businesses are technology-related. Six of the 10 largest billionaire companies on the Forbes list are technology entrepreneurs, e.g. founders of Microsoft, Facebook, Amazon, Google, etc. Since the 1980s, BI have become a booming industry worldwide as information on technology and high-tech developments have been paramount to the fastest growing business for both small and medium-sized enterprises (SME) and the largest corporations [1].

Energy management is a strategic approach to the control and optimization of energy use in various contexts, from industrial facilities to commercial buildings and residential houses. It involves systematic planning, monitoring and conservation of energy resources to achieve efficiency, reduce costs and minimize environmental impacts. The importance of energy management has grown significantly in recent years due to increased awareness of climate change, rising energy costs and the need for sustainable practices. By implementing effective energy management practices, organizations and individuals can not only reduce their carbon footprint, but also improve operational efficiency and competitiveness. Effective energy management requires cross-departmental cooperation, management commitment, and continuous evaluation and improvement of energy performance. By adopting a holistic approach to energy management, organizations and individuals can achieve significant cost savings, environmental benefits and positively contribute to a sustainable future [2].

Based on everything mentioned and on the basis of previous research, this paper will analyze the possibilities of business incubators, how with their available and mentioned capacities they can usefully serve as a guide for the implementation of energy management in entrepreneurial ecosystems, especially in startups whose most important position is "how to rationalize everything types of consumption that are part of fixed

[1]Corresponding author, vladimir.milosev@tfzr.rs, ORCID: https://orcid.org/0009-0004-2904-7627
[2]rade.dragovic@tfzr.rs, ORCID: https://orcid.org/0000-0002-0215-4076
[3]igor.kostovski@tfzr.rs, ORCID: https://orcid.org/0000-0003-3938-9538

allowances".

BUSINESS INCUBATORS

A business incubator is an organization or space that provides support to startups and entrepreneurial ecosystems in the development of business ideas and the launch of new projects. BI typically offer co-working spaces, mentoring support, training, connections to investors, and other resources necessary for entrepreneurial ecosystems to succeed. Their primary purpose is to provide a nurturing environment and a range of resources and services to help entrepreneurs turn their innovative ideas into successful and sustainable businesses. BI often aim to help entrepreneurs overcome challenges they may have in the early stages of a business and provide them with an environment in which to grow and develop. Efforts to support the formation and maintenance of emerging businesses have launched business incubators as an important mechanism to support entrepreneurship [3].

Despite a significant increase in interest among academics, citizens and policy makers, there is only limited consensus on what business incubators are and what factors contribute to the success of business incubators. The focus of much of the research on business incubators was on the social and fiscal contribution from various aspects of government policy and vice versa. The rapid expansion of business incubators means that there is a need to develop a systematic approach to measuring their performance. A comprehensive performance measurement framework can help BI managers identify their strengths and weaknesses and develop evidence-based improvement plans. The wide range of criteria used to assess the performance of BI makes it difficult to determine the performance of individual BI and also creates challenges when trying to undertake meaningful comparisons between BI [4].

By summarizing all the elements that characterize BI, the following types of business incubators can be distinguished:

1. Vertical-specific incubators – focus on a certain industry or sector, such as technology, healthcare or food;
2. Generalist incubators - cover a wide range of entrepreneurial ecosystems in various industries;
3. Corporate incubators - they are established by large corporations in order to support ecosystems in their industry;
4. University incubators - are often associated with universities or research institutions, offering ecosystems access to academic resources, research facilities and expertise;
5. Government-supported incubators - are initiatives supported by government agencies or organizations for economic development [5].

Business incubation is a concept that includes several interested parties, dozens of different "objects", different types of resources and several categories of services (altogether about 100 specific services). The models shown in Figure 1. have been developed by researchers, consultants and practitioners since 1985, here as of 2013. They have created about 20 different models [6].

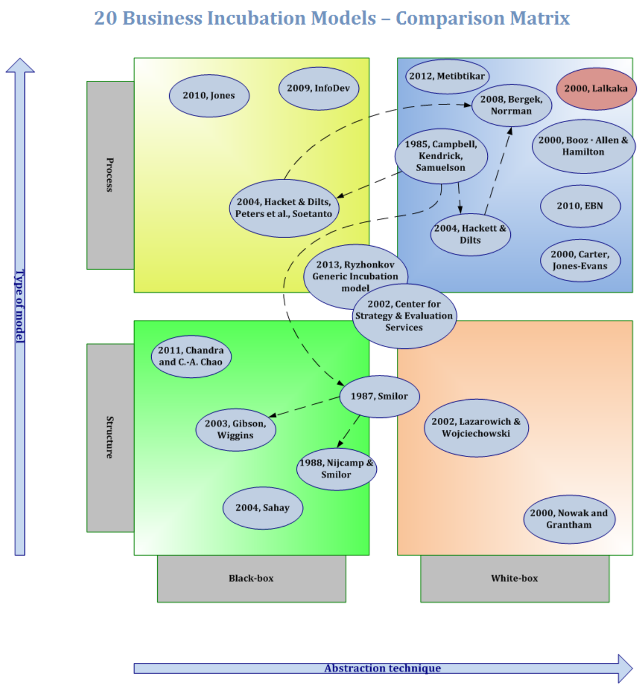

Fig. 1. *20 business incubation models*

1. Model: Series introduction. Methodology. Model Campbell, Kendrick and Samuelson (1985)
2. Model: Model Smiler (1987)
3. Model: Generic incubator model by Nijkamp and Smilor (1988)
4. Model: Carter and Jones-Evans (2000) process model
5. Model: Virtual Incubation Model Nowak and Grantham (2000)
6. Model: Corporate Incubator Model Booz, Allen and Hamilton (2000)
7. Model: "New Economy" Incubator Model Lazarowich and Wojciechovski (2002)
8. Model: Incubator Development Model (Technology Business Incubator Manual) Lalkaka (2000)
9. Model: NBIA model by Costa-David, Malan and Lalkaka (2002)
10. and 11. Model: Gibson and Wiggins model (2003) and Sahay model (2004)
12. and 13. Model: Generic business incubator model Hackett and Dilts (2004)
14. Model: Model Bergek and Norrman (2008)
15. Model: InfoDev Process Model (2009)
16. Model: Jones' Value Chain Incubation Model (2010)
17. and 18. Model: Model Chandra and Chao C.A. (2009) and the Metibtikar model (2012)
19. Model: (Becker and Gassmann, 2006)
20. Model: Rizhonkov's Generic Model of Business Incubation (2013)

Business incubators have evolved over the years due to various factors such as global trends, economic needs, technical revolutions and challenges. BI play a vital role in supporting young companies, helping them grow and increase their commercial success. While the proliferation of incubation models is well known, there is limited awareness of how their value propositions have transformed over time [7].

ENERGY MANAGEMENT

Energy management includes a strategic and systematic process of optimizing energy performance within an organization or system. Effective energy management aims to improve energy efficiency, reduce energy costs and minimize environmental impact. The importance of energy management has grown significantly in recent years due to increased awareness of climate change, rising energy costs and the need for sustainable practices. By implementing effective energy management practices, organizations and

individuals can improve operational efficiency and competitiveness [8].
Several key aspects and energy management strategies involved in energy management are:

1. Energy audits: An energy audit is a systematic process of assessment and evaluation of energy use in buildings, facilities or processes; conducting energy audits to assess current energy use patterns, identify inefficiencies and identify opportunities for improvement;
2. Energy efficiency measures: The pursuit of energy efficiency includes a wide range of strategies including optimization of heating, cooling and lighting systems, integration of renewable energy sources, improvement of insulation and window design and adoption of smart building technologies;
3. Monitoring and control systems: Installing energy monitoring and control systems to monitor energy consumption in real time, identify anomalies or inefficiencies and enable proactive management and optimization of energy use;
4. Changes in behavior: Promoting energy awareness and engagement of tenants in buildings or employees in companies, in practice energy conservation through education, training and incentives;
5. Renewable energy integration: Incorporating renewable energy sources (eg solar, wind, geothermal) into the energy mix to reduce reliance on fossil fuels and reduce carbon emissions;
6. Demand Response Programs: Participating in demand response programs to manage energy demand during crisis periods, thereby reducing grid load and potentially earning a financial incentive;
7. Energy Management Systems (EMS): Implementation of EMS software or platforms to centralize energy data, analyze trends, set performance goals, and automate energy management tasks;
8. Continuous improvement: Organizations and businesses face challenges related to improving energy performance indicators, continuing to improve energy efficiency and managing third-party international certificates;
9. Compliance and Standards: Ensuring compliance with energy regulations, standards and certifications (eg ISO 50001) to demonstrate commitment to best energy management practices and achieve energy efficiency targets;
10. Financial analysis: Conduct cost-benefit analysis and financial modeling to assess the economic viability of energy efficiency projects and prioritize investments based on return on investment (ROI) and payback period [9].

Energy management primarily represents efficient energy management, with the aim of reducing operating costs, improving environmental sustainability and strengthening organizational resilience and competitiveness in a dynamic energy landscape. It requires a holistic approach that encourages cross-departmental collaboration and is committed to continuous improvement and innovation. By implementing effective energy management strategies, organizations can optimize resource use and adapt to evolving challenges while supporting a sustainable future [10].

THE CONCEPT OF BUSINESS INCUBATORS IN THE FUNCTION OF ENERGY MANAGEMENT

Business incubators play a key role in advancing energy management initiatives by supporting startups and entrepreneurial ecosystems in developing innovative solutions. Business incubators are essential in promoting energy management by providing entrepreneurial ecosystems with the resources, mentorship and networking opportunities needed to develop innovative solutions. They create an environment conducive to experimentation and collaboration, helping entrepreneurs navigate challenges and perfect their ideas. Through access to funding, expert guidance, and industry connections, incubators can accelerate the growth of businesses focused on sustainable energy practices, ultimately driving advances in energy efficiency and management [11].

A few key reasons why BI are necessary to implement energy management:
- Access to resources: Incubators provide startups with essential resources, including funding, mentoring and technical support, enabling them to effectively develop and implement energy management solutions.
- Networking opportunities: These facilitate connections with industry experts, investors and potential partners, fostering collaboration and knowledge sharing within the energy management ecosystem.
- Support for innovation and research and development: Incubators promote research and development, encouraging startups to innovate and create new technologies or processes that improve energy efficiency and sustainability.
- Market Validation: Through incubation programs, startups can test and refine their solutions in the real world, receiving valuable feedback and confirming their market potential.
- Skills development: Business incubators often provide training and workshops, equipping entrepreneurs with the skills needed to navigate the complexities of energy management and business growth.
- Regulatory guidelines: Many incubators help startups understand and comply with energy regulations and standards, ensuring that their solutions are aligned with industry requirements.
- Support for scalability: Incubators help startups scale their operations and solutions, enabling wider adoption of energy management practices across sectors.
- Promoting sustainable practices: By fostering clean technology and energy-efficient innovations, incubators contribute to broader sustainability goals and the transition to a low-carbon economy.

By supporting the growth of startup companies in the field of energy management, business incubators are instrumental in driving innovation and implementing efficient energy solutions that benefit organizations and the environment alike [12].

GUIDELINES FOR THE APPLICATION OF THE CONCEPT

Business incubators play a key role in the development of the entrepreneurial ecosystem, especially when it comes to initiatives related to energy management. By providing support to startups, incubators can significantly contribute to the development of innovative solutions in the field of sustainable energy.

Role of Business Incubators - Supporting Innovation: business incubators offer resources such as training, mentoring programs and access to technologies that enable entrepreneurs to develop innovative products and services in the energy sector; Networking: connecting with investors, experts and other businesses allows startups to exchange ideas and resources, which can lead to faster innovation development; Financial Support: many incubators offer access to funds, grants and other forms of financing that are necessary for the implementation of energy efficiency projects.

Implementation of Energy Management - Development of Sustainable Strategies: incubators can help entrepreneurs develop strategies that focus on reducing energy consumption and increasing efficiency through innovative solutions; Pilot Projects: through incubators, startups can implement pilot projects that test new technologies or approaches, which can serve as a model for wider application; Training and Education: incubators can organize educational programs and workshops that will help entrepreneurs to better understand the principles of energy management and apply them in their business.

Challenges and Recommendations - Financial Sustainability: many startups face problems in the first stages of development. Incubators should work to find sustainable financing models, Access to Resources: it is necessary to ensure easier access to laboratory spaces and technologies that are key to the development of energy innovations; Joint Collaboration: fostering collaboration between different incubators, academic institutions and industry can increase the effectiveness of energy initiatives.

Business incubators are essential for improving energy management within entrepreneurial ecosystems. Their ability to support innovation and connect different actors can significantly contribute to the development of sustainable solutions that will shape the future of energy efficiency. Through joint work and support, we can create an ecosystem that will encourage innovation and contribute to the preservation of the environment.

CONCLUSION

Business incubators represent key support in the implementation of energy management within entrepreneurial ecosystems. Their role in providing resources, mentoring and networking enables startups to develop innovative solutions that contribute to energy efficiency and sustainability. Through joint work, incubators can improve cooperation between different actors, facilitate access to financing and technologies, and promote education about energy efficiency. This synergy not only encourages innovation, but also contributes to the development of sustainable business models that are key to the future of the energy sector.

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SUSTAINABLE SUPPLY CHAIN MANAGEMENT IN THE CONTEXT OF NATURAL RESOURCE CONSERVATION

Review paper

Stefan Ugrinov[1], Mihalj Bakator[2] ,Edit Terek Stojanović[3], Mila Kavalić[4], Verica Gluvakov[5]
[1,2,3,4,5,6]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Abstract: The purpose of this paper is to emphasise the important role of sustainable supply chain management (SSCM) in natural resource conservation. It suggests that SSCM can be achieved by practising sustainable sourcing, resource efficiency, and engaging all the stakeholders in the process. Sustainable sourcing refers to the acquisition of raw materials from environmentally sound and socially friendly sources. When it comes to resource efficiency, it refers to the optimal utilisation of materials and energy throughout the supply chain. It aims to minimise waste and reduce pollution. While the practise of SSCM is not free from economic costs, regulatory complexity, and lack of transparency, it can be achieved with innovative practices such as new technology and the better utilisation of the circular economy principles. The paper outlines the important roles that governments, enterprises and consumers play in the conservation of natural resources. Regulation, incentives, and informed consumers are the driving forces behind this practice. The paper concludes by presenting SSCM as a strategic move, which not only preserves the environment but also offers a competitive advantage in the marketplace.
Key words: sustainable,supply chain, sourcing, resources, circular economy

INTRODUCTION

Sustainable supply chain management (SSCM) is a growing field of study because it clarifies how business practices can mitigate the environmental problems caused by global industrial growth. In general, increased industrial activity places greater demand on natural resources, thereby making the environment more vulnerable to damage [1]. Sustainability can help limit these impacts and ameliorate the effects by bringing the goals of the supply chain management into closer alignment with the goals of resource conservation. By focusing on resource utilisation, supply chain management can achieve a greater level of environmental protection through waste reduction, lower carbon emissions, and a more efficient use of resources from the initial stages of production to the point of market distribution. When combined such efforts help to avoid drawing upon the ecosystem and are commensurable with global environment targets, such as those within the Paris Agreement .

Crucially, SSCM encourages the use of renewable energy in supply chains, supporting the global transition away from fossil fuels (for example, by sourcing renewable energy for production and by investing in more energy-efficient infrastructure), as well as by working with suppliers to encourage sustainable energy generation [2]. Reconciling development on our planet with the health of our planet requires an alignment of supply chain operations with environmental objectives.

These strategies are needed to bring natural resource conservation into supply chains. Sourcing materials sustainably means selecting suppliers that operate according to environmental standards. For example, buying timber from certified sustainable forests or minerals from ethically run mines helps to mitigate the negative effects of resource extraction. A second key strategy is to implement circular economy principles, such as recycling, reuse and repurposing materials, which ensures that resources are used for as long as possible and new extraction is minimized [3].

Many of the most significant barriers to SSCM lie in the high cost of sustainable practices – in both financial and environmental terms – the complexity of global supply chains, and the

[1]Corresponding author, stefan.ugrinov@tfzr.rs, ORCID: https://orcid.org/0009-0000-7206-655X
[2]mihalj.bakator@tfzr.rs, ORCID: https://orcid.org/0000-0001-8540-2460
[3]edit.terek@tfzr.rs, ORCID: https://orcid.org/0000-0003-0013-8141
[4]mila.kvalic@tfzr.rs, ORCID: https://orcid.org/0000-0001-7053-2334
[5]verica.gluvakov@tfzr.rs, ORCID: https://orcid.org/0000-0003-1083-0203

comparative incoherence of regulations between regions [4]. Environmentally sustainable technologies and materials come at a premium, and for businesses with low profit margins, investment can be difficult. Additionally, oversight in supply chains can be problematic if they are complex and multi-tiered, or not transparent. If the low cost of inputs is not punished with a carbon price or other regulatory penalty, it can be difficult to justify sustainability investments that do not confer a competitive advantage.

Despite these constraints, SSCM case studies show that the approach works, and how companies can benefit from it. One example of SSCM comes from a consumer goods company that has been able to reduce their water use in the supply chain and promote sustainable agriculture Another example is a tech company that has been able to put in place a circular economy model to reduce their dependence on raw materials and electronic waste. These examples show that SSCM is both doable and beneficial for businesses committed to sustainability [5]. These companies are able to not only set an example for others to follow, but also learn from them. In this way, they contribute to the global effort to preserve natural resources.

THE ROLE OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT IN ENVIRONMENTAL PROTECTION AND NATURAL RESOURCE CONSERVATION

Given the rising awareness of the need to protect the environment, sustainable supply chain management (SSCM) has become an essential element of contemporary business strategies. More than simply reacting to government regulations or customer demands, SSCM is an attempt to integrate environmental objectives into supply chains so that industrial practices do not have detrimental effects on the environment [6].Companies have come to regard protecting the environment as an integral part of business operations, and SSCM as a means of ensuring that their activities can satisfy current needs without compromising the future's ability to meet its own needs.

One of the most important contributions of SSCM to the protection of the environment is to promote waste reduction all along the supply chain. In fact, the generation of waste is one of the main sources of environmental pollution. Therefore, it is evident that minimising waste production is a fundamental aspect of sustainability [7]. This could be accomplished through SSCM practices such as efficient production processes, more effective use of packaging and optimised inventory management systems, which help to avoid overproduction. Companies also carry out recycling and reuse projects, making use of what could be considered waste in the production processes in order to make it a valuable input for the next cycle.

Reducing carbon emissions is another key dimension of SSCM. Supply chains, particularly those that cross borders, are major contributors to greenhouse gas emissions, due to the huge amounts of energy used for transportation, manufacturing, and the use of fossil fuels. SSCM encourages technological change towards cleaner technologies, such as the use of electric vehicles, highly energy-efficient machinery, and renewable energy sources [8]. Companies should also seek ways to minimise their carbon footprint through better logistical arrangements, such as sending shipments directly and combining shipments. These initiatives will help to achieve global climate goals and enhance the company's reputation among environmentally conscious customers.

Another important way that SSCM can promote environmental protection is via the use of renewable energy in supply chains. As the global economy moves away from fossil fuels, SSCM encourages the adoption of renewable energy throughout the supply chain. For example, solar panels and wind turbines are installed in factories and offices, and renewable energy credits are purchased to offset the emissions produced by the supply chain. The use of renewable energy lowers the carbon footprint of the supply chain, but it also signals to stakeholders that the company is serious about sustainability.

SSCM can encourage suppliers and business partners to adopt more sustainable practices Many companies are part of long and complex supply chains involving multiple suppliers – with each supplier contributing to the ultimate environmental footprint of the company's operations. SSCM enables organisations to set sustainability standards for their suppliers and then to require suppliers to stick to these standards [9].For example, companies can set environmental standards covering topics ranging from resource use, to waste management and emissions. Organisations can use their position as a customer of suppliers to provide resources and training to help suppliers meet the required standards. This helps to mitigate the environmental impact of supply chains and extend sustainability more broadly throughout the supply chain.

Companies must also deal with natural resource conservation in their supply chains by using sustainable sourcing and the circular economy. Sustainable sourcing of raw materials prevents deforestation, habitat destruction and the depletion of non-renewable resources on a large scale. The circular economy keeps materials in use for as long as possible, reusing and recycling to reduce the need for new raw materials and reduce waste [10]. Some companies are also experimenting with resource efficiency, using less material and energy in their production, optimising their manufacturing processes, and finding ways to use materials with lower environmental impact.

Integrating natural resource conservation into supply chains is also achieved by engaging with stakeholders, including 'upstream' suppliers and 'downstream' customers and industry groups. Collaborative industry-wide sustainability standards and certification schemes are an effective tool to drive natural resource conservation and sustainability throughout a supply chain.

CHALLENGES AND SUCCESSES IN IMPLEMENTING SUSTAINABLE SUPPLY CHAIN MANAGEMENT FOR NATURAL RESOURCE CONSERVATION

Although the adoption of SSCM has many advantages, including energy conservation and the protection of natural resources, companies have many challenges to overcome before they can adapt eco-friendly strategies into their supply chain management. The main problem is the economic cost of transforming the business to sustainable operations. For many companies, especially those in the cost-oriented business sector, the startup investments for sustainable technological materials and processes are too high. Energy-saving machines, renewable energy and sustainable raw materials are more expensive than traditional ones. Stakeholders who do not accept short-term sacrifices in their financial performance will also pose a challenge to adopting sustainable practices [11]. Small businesses usually have limited funds, which can easily be used up if they invest in sustainability initiatives. Naturally, they will be less willing to invest in sustainability than larger corporations, which are better equipped to absorb these costs.

Secondly, the sophisticated nature of global supply chains exacerbates the challenges of SSCM. Companies may be situated in sophisticated networks spanning multiple countries, each with different regulatory regimes, cultural habits and levels of technological sophistication. Ensuring consistency in sustainability practices across all supply chain tiers can be challenging, particularly when suppliers are situated in areas with lower levels of environmental regulation [12]. For instance, a company headquartered in a country with strict environmental regulations might struggle to implement these regulations on suppliers in countries with weaker environmental regulations or poorly enforced environmental standards. This seems like a major obstacle to achieving uniform sustainability across the supply chain.

A second major impediment is transparency. Many firms lack adequate visibility into their supply chains, especially at the lower tiers where raw materials are sourced. Without greater transparency, it is hard to properly assess the environmental impacts of the practices of suppliers, and difficult to ensure that they comply with sustainability standards [13]. For example, a company could be sourcing materials from suppliers engaging in environmentally damaging activities, such as illegal logging or unregulated mining, simply because these activities would occur several tiers removed from the company's operations. Improvements in transparency require companies to invest in technologies and processes that will help track and report on the activities of their supply chains, such as blockchain technology, which can provide a tamper-resistant record of transactions across the supply chain.

SSCM has proven to be so difficult that many companies and industries are still in the early stages of adopting effective practices to conserve natural resources. Despite these challenges, some companies in the apparel, electronics and other industries have begun to implement SSCM practices to conserve natural resources in their supply chains. In the apparel industry, some of the world’s largest brands have made a commitment to use only sustainable sourcing for certain materials. They source cotton from farms that are certified according to a sustainable standard to use water-efficient irrigation, avoid hazardous pesticides, and support biodiversity. In the electronics industry, some companies have reduced the environmental and social impacts of their products by relying less on conflict minerals. They use elaborate due diligence that restricts their sources to conflict-free metals in a supply chain that deploys an additional level of scrutiny. They also invest in the development of substitute metals and technologies to reduce their use of conflict minerals [14].

Other case studies demonstrate initiatives in the food and beverage sector to reduce water use and promote sustainable agricultural practices. Reducing water use in supply chains, for example, has involved reduced water consumption per hectare of crop through investment in more efficient irrigation technology such as drip irrigation. In the automotive sector, supply chains have been made greener through the use of lightweight materials and the development of electric vehicles (EVs), which have made the automotive sector a leader in climate action and sustainability. Together, these case studies show how SSCM can have meaningful environmental impacts while also generating business value, and suggest that the perceived challenges of SSCM are not insurmountable [15].

THEORETICAL MODEL

There could be no better way to promote ecosystem conservation within supply chains than by ensuring the sustainable sourcing of raw materials. Environmental certifications of suppliers can ensure a commitment to stringent environmental requirements, which reduce the risk that the company might source from operations that degrade ecosystems or waste resources. Certification schemes such as ISO 14001 or FSC validate an organisation’s environmental performance, and could also incentivise company management to commit to continuous improvement in their practices.

Ethical and transparent sourcing practices reinforce sustainable sourcing practices by instilling accountability and visibility within the supply chains. Blockchain technology helps to make supply chains more transparent so that companies can know the origin of the raw materials in their supply chain and verify their sustainability. This reduces the risk of unsustainable raw materials ending up in the supply chain, such as conflict minerals or illegally harvested timber.

Second, preferring renewable resources encourages sourcing from sustainable suppliers. If a company picks renewable resources over finite, scarce ones, it encourages the use of such materials for the long-term environmental sustainability of extraction. That means working with suppliers who are similarly committed to responsible use of resources, either through sustainably managed forests or recycled material vendors.

Another important way in which local sourcing advances the sustainability agenda is by reducing the environmental footprint associated with logistics. While local sourcing implies a reduction in greenhouse gas (GHG) emissions through shorter supply chains to and from markets, it also promotes more sustainable uses of local ecosystems by supporting local agriculture and manufacturing. Again, this is an issue of resource efficiency: shorter chains usually enable lower energy use for transportation and storage.

Long-term, contracts ensure strong supplier relationships, an important basis for sustainable sourcing. These relationships provide commercial stability to working together that can serve as an incentive for improving environmental practices. Suppliers can collaborate on sustainability goals, creating incremental change such as reducing waste, increasing resource efficiency and using more renewable energy. Long-term partnerships, over time, result in more ambitious conservation outcomes.

Resource efficiency is thus inherently connected to sustainable sourcing – for example, lower energy usage in factories saves energy across the board and therefore reduces the environmental footprint of production. Waste minimisation and recycling go hand in hand, as minimising waste will not only reduce virgin materials, but also support the fundamentals of the circular economy, whereby products and their components are reused for as long as possible and recycled when possible.
For example, water conservation measures can occur as a result of a shift in sustainable sourcing (eg, among industries with high water-oriented use). Improving efficiency along the supply chain leads to better and more sustainable use of freshwater resources, which is increasingly acknowledged as vital for ecosystem health and long-term sustainability. Similarly, lean inventory conservation will also contribute to resource efficiency through minimisation of waste created through overproduction and inventory processing (relying on natural resources).
Both lifecycle assessment and Design for Environment (DfE), which helps design products to use fewer resources and to be easier to dismantle, contributing less waste, are also essential. Misuse of the food supply lifecycle means that the issue of marine plastic is even more acute Importantly, when companies work together with stakeholders and suppliers, for example, supplier development programmes, multi-stakeholder partnerships and other forms of collaboration have magnified impacts. Together, these contribute to sustainable sourcing and resource efficiency.
Consumer education and engagement can also lead to market incentives for corporate sustainability, such as when consumers display preferences for sustainably harvested goods. Practices that emphasise regulatory compliance and advocacy for strong sustainability laws are complemented by sustainability reporting and transparency, which requires steady reporting to stakeholders on conservation efforts made.

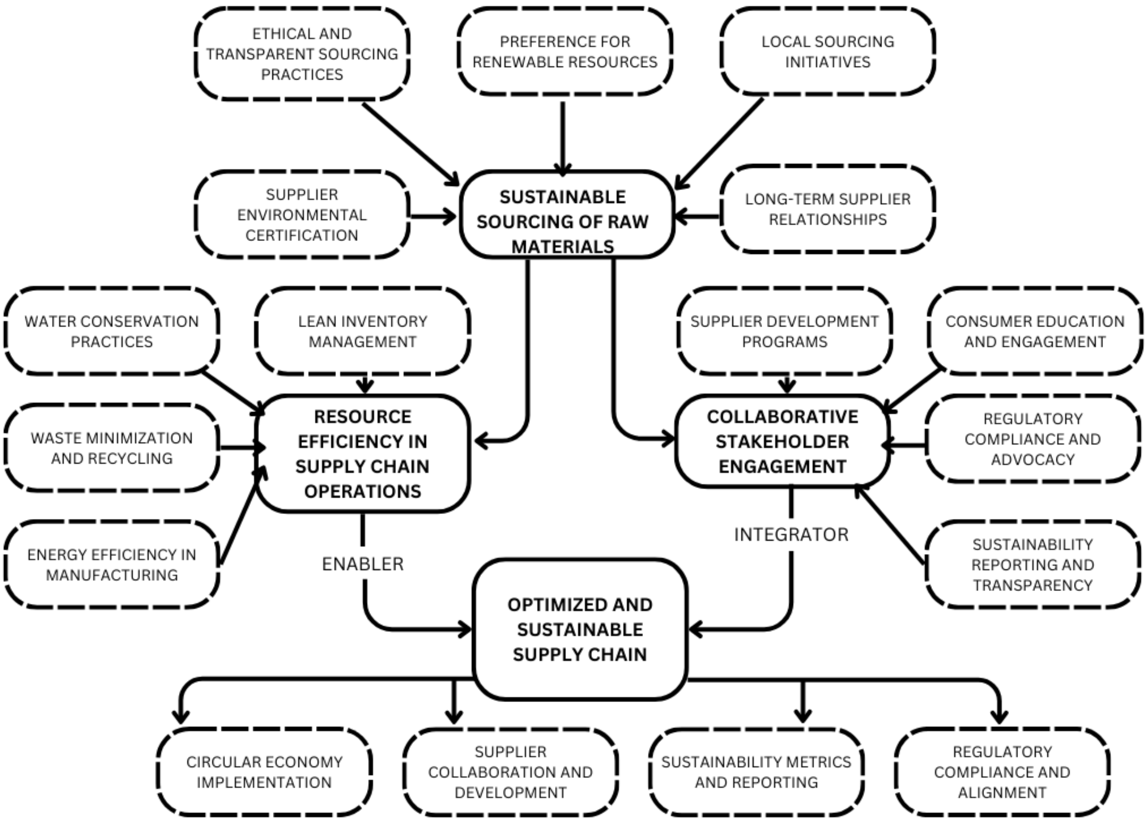

Fig. 1. *Sustainable supply chain management in the context of natural resource conservation*

SUGGESTIONS AND GUIDELINES

The developed model provided insights based on which suggestions and guidelines for sustainable supply chain management in the context of natural resource conservation are highlighted:

- Governments should implement stricter environmental regulations and provide incentives for sustainable practices. These regulations could include mandatory sustainability reporting and penalties for non-compliance, ensuring that companies prioritize natural resource conservation. Incentives such as tax breaks, grants, and subsidies can encourage companies to invest in renewable energy, sustainable sourcing, and resource-efficient technologies.
- Enterprises should establish transparent supply chains by leveraging technology like blockchain. Blockchain can enhance traceability and accountability, ensuring that all materials are sourced ethically and sustainably throughout the supply chain. This transparency helps prevent environmental degradation and ensures compliance with environmental standards at every level.
- Companies should invest in long-term relationships with environmentally certified suppliers. Building strong partnerships with suppliers who are committed to sustainability ensures a consistent supply of materials that meet environmental standards, reducing the risk of resource depletion. These relationships can also foster collaboration on sustainability initiatives, driving continuous improvement in environmental practices.
- Businesses should adopt circular economy principles to reduce waste and promote resource efficiency. Implementing take-back programs, recycling initiatives, and designing products for reuse can significantly minimize the environmental impact of supply chains. By keeping materials in use for longer, companies can reduce their reliance on new raw materials and conserve natural resources.
- Individuals should support companies that prioritize sustainable supply chain management by making informed purchasing decisions. Consumers can influence market demand by choosing products that are sustainably sourced and produced, encouraging more businesses to adopt environmentally friendly practices. Public awareness campaigns and labeling schemes can help consumers identify and support these companies.
- Governments should foster multi-stakeholder partnerships to address global sustainability challenges. Collaborative efforts involving businesses, NGOs, and academic institutions can lead to the development of industry-wide standards and innovative solutions for natural resource conservation. These partnerships can also facilitate knowledge sharing and capacity building, enabling all stakeholders to contribute effectively to sustainability goals.
- Enterprises should implement energy-efficient technologies and practices throughout their supply chains. This could involve upgrading manufacturing processes, optimizing logistics, and investing in renewable energy sources to reduce the carbon footprint of their operations. These efforts not only conserve energy resources but also help companies meet global climate targets.
- Companies should regularly conduct lifecycle assessments to evaluate the environmental impact of their products. Understanding the full lifecycle impact allows companies to identify areas where they can reduce resource consumption and improve sustainability. Design for Environment (DfE) principles should be integrated into product development to minimize environmental impact from the outset.
- Governments should create public awareness programs focused on the importance of sustainable supply chains. Educating citizens about the environmental impact of their consumption choices can drive demand for sustainably produced goods. These

programs can also encourage responsible consumption and waste reduction at the individual level.

- Individuals should participate in recycling and take-back programs offered by companies. By returning used products for recycling or refurbishment, consumers help close the loop in the supply chain, reducing the need for new raw materials and minimizing waste. Active participation in such programs supports the broader goal of resource conservation.

CONCLUSION

Sustainable supply chain management (SSCM) plays a vital role in natural resource conservation. Specifically, corporations can significantly reduce their environmental footprint by emphasising sustainable sourcing, resource efficiency and stakeholder collaboration along various supply chains. Sustainable sourcing refers to procuring raw materials in a way that prevents exploitation of natural resources and effectively anticipates and responds to the needs of future generations. Supplier certification and increased preference for biologically renewable resources are key approaches that support this sustainable strategy. Resource efficiency is another strategy that complements the sustainable sourcing strategy by optimising material and energy usage throughout an organisation's supply chain. By enhancing efficiency, the corporation reduces excess consumption, which ultimately results in less waste and the use of less water.

Of course, the obvious downside for firms is that implementing SSCM has costs, and involves wrangling with regulators while also making companies more transparent. But companies that manage these hurdles often do so through innovation – technology investments, for example, that increase supply chain transparency, or a transition towards circular economy strategies that lengthen the lifecycle of materials. Ultimately, the investment in sustainability is not only an investment in ecological concerns, but can become a competitive advantage for firms trying to keep up with an increasingly green market.

Thus, to succeed in SSCM and concomitantly in the preservation of the natural resource basis, government, industry and consumers need to interact synergistically and mutually reinforce their verve. There are several leading roles that governments can play in this context – such as devising supportive regulations and providing incentives and similar leading roles for industry – in this case leading as the sustainability-conscious, ecological "industries of the 21st century," and consumer as the crucial, conscious customers who buy the sustainable end-products and recycle.

As sustainability increases in importance, the uptake of SSCM practices is likely to increase too in a positive feedback that will further reinforce natural resource conservation across the globe. All relevant actors have an important role to play in optimizing the interaction between economic growth and environmental protection.

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ARTIFICIAL INTELLIGENCE – AN ESSENTIAL FACTOR IN CORPORATE STRATEGIC COMMUNICATION

Review paper

Zlatko Lacković[1], Milan Ivanović[1], Krešimir Lacković[2]
[1] Panon – think tank, Osijek, Croatia
[2] Sveučilište Sjever - Koprivnica, Croatia

Abstract: This In this research, artificial intelligence is set as a support for strategic communication, with the aim of defining a business strategy and its effective implementation. In this sense, the object is strategic management and necessary communication, and the subject is artificial intelligence and its application possibilities. Research on artificial intelligence and its application confirms the hypothesis that artificial intelligence is an important factor in the effectiveness of the strategic communication process. In addition, the development of information technology lays the foundation for future research on this topic

Key words: Artificial intelligence, Corporation, Management, Strategy

INTRODUCTION

The development of society, especially the economy, resulted in the creation of large companies known as corporations. Such economic entities are composed of several complementary subsidiaries that may be physically dislocated. In such situations, it is not easy to ensure effective communication. This problem is successfully solved using information technologies. In this case, the object of consideration is communication by means of which a business strategy is effectively set and ensures its implementation, i.e. strategic communication. As an important factor in the effectiveness of information technologies in this case, an additional collection of software known as artificial intelligence is proposed. The fundamental task of artificial intelligence is support in analyzing the environment, defining the vision and mission, and developing strategic goals. Artificial intelligence can provide special support in determining the plan and implementing and controlling the business strategy. At the end of the strategic management process, artificial intelligence particularly helps with process analysis as a basis for setting future strategy.

The hypothesis of this research is artificial intelligence as an important factor in strategic communication. Namely, the whole process gains in speed, precision and a large number of possible information as well as already proposed solutions for some strategic decisions. In this sense, an example of a strategic process will be set and the possibilities offered by artificial intelligence will be listed. At the end, the information strategic system and the process of functioning with the possibilities of artificial intelligence are proposed. These facts confirm the hypothesis, but also open the possibility for new research in accordance with the further development of the economy and information technologies.

CORPORATE STRATEGY AND THE PROCESS OF ITS APPLICATION

Business strategy and strategic management have been known in theory and practice for a long time, but strategic communication is gaining more and more importance, especially with the development of IT technologies. This particularly applies to larger economic entities known as corporations. Corporation is the most developed form of capitalist enterprise. It has many advantages because it managed to remove all the weaknesses of partnerships, especially those related to the risk in case of bankruptcy, because the owner of the shares only loses what he invested in the shares. Corporations are very elastic, especially when companies are organized according to the principle of a confederation or a network of entrepreneurs. They easily reorient themselves from one investment to another, and if they are successful, they very easily get additional capital through a new issue of shares. In such a complex system, it is not easy to set up a business strategy and ensure its successful application. There are several definitions of business strategy, one of them says that it is the way in which companies achieve their goals and that it is also a kind of navigation map intended for the period in which the goals will be achieved with certain methods and resources. The term strategic management dates back to the fifties of the twentieth century, and became very popular, and even necessary in theoretical and practical application, during the sixties and seventies of the twentieth century, [3] [4].

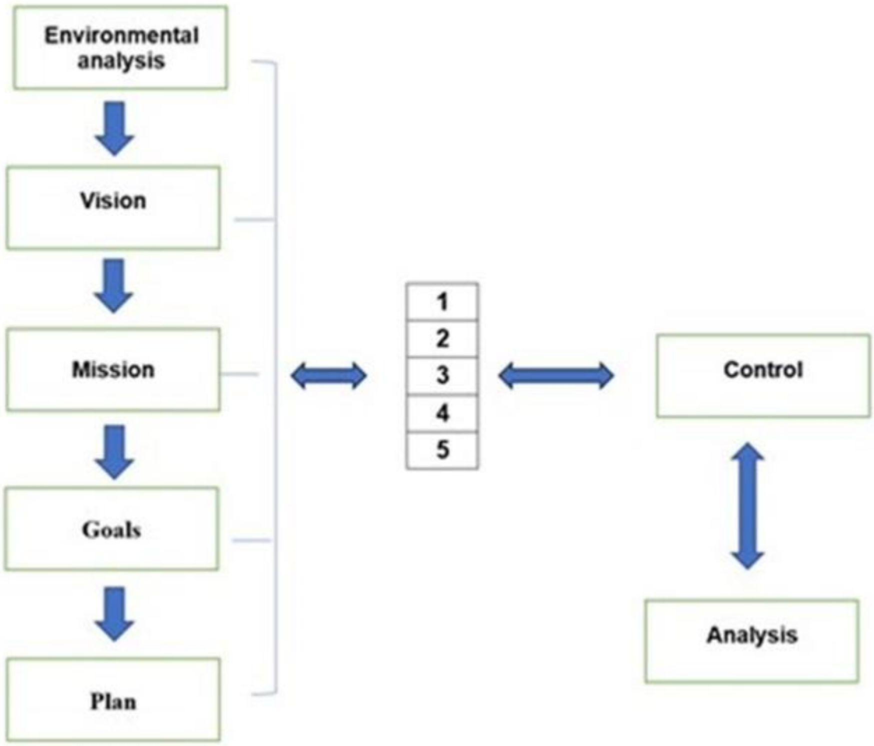

Fig. 1. *The process of strategic corporate management*

Unlike business strategy, which represents a defined roadmap to the future of each company, strategic management is a process that consists of many steps. In this sense, there are opinions that defining the strategy is the first step of that process. The second step consists of determining the source of financing, expected costs and determining the procedures for application. The third step refers to the development of the strategic process that was established in the first two steps. According to Figure 1, the process begins with the definition of strategic components, which are: Analysis of the environment, vision, mission and plan. The initial phase is the analysis of the environment, which includes the research of all external factors that can influence the definition and implementation of the business strategy. The vision of the company is the ideal picture of the future you wish for your company. The vision should be in line with the long-term goals of the business and represent what it strives for. The company's mission statement should define the reason for existence and the rules by which the company behaves and acts - The mission adapts and changes over time because business goals change. A strategic plan is a document that determines in quantitative, value and term form all the company's resources. Management and coordination and controlling the implementation of the strategy is the responsibility of managers according to their level of management. At the end of the process, an analysis is desirable in order to determine the success of the business strategy, but also as a basis for the future strategy

STRATEGIC COMMUNICATION

Strategic communication is a relatively new term that includes various forms of planned and meaningful communication, which has a clearly defined goal and messages to the public addressed and the strategies and tactics used, and usually includes public relations, marketing, political communication, public diplomacy and others related disciplines, [21]. In practice, the term 'corporate communication' is increasingly used to describe the function of information and communication, which is similar to the function of "public relations". In this paper, "corporate communication" is preferred, with the explanation that it is "public", [7]. Furthermore, some also see public relations as being about the organization of external communications (Steyn 1999). inextricably linked to political actions and rhetoric. Therefore, there is increasing criticism and concern about this power and its implications for democracy. This has led to increased criticism of corporate/political actions and rhetoric, and increased demands for corporate social responsibility, [13].

The basic assumption of this research is that there is no certain theoretical similarity between corporate communication and public relations. In fact, public relations or PR (Public relations) is an activity that appeared as one of the tools of modern marketing, but it is increasingly taking on a strategic role in larger complex systems as well as in smaller economic entities. The activities of the PR function derive from the very definition. Public relations as a process of strategic management builds mutually beneficial relationships between the message exchange function that focuses on influencing the management of production and business processes, that is, on behavior in the company. In addition, it also affects the management function, which emphasizes communication with the public in order to include feedback in decision-making.

Based on the previous definitions, it can be concluded that there is an essential similarity between strategic communication and public relations. What distinguishes these two activities is, first of all, the long-term goal of strategic communication. In addition, strategic communication is always related to some long-term production of some main strategic product of the corporation. Corporate communications are certainly also an instrument of management by which all consciously used forms of internal and external communication are coordinated as successfully and efficiently as possible, in order to create a suitable foundation for relations with groups on which the company depends", [14].

In any case, it is necessary to set a certain roadmap and intensity of strategic activities, or process. In addition, effective management of the process in all its phases, ie strategic management of communications, should be ensured. In conclusion, to add value, we need to look at how we can solve business problems with communication solutions, and it is expected that communication will be more involved in the development of business strategy and positioning. The development of IT technologies, especially artificial intelligence, can be of great help in these approaches.

THE ROLE OF ARTIFICIAL INTELLIGENCE IN CORPORATE STRATEGIC COMMUNICATION

Information and communication system

As part of defining the process of corporate communication and the role of artificial intelligence in that process, the hardware-software combination system should first be defined. In this sense, an example of that system, which consists of First of all, from the management of a corporation that has a defined information and communication system where the computer is supported by artificial intelligence. All communications with corporate dislocated branches are carried out over the Internet through already known channels, including social networks. In addition, the aforementioned Internet channels also enable communication with other participants known as the business environment.

In particular, it should be emphasized that artificial intelligence as a complex software should be installed in accordance with the needs of the corporation in order to provide support for the information and communication process when determining the strategy and implementing strategic management. The strategic communication process suitable for large corporations has been defined by many authors, such as: When creating and implementing strategic management, the support of an appropriate communication process is essential, and accordingly, appropriate software is needed. With the development of IT technologies, especially in complex corporations, artificial intelligence can play a particularly important role as a system of software and tools. In this sense, management software suitable for the type and complexity of the production and complete business process of the corporation should be installed. As part of the artificial intelligence kit, there are appropriate tools that will be used to create phases and manage the strategic corporate communication process, [1] [2].

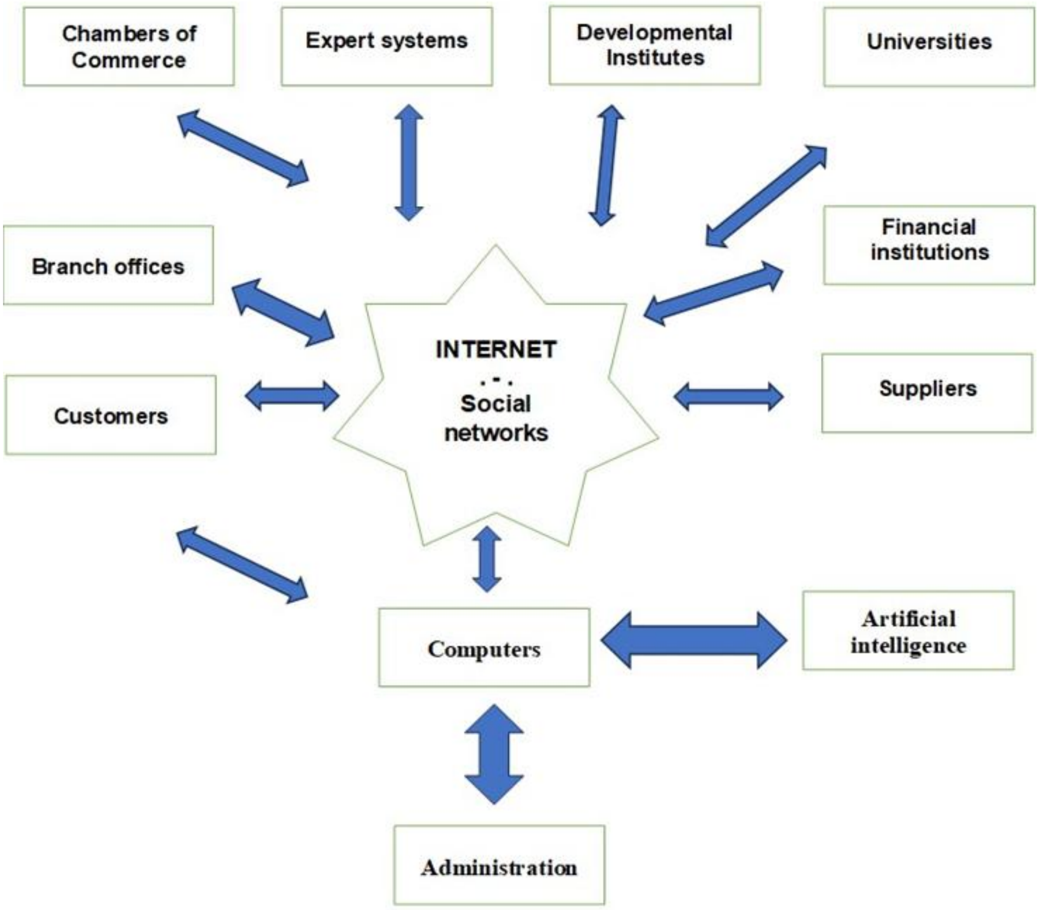

Fig. 2. *Hardware-software system of applying artificial intelligence in strategic corporate communication*

Analysis of artificial intelligence software and tools

Technical and technological development, especially the Internet, has opened up new possibilities for the application of IT technologies, which especially refers to artificial intelligence. The topicality of the topic, especially in terms of its application in various economic and social activities, can best be seen from the definition itself. In this sense, there is a large number of authors who have defined artificial intelligence. According to the Croatian Encyclopedia Artificial Intelligence (UI), according to the acronym AI, from Artificial

Intelligence), a part of computing that deals with developing the ability of computers to perform tasks that require some form of intelligence; also a label for the property of a non-living system that exhibits intelligence (intelligent system) The key is that an AI must be able to master different areas and learn new areas that it has not encountered before. It is not necessary to have equal abilities in all domains, [9].

In operational business terms, artificial intelligence is actually a collection of software used to support the decision-making process by analysts and managers. In this sense, it can help to analyze and process a large amount of data and then turn it into knowledge-based information to support some profitable business decisions. The information and communication system is managed by a computer using specially designed management software that is adapted to the complexity, type and size of the corporation. In addition, the control software is coordinated with special software or tools. These tools enable effective communication in terms of creating and implementing business processes, and in this case it is strategic communication. In the given example, strategic management begins with the analysis of the environment and the definition of the vision/mission, goals and plan, which determines the business strategy of the corporation. This is followed by implementation followed by real-time monitoring. As a continuation of control and preparation for analysis, evaluation or evaluation of the process can be carried out. Most definitions of evaluation include the concept of judging the value of the subject of evaluation. For example, according to the OECD, evaluation is a process, as systematic and objective as possible, which determines the value or significance of an activity, policy or program, planned intervention, ongoing intervention or completed intervention. We can say that evaluation is the process of valuing, assessing, or determining the value or importance of something. The last activity in strategic management and communication is process analysis, which is also a kind of foundation for future strategy.

There are a number of software tools to assist in the development of the strategic communication process. Below are three groups of tools that are a support in different phases of the strategic communication process, [10] [11] [12].

1. **DOMO's** leading AI decision-making software has been recognized as a challenger in the 2023 Gartner Magic Quadrant for Analytics and BI Platforms. Domo is designed to help businesses connect to multiple data sources, create visual reports, manage their data and send messages in real time. It can help in setting strategic goals.

2.**Qlik Sensea:** This tool summarizes and processes large amounts of data for quick analysis. It facilitates data extraction, transformation and cleaning from various sources. Simplifies data preparation with AI-driven suggestions for data connections. It offers a wide range of visualization types for detailed data exploration.

3.**Microsoft Power** UI-Enables connection to various data sources, including CRM systems and third-party services and environmental trend analysis. In addition, it provides real-time information for process control.

4.**Yellowfin** is a tool available with dashboards, data discovery, data visualization. Creating folders allows access and monitoring of business data from anywhere. That's why this tool is a good reporting solution that supports the business decision-making process.

5. **BRAZE** - Integrates with all your data sources (CRM, MAP, etc.) and looks for signals that a customer may be at risk of churn or showing interest in potential sales opportunities. It suggests potential messaging strategies to use based on that same data. Many organizations are laser-focused on customer retention. Braze helps even the smallest teams save thousands of hours sifting through data to understand what their customers need, whether it's an additional feature or more engagement from their account managers. Sometimes the signals associated with burping are hard to see. Braze can help your sales team re-engage prospects with marketing content, customer support and more. Braze can also help marketers create personalized offers using data. You can also A/B test your campaigns to see how they affect sales.

DISCUSSION

The previous considerations covered the essential elements of defining corporations as complex economic entities and determining the business strategy as its effective implementation. An important factor in the process of strategic management is communication in all stages of the process. The role of artificial intelligence and its role, i.e. support for the mentioned processes, was specially investigated. In order to confirm the hypothesis about artificial intelligence, an example of a communication system and the role of artificial intelligence in the strategic communication process is given. As support in confirming the hypothesis, relevant sources from the field of strategic corporate communication and the possibilities provided by artificial intelligence were investigated. With regard to the accelerated development of information technologies, new possibilities for the application of artificial intelligence are opening up, so this creates a foundation for future research, [18] [19].

CONCLUSION

Based on the research and the proposed example and discussion, more can be concluded. First of all, it is a very dynamic and developing topic. In addition, the elements of communication in strategic business processes and especially the role of information technologies were discussed. Modern methods of defining strategic processes and finally the role of artificial intelligence in these processes were determined as an essential part of confirming the hypothesis of this research. The dynamics of the development of the economy, and especially of information technology, creates the conditions and space for continued research, all with the goal of efficient development of business processes in economic entities.

In the continuation of the research within this topic, it would be useful to explore the possibilities of applying artificial intelligence in the marketing of corporations, especially in market research in order to create synergy between the needs of customers and the development of the corporation's products or services. In addition, there are opportunities to ensure more efficient maintenance of permanent assets through the connection of the corporation's artificial intelligence with professional and scientific institutions. In this sense, it is necessary to research new software, especially tools for the application of artificial intelligence.

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THE APPLICATION OF INDUSTRY 4.0 AMONG ENTREPRENEURS IN THE REPUBLIC OF SERBIA

Research paper

Bojan Stankov[1], Sanja Stanisavljev[2], Mila Kavalić[3], Verica Gluvakov[4], Snežana Mirković[5]
[1] Hemofarm a.d. Hemofarm A.D., Beogradski put bb, 26300 Vršac, Srbija
[2,3,4] Technical Faculty "Mihajlo Pupin", Zrenjanin, University of Novi Sad, Zrenjanin, Serbia
[5]BB TRADE doo, Zrenjanin, Serbia

Abstract: The main goal of this research is to assess the attitudes of entrepreneurs in Serbia regarding the application of Industry 4.0 principles within their businesses. This will be achieved through the following specific objectives: to explore entrepreneurs' understanding of the Industry 4.0 concept, to evaluate the extent to which entrepreneurs perceive the implementation of Industry 4.0 elements in their companies, to analyze the obstacles and challenges faced by businesses in the implementation of Industry 4.0, and to investigate entrepreneurs' expectations concerning the future impact of Industry 4.0 on their operations. According to the results, the majority of respondents have heard of Industry 4.0 but have not yet implemented it. Respondents see potential for implementation, express a desire, and show interest in doing so. The reason for introducing Industry 4.0 is to facilitate company management and offer a more modern approach to data.
Key words: Industry 4.0, Republic of Serbia, Entrepreneurs

INTRODUCTION

The automation of technological systems, based on the internet, forms the framework of the Industry 4.0 (I4.0) concept, which emerged in 2011. It is built on a new model of connecting machines and computers (Cyber-Physical Systems – CPS), their networking (Cloud Computing and the Internet of Things (IoT)), with extensive application and support of artificial intelligence (AI) throughout the entire model. This leads to the model of Smart Manufacturing, and today we already talk about: intelligent vehicles, roads, grids, cities, services, and everything, [1]. Industry 4.0 represents a new generation of digitized facilities based on the combination of cyber-physical systems (CPS) and digital technologies, with the predominance of new intangible software and management technologies over material ones. The Fourth Industrial Revolution can be seen as a continuation of the technical, but also broader civilizational advancement of the modern and contemporary history of the world. It is primarily associated with the emergence and development of industry from the second half of the 18th century, as well as transportation, communication, and, in modern times, information and related technologies. Within Industry 4.0, a term promoted at the CeBIT exhibition (Centrum für Büroautomation, Informationstechnologie und Telekommunikation, Center for Office Automation, Information Technologies, and Telecommunications) in Hanover in 2011, the goal was set to connect the elements of design, production, and logistics processes with a cyber-physical system, in which system components (machines and products) become "smart," gaining the ability to learn and communicate independently. The use of this technology, during a time when the world was battling the serious challenges of the COVID-19 pandemic, demonstrated its immense potential, as it allowed users easier access to resources through virtual platforms that had suddenly become inaccessible, [2]. This paper will present research on the current state of the application of Industry 4.0 concepts among entrepreneurs in the Republic of Serbia.

[1] stankovbojan15@gmail.com, ORCID: https://orcid.org/ 0009-0005-7881-2062
[2] sanja.stanisavljev@tfzr.rs, ORCID: https://orcid.org/0000-0003-3565-2597
[3] Corresponding author, mila.kavalic@tfzr.rs, ORCID: https://orcid.org/0000-0001-7053-2334
[4] verica.gluvakov@tfzr.rs, ORCID: https://orcid.org/0000-0003-1083-0203
[5] bbhrmanager@gmail.com, ORCID: https://orcid.org/0009-0001-0084-5463

RESEARCH METHODOLOGY

Problem and subject of research

The research problem arises from the importance of understanding whether the application of Industry 4.0 has been successful in businesses. It is crucial to assess how well entrepreneurs have adapted to the new forms of technology and industry, as well as to identify any issues that may need to be addressed for the sake of further improvement and business development. The research focuses on the current state of businesses, specifically the lack of digitization and inefficiencies in operational processes.

Research goals

Through a theoretical approach to the problem, the goal is to clarify the concept of Industry 4.0 application among entrepreneurs in the Republic of Serbia and explain its significance, as well as determine whether it has begun to be implemented. Considering the chosen subject of research within the proposed thesis, the main empirical objective is to show, according to the opinions of entrepreneurs, to what extent Industry 4.0 can be observed in their businesses. In other words, the goal is to establish to what extent entrepreneurs have succeeded in adapting or attempting to apply the technology in their companies. The research aims to determine whether Industry 4.0 reduces the workforce, leading to significant layoffs, and whether this technology is suitable for employment, i.e., whether it results in job reductions.

Research hypotheses

The hypotheses proposed in this paper are as follows:
H1: Awareness of Industry 4.0 among entrepreneurs in the Republic of Serbia is at a high level.
H2: The applicability of Industry 4.0 among entrepreneurs in the Republic of Serbia is at a high level.
H3: The prospects for the application of Industry 4.0 among entrepreneurs in the Republic of Serbia are at a high level.

Research techniques and instruments

To ensure that the research results provide a realistic picture of the current situation in the Republic of Serbia, the data collection method used is a survey technique accompanied by an appropriate instrument—an anonymous questionnaire created specifically for the purposes of this research. The survey was conducted using Google Forms and sent via email to entrepreneurs or company owners.The questionnaire contains 15 questions grouped into four dimensions. The first dimension covers basic information about the respondents, while the other three dimensions focus on examining Industry 4.0: Awareness of Industry 4.0 (questions: 5, 7, 14), Applicability of Industry 4.0 (questions: 6, 8, 12, 13), and Opinions on the Application of Industry 4.0 (questions: 9, 10, 11, 15). The results of the questions are presented through graphs and descriptive interpretations of each. The research also employs the content analysis method to create the theoretical foundation for the study, establish research goals and tasks, and formulate the research hypothesis.

Research population and sample

The sample of respondents consists of company directors, with approximately 100 participants. Companies such as Eurocons Group d.o.o., SLAVIAMED Belgrade, MARMEDIKA, WEST Kovin, Soja Protein Bečej, Masterfrigo, Palladio, Automation and Process Engineering, and many other companies are included.

THEORETICAL FRAMEWORK OF THE RESEARCH

Application of Industry 4.0 - Industry 4.0 implies further digitization by connecting processes within the production system and linking them with external processes such as the market, suppliers, research and educational institutions, banks, government services, etc. In this way, Industry 4.0, based on the cohesion of all actors and functions through networking and data integration, creates the prerequisites for achieving a truly automated value chain [15; 16]. Industry 4.0 helps factories remain competitive and survive in today's world by using various types of digital technologies. Essentially, Industry 4.0 means that everything in a factory becomes digitalized, from production realization, process control, to the provision of industrial services, [3]. The Industry 4.0 concept is based on the digital transformation of planning and production, the personalization of manufacturing, comprehensive machine networking, and the application of new internet services and technologies. By digitizing development and production, companies can quickly develop new products in a virtual three-dimensional (3D) environment, test them, and bring them to market, [4]. Industry 4.0 can be applied in the areas such as product identification and for precision agriculture.

Advanced robotics-autonomous robots - Amazon uses robots in its warehouses, which reduces costs and enables better use of space. KUKA, a European robotics manufacturer, offers autonomous robots that can communicate with each other, allowing them to adjust their actions (e.g., one robot handles one production phase and signals the next robot to begin only after completing its task), [14].

Additive manufacturing - Aviation companies use additive manufacturing to implement new designs that reduce aircraft weight, thereby lowering the cost of expensive materials such as titanium. Custom medical implants—prostheses are made by first scanning the patient's individual anatomy, and then using additive technology to create a unique prosthesis tailored to the patient, [14].

Augmented reality - Siemens has developed a platform for Industry 4.0. A suite of software connects production and HVAC process machines, offering companies various capabilities. Schneider Electric has also developed an Industry 4.0-based system that allows for the monitoring of electricity and other machinery in the field via a cloud platform, [14].

Industry 4.0 in manufacturing companies - The vision of Industry 4.0 emphasizes global networks of machines in a smart factory environment capable of autonomously exchanging information and controlling each other. This cyber-physical system allows the smart factory to operate autonomously, [7]. Industry 4.0 is seen as a new industrial stage where several emerging technologies converge to provide digital solutions. However, there is a lack of understanding of how companies are applying these technologies. Therefore, the goal is to understand the patterns of technology adoption in Industry 4.0 within manufacturing firms. We propose a conceptual framework for these technologies, divided into front-end and base technologies. Front-end technologies address four dimensions: Smart Manufacturing, Smart Products, Smart Supply Chains, and Smart Work, while base technologies consider four elements: IoT, cloud services, big data, and analytics, [9]. The rise of the Industrial Internet of Things (IoT) has introduced new challenges in logistics that may require technological changes such as the need for transparency (supply chain visibility); integrity control (ensuring the right products, at the right time, place, quantity, condition, and price) in supply chains, [8].

Examples of Industry 4.0 application - Regarding the Fourth Industrial Revolution, or "Industry 4.0," China cooperates with all industrial countries. It collaborates with Germany on standardization, with a German-Chinese alliance formed for vocational training and education, as well as a joint framework for the action plan "Design Innovation Together!" It also maintains collaborations with countries like Switzerland and France. The Chinese government is taking all steps to ensure that Chinese industry plays a key role in developing the global market, with the goal for China to become one of the most technologically advanced countries in the world by 2025, [16; 17].

Jean-Pascal Tricoire, Chairman and CEO of Schneider Electric - Virtually no manufacturing company in the world will remain unaffected by Industry 4.0—it will impact their corporate strategies and fundamentally change the way they operate. Preparing for Industry 4.0 is a long and expensive journey that involves the entire company, and no one can afford to ignore it, [11].

Stefan Hartung CEO of Bosch - European member states are committed to adapting their innovation systems to benefit from Industry 4.0, and the European Commission is also tasked with enabling less developed regions to do the same. However, there is limited knowledge about the factors driving competitive capacity in Industry 4.0 through the regional integration of enabling technologies. Based on regional participation data in the 7th European Framework Programme for Research and Technological Development, we explore the factors underlying competitive capacity through technology integration that enables Industry 4.0. Evidence shows that EU funding, central positioning in research networks, and inter-regional cooperation play a significant role in technology integration, with important policy implications, [12].

Simulations - Siemens and a German tool supplier have developed a virtual machine that simulates the processing of specific production parts using data from the actual machine processing them. This has reduced preparation time for processing by approximately 80%. Online shoppers can define the design of the furniture they purchase from a Polish start-up manufacturer. A mobile parametric modeling app allows customers to adjust dimensions, configuration, type of wood, and color and visualize the final result before the order is sent to production, [5].

Pharma 4.0 - Pharma 4.0 conceptualizes highly systematic automated processes, which can be batch, continuous, or hybrid, managed by an integrated production control strategy. Quality by design and process analytical technology principles are used to strengthen the Pharma 4.0 hypothesis. They offer the potential for strong, efficient, and fast production. Industry 4.0 is employed in medical technology, healthcare facilities, and biopharmaceutical manufacturing. Pharma 4.0 offers better tools for ensuring product safety and supply chain security. This review explains the impact of data analytics, digitalization, Industry 4.0, artificial intelligence, digital twins, and continuous manufacturing on Pharma 4.0, [6].

RESULTS AND DISCUSSION

Research sample

Most respondents are employed in private companies. About 88.9% work in private companies, 10% in public companies, and 1.1% in other sectors. The majority of respondents hold the position of director (43.3%), followed by 28.9% as heads of engineering, and the remaining 27.8% hold other positions such as maintenance engineers and other company employees. It can be observed that the largest sector among the respondents is pharmaceutical companies and others, accounting for 23.5%. Following this, there is an equal share of companies producing HVAC equipment at 17.6%, companies involved in process automation at 11.8%, and 0% for companies in robot manufacturing. It is noticeable that the majority of represented companies have over 100 employees, as larger companies tend to have greater implementation of Industry 4.0. Around 55.6% are medium-sized enterprises (up to 250 employees), 31.1% are small enterprises (up to 50 employees), and 10% are large enterprises (250 employees or more).

AWARENESS OF INDUSTRY 4.0

Figure 1 shows how many respondents have heard of Industry 4.0 so far.

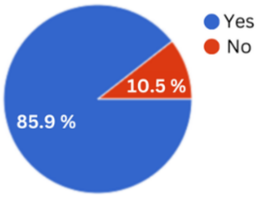

Fig. 1. *Presentation of respondents' information for Industry 4.0*

The fact that about 89.5% of people have heard of Industry 4.0 speaks to the enormous development of this topic and its penetration into public awareness. This is a positive sign, as it indicates that people are ready to adapt and adopt new technologies that will transform the industrial sector. Figure 2 shows how much the respondents' companies lag in the implementation of Industry 4.0 principles.

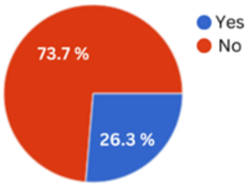

Fig. 2. *Presentation of the application of Industry 4.0 principles in companies*

Despite these challenges, it is important for companies to take steps toward implementing the principles of Industry 4.0. Figure 3 shows that the respondents are familiar with the characteristics of Industry 4.0. Figure 3 also shows whether, for those who answered "no" to the previous question, they were aware that Industry 4.0 offers any of the following:

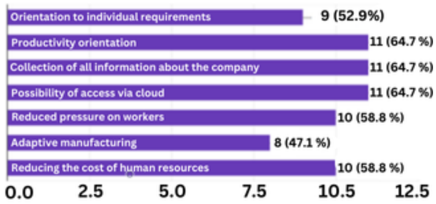

Fig. 3. *Industry 4.0 opportunity presentation*

APPLICATION OF INDUSTRY 4.0

Figure 4 shows whether the respondents have machinery for production, HVAC equipment, and other assets in their company that could be utilized for Industry 4.0.

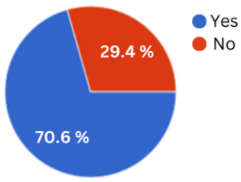

Fig. 4. *Presentation of the possibility of using Industry 4.0*

This is a significant number of respondents who have equipment in their companies that could be utilized for the implementation of Industry 4.0 principles. Figure 5 shows whether the respondents have ever considered connecting their entire company and being able to control it remotely at any given time.

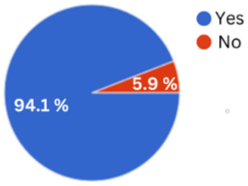

Fig. 5. *Presentation of the number of respondents who are interested in remote access to the company*

This is approximately important to everyone - the ability to control the company and have an overview of the most essential aspects. Figure 6 shows whether there is a possibility that the respondents would implement Industry 4.0.

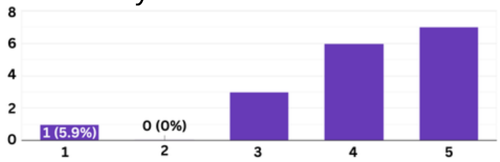

Fig. 6. *Presentation of the possibility of using Industry 4.0*

The respondents' answers indicate the possibility of implementing Industry 4.0 principles in their companies, suggesting a growing awareness of the benefits of this transformation. Figure 7 shows whether the respondents are interested in Industry 4.0.

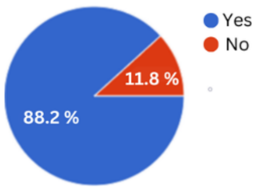

Fig. 7. *Presentation of interest in using Industry 4.0*

With appropriate support and incentives, the strong interest in Industry 4.0 can be transformed into concrete action, leading to significant progress.

REASONS FOR INTRODUCING INDUSTRY 4.0

Figure 8 shows what respondents would cite as the reason for introducing Industry 4.0 in their company if they decided to implement it.

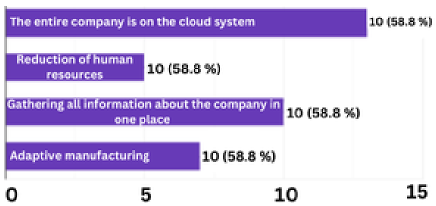

Fig. 8. *Reasons for introducing Industry 4.0*

The responses given to this particular question are mostly similar, as they align with what Industry 4.0 itself offers. Most companies share similar interests, as they are involved in some form of production, leading to comparable answers. Figure 9 shows the number of respondents who believe that there have been improvements in processes and production after the introduction of Industry 4.0.

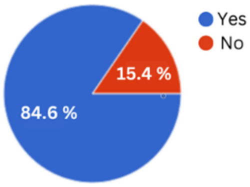

Fig. 9. *Presentation of the number of respondents who think that there have been process and production improvements after the introduction of Industry 4.0*

The improvement in production quality and control is certainly a top priority, as indicated in the chart itself. Figure 10 shows whether the respondents believe that the elements brought by Industry 4.0 can replace previous work concepts in their company.

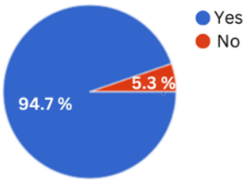

Fig. 10. *Presentation of respondents who know what Industry 4.0 brings*Advanced technology undoubtedly offers more than the previous work concept in the company.

Figure 11 shows whether the respondents would recommend the implementation of Industry 4.0 in business operations to others.

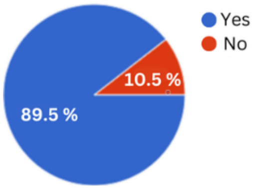

Fig. 11. *Presentation of possible recommendations to future users of Industry 4.0*

The figure shows that the majority of respondents would recommend other companies to adopt this type of technology.

VERIFICATION OF HYPOTHESIS CONFIRMATION

Based on the conducted and presented research, it can be concluded that all three hypotheses have been confirmed:
H1: Awareness of Industry 4.0 among entrepreneurs in the Republic of Serbia is at a high level.
H2: The applicability of Industry 4.0 among entrepreneurs in the Republic of Serbia is at a high level.
H3: The prospects for the application of Industry 4.0 among entrepreneurs in the Republic of Serbia are at a high level.

CONCLUSION

The paper presents research on the current state of Industry 4.0 implementation in the Republic of Serbia. Based on the results, it can be concluded that Serbia is at a very low level in terms of utilizing Industry 4.0 concepts. Most entrepreneurs are familiar with it, but many of the companies researched in this paper are large companies. However, even among smaller companies, many are opting for the Fourth Industrial Revolution. Each has its own reason for the final decision, whether it is due to the current trend, as there is increasing talk about it, and everyone wants to implement something like that in their company. This is a new topic and a new future, marking a step toward digitalization. Many global leaders have already embraced Industry 4.0; the question remains when its wider adoption will begin in our country.

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GREEN BEHAVIOR OF EMPLOYEES

Review paper

Dragana Kovač[1*], Edit Terek Stojanović[2], Mila Kavalić[3], Maja Gaborov[4], Melita Ćoćkalo-Hronjec[5]
[1,2,3,4]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia
[5]High school „Laza Kostic", Novi Sad, Republic of Serbia

Abstract: Organizations that do business nowadays are more and more oriented towards doing business that does not pollute the environment. On the one hand, legal regulations oblige them to do so, on the other hand, it is an awakening of awareness about responsibility towards the environment. It is evident that the environment is highly polluted, that a large amount of waste is deposited, and that non-renewable energy sources are largely exhausted. For this reason, organizations try to adapt their business to these conditions and encourage green or ecological behavior of their employees. Through green behavior, employees in their daily activities at the workplace reduce the negative impact on the environment. In this paper, the concept of green behavior of employees is defined, the dimensions and models of green behavior of employees are presented, and some of the guidelines for improving green behavior of employees are listed.
Key words: green behavior, ecological behavior, sustainable development

INTRODUCTION

In recent times, concern for the preservation of the environment and the reduction of pollution has emerged as an imperative in many organizations. Striving to reduce environmental pollution and save natural resources while achieving economic profitability leads to sustainable business, [1]. In order for a sustainable business strategy to be successful, it is necessary for employees in organizations to adapt their behavior to it. Green behavior of employees refers to all sustainable behaviors of employees in the workplace, [2]. The green behavior of employees represents a set of activities of employees at the workplace that aim to preserve natural resources and the environment and thus reduce environmental pollution, [3,4].

Activities that employees carry out or should carry out in the workplace in order to reduce the negative impact on the environment are also called dimensions of green employee behavior. Some of those dimensions are: recycling, energy efficiency, rational use of resources, [5].

Numerous external and internal factors influence decision-making in employee behavior. The same is the case with green behavior, that is, how the employees will behave in this sense. Some of the models that analyze the activities of green behavior of employees and in which direction they go are: theory of planned behavior, theory of social learning, theory of norms and values, model of ecological leadership, model of organizational culture, [6,7].

Organizations operating today are obliged to take care of the environment. For this reason, they should guide their employees towards green behavior. Through various types of education and providing information on the importance of environmental protection, by setting a personal example of leaders and creating an ecological organizational culture, the ecological behavior of employees is also encouraged, [8, 9].

The green behavior of employees is becoming an increasingly important factor for the success of modern organizations. Incorporating sustainable practices helps organizations reduce negative environmental impacts, which can contribute to lower operating costs and increased efficiency. Using resources in a more responsible way, such as saving energy, reducing waste or recycling, helps companies reduce costs of electricity, materials and waste. Encouraging employees to get involved in environmental initiatives helps to strengthen organizational culture and create a positive reputation. Organizations that actively promote green behavior among employees can attract environmentally conscious consumers and investors, which can improve their image at the market.

[1] Corresponding author, milosavljevd@yahoo.com, ORCID: https://orcid.org/0000-0002-5421-4376
[2] terekedita@gmail.com, ORCID: https://orcid.org/0000-0003-0013-8141
[3] milazakin@gmail.com, ORCID: https://orcid.org/0000-0001-7053-2334
[4] majagaborov26@gmail.com, ORCID: https://orcid.org/0000-0002-3810-6156
[5] melita.cockalo@gmail.com

THE CONCEPT OF GREEN EMPLOYEE BEHAVIOR

One of the key topics of modern business, where environmental protection is a priority of many organizations, is the concept of green or ecological behavior of employees. Green behavior of employees refers to activities and procedures that employees undertake with the aim of reducing the negative impact on the environment, [4, 10]. Defining this behavior refers to directing the activities of employees towards the preservation of natural resources, reduction of pollution and more efficient use of energy, [11]. Environmental behavior of employees includes all those activities that help organizations to reduce the negative impact on the environment, whereby this behavior can refer to daily work habits, but also to long-term initiatives within the company. This term includes a wide range of activities, from energy efficiency and recycling, to waste reduction and the use of sustainable resources, [12]. The green behavior of employees is becoming an indispensable part of sustainable business strategies, which companies are increasingly integrating into their daily operations, [3].
Therefore, in order to define the concept of green behavior of employees, it is necessary to understand the basic principles of sustainable business and how they affect the activities of individuals in the workplace. Sustainability is often defined as the ability to meet the needs of present generations without compromising the ability of future generations to meet their own needs. That is, sustainable business implies the integration of environmental, social and management factors into business strategies in order to achieve a balance between economic goals, social needs and environmental protection, [13]. The green behavior of employees exactly supports this idea, because it implies reducing the use of natural resources, minimizing the emission of harmful gases and responsible waste management. In this way, employees become active participants in preserving the ecosystem and reducing the ecological footprint of the organization.
The green behavior of employees has a long-term effect on the entire society, because it promotes awareness of environmental protection outside the workplace. Employees who adopt these practices often apply them in their daily lives, which contributes to a wider positive impact. In this way, companies not only become socially responsible organizations, but also actively contribute to the reduction of environmental problems in the community, [14, 15]. The green behavior of employees can be measured through specific indicators, such as the reduction of energy consumption, the amount of recycled material, or the reduction of harmful gas emissions. These indicators allow companies to monitor progress and identify areas where further improvement is needed. Through regular monitoring of these parameters, companies can continuously improve their environmental performance, [16].
Given that the environmental behavior of employees is considered one of the key elements of sustainable business, companies that actively work on defining and promoting it have long-term benefits, both economic and reputational. By encouraging this kind of behavior, they not only contribute to the preservation of the environment, but also create a working environment in which employees feel that they are part of a wider positive contribution to society and the planet.

DIMENSIONS AND MODELS OF GREEN EMPLOYEE BEHAVIOR

Dimensions of employees' green behavior

The dimensions of green employee behavior represent different aspects of environmentally responsible activities that employees undertake in order to reduce the negative impact on the environment within the workplace. Some of the dimensions of green employee behavior are, [5, 17]:

- Rational use of resources;
- Recycling and proper waste management;
- Energy efficiency;
- Reduction of emissions of harmful gases;
- Sustainable procurement;

- Use of digital technologies;
- Raising environmental awareness and educating employees.

Rational use of resources implies efficient and responsible use of energy, water and other materials for business. Employees can help reduce energy consumption by turning off computers, lights and other devices when not in use. Also, using printing on both sides of paper, or switching to fully digital documents, reduces the use of paper and contributes to the preservation of forests, [6, 18].
Employees can contribute to green behavior by properly sorting waste and using recyclable materials. Placing separate bins for different types of waste in the workplace can facilitate the recycling process, [19].
Energy efficiency includes all activities that contribute to reducing energy consumption within the workplace. Employees can use energy-efficient appliances, optimize room heating and cooling, and use natural lighting when possible. For example, turning off lights and appliances at the end of the working day or during a break can significantly reduce energy consumption, [20].
Reducing the emission of harmful gases can be done by changing the mobility of employees. This would mean that employees use public transport, bicycles, share transport among themselves or walk to work. Also, one of the types would be working from home, which would reduce the journey to work, and thus the total emission of harmful gases, [21].
The use of digital tools and technology is another dimension related to reducing the consumption of physical resources, such as paper and energy, through the use of digital platforms and software solutions. Employees can use e-mail, cloud services and video conferencing instead of printing documents and physically attending meetings. This practice not only reduces resource consumption, but also facilitates business processes, making them more efficient and environmentally friendly, [22].
Raising environmental awareness and educating employees is perhaps the most important dimension of employees' environmental behavior. Only employees who are environmentally aware, sufficiently educated and informed will behave responsibly towards resources and contribute to the sustainability of business. For this reason, organizations should organize trainings and workshops that would include environmental protection topics, [23].

Models of green employee behavior

Models of employee green behavior represent theoretical frameworks that explain how and why employees adopt environmentally responsible practices in the work environment. These models help in understanding the factors that influence employees' decision-making regarding environmental activities. There are several key models used to analyze the green behavior of employees, and each of them offers a specific insight into employee motivation and behavior related to environmental protection, [6, 7].
One of the most important models is the theory of planned behavior, which was developed by Eisen's theory in 1985. This model explains how employees' intentions to behave environmentally depend on three basic factors: attitudes towards environmental practices, subjective norms and perceived control over behavior, [24]. According to the social learning model, employees learn green practices by observing and imitating the behavior of others in the organization. Leaders, managers and colleagues play a key role in this process. If employees see that their superiors regularly implement environmentally responsible practices, such as rational use of resources or waste reduction, they are more likely to adopt such behaviors themselves. Also, this model indicates the importance of rewarding environmental behavior and recognizing those who excel in the application of green practices, [25, 26]. The theory of norms and values is a model based on the assumption that employees are guided by internal moral beliefs and values when adopting environmental behavior. According to this approach, employees who have a developed sense of responsibility towards the environment and who are aware of environmental issues are more likely to behave in accordance with sustainable principles. This model suggests that ethical norms and values, as well as personal attitudes towards environmental protection, are key factors in the adoption of green practices,

[27]. The model of organizational culture emphasizes the importance of the environment in which employees find themselves. This model emphasizes that companies that actively promote sustainability through their values, strategies and policies can significantly influence the behavior of their employees. When environmental principles are integrated into the organization's culture, employees are likely to adopt green practices more easily. This model implies that the culture of the organization, through values and norms, shapes the behavior of employees in relation to environmental issues, [28]. The environmental leadership model focuses on the role of leaders in encouraging green behavior among employees. Leaders who behave in an environmentally responsible manner and who publicly support environmental initiatives can significantly influence the adoption of this behavior among employees. According to this model, leaders set standards through their own example and serve as role models for employees. Also, leaders who encourage open communication on environmental topics and encourage innovative sustainability solutions create an environment where employees feel supported and motivated to participate in environmental initiatives, [29].

GUIDELINES FOR PROMOTING THE GREEN BEHAVIOR OF EMPLOYEES

The success of organizations in the modern market today certainly depends on the business by which organizations do not pollute the environment. For this reason, it is first of all necessary to improve green behavior and environmental awareness among employees, in order to strive for sustainable development and reduce the negative impact on the environment. The adoption of green practices requires a strategic approach that includes education, encouraging responsible behavior and implementing concrete measures that enable employees to contribute to environmental sustainability on a daily basis, [9, 30].

First of all, it is necessary to start with the education of employees and the importance of ecological practices. In order for employees to be motivated to act responsibly towards the environment, they need to be well informed about the importance of environmental issues such as climate change, waste reduction, recycling and conservation of natural resources. Organizing trainings, seminars and workshops can significantly raise the level of awareness among employees. For example, education about energy efficiency can help employees better understand how small changes, such as turning off appliances or using resources rationally, can have a big impact on reducing the company's overall environmental footprint, [31].

Companies should define specific goals related to the reduction of energy, water, paper or waste consumption, so that employees have a clear framework in which to act. Setting realistic and measurable goals, such as reducing energy consumption by a certain percentage during the year, can help employees focus on specific tasks and contribute to achieving results. Also, standardization of procedures for recycling and responsible management of resources enables green practices to be more easily applied in everyday business processes, [3].

Creating an environmentally responsible organizational culture is also a key guideline for promoting green behavior. A sustainable organizational culture implies that environmental principles become part of the company's daily operations and values. Management plays a key role in creating this kind of culture, because the example set by leaders directly affects the behavior of employees, [32].

Establishing a recycling system and proper waste management also contributes to the green behavior of employees. Placing clearly marked recycling bins in the workplace makes it easier for employees to separate waste properly. In addition, the application of technology and digital tools will affect the reduction of the use of physical resources and thus the reduction of waste, [33].

Encouraging innovation and creative solutions in the field of sustainability can significantly improve green practices in a company. Employees should be encouraged to propose new ideas and solutions to environmental challenges facing the organization. Organizing internal competitions or brainstorming workshops can help to discover innovative ways to improve energy efficiency, reduce waste or optimize resource consumption. Also, companies can invest in research and development of sustainable technologies and products, thereby further encouraging employees to think ecologically and contribute to the overall sustainability of the organization, [34].

Certainly, rewarding employees for active participation in green initiatives will motivate employees to behave in an environmentally responsible manner. Also, organizations should stimulate sustainable mobility among employees. Through the introduction of subsidies for the purchase of bicycles or monthly tickets for public transport, it can motivate employees to use more sustainable means of transport. Also, allowing flexible working hours or working from home can contribute to reducing harmful gas emissions, as it reduces the need for daily commuting. In this way, companies directly influence the reduction of the negative impact of transport on the environment, [35].

CONCLUSION

Organizations that want to do business successfully today strive for environmentally sustainable business. Environmentally sustainable business involves the application of business practices that minimize the negative impact on the environment and promote the long-term sustainability of resources. The goal of ecologically sustainable business is to strike a balance between economic growth and the preservation of natural resources. The green behavior of employees plays a key role in the implementation of environmentally sustainable business. Employees can contribute to the organization's environmental goals through small but significant changes in their daily work activities. For example, reducing paper consumption by using digital documents, turning off computers and other electronic devices when not in use, and properly separating waste for recycling can significantly reduce a company's environmental footprint.

The environmental behavior of employees in Serbian companies is becoming an increasingly important topic in the context of global environmental challenges and efforts to reduce the negative impact of business on the environment. In Serbia, companies are facing growing pressure to integrate sustainable practices into their daily business activities, which includes environmentally responsible employee behavior. The introduction of ecological practices requires changes at the individual level, but also the adjustment of the entire organizational culture. Within the broader framework of corporate social responsibility, companies in Serbia are beginning to integrate formal policies on environmental protection. These policies are not only related to production processes, but also to the way in which awareness of environmental issues is conveyed to employees. The introduction of ecological practices in Serbian companies is a process that requires time and investment, but it brings numerous benefits, both for companies and for the wider social community.

Leaders are the ones who play a key role in the formation of environmental awareness among employees. Future studies could investigate different leadership styles and which styles have the greatest impact on the formation of green initiatives in organizations. It could also be investigated which motivational factors influence the green behavior of employees, that is, which of the motivational factors would be the most effective. The subject of future research could be technological progress and its impact on the green behavior of employees. Studies could examine how new technological solutions facilitate the green behavior of employees, as well as whether these innovations increase employees' awareness of the environmental impact of their activities. It is important to investigate the role of employee training in promoting green behavior. Future studies could analyze the effectiveness of different training approaches and how they affect employee engagement in sustainable practices. Research can also include the long-term effects of such initiatives, i.e. whether positive changes in behavior have effect in the long term.

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COMMISSIONING AND QUALIFICATION OF A PHARMACEUTICAL FACILITY

Research paper

Ilija Tabašević[1], Dragan D. Milanović[2], Mirjana Misita[2]
[1]Hemofarm, Vršac, Serbia
[2]University of Belgrade, Faculty of Mechanical Engineering, Beograd, Serbia

Abstract: This work is part of the research of the ongoing doctoral dissertation, which aims to integrate nine years of work on projects in the pharmaceutical industry into a scientific research undertaking and to create a cybernetic model for the qualification of pharmaceutical plants. The conclusions of the study presented in this paper aim to unify the responsibilities between the pharmaceutical industry and the contractors, on pharmaceutical plant construction projects. An integrated approach during the qualification of pharmaceutical plants is essential for the success of the entire project because the activities during commissioning and qualification are extremely complex, time-consuming, financially challenging, and affect the start of production activities. This research was conducted using a questionnaire, exclusively for experts in the field of qualifications of pharmaceutical plants. As such, it provides a significant insight into the theoretical and practical guidelines necessary for the precise definition and implementation of an integrated approach and cooperation between contractors and the pharmaceutical industry, taking into account regulatory frameworks and pharmaceutical standards. The defined factors establish the necessary framework for optimizing cooperation and interaction between key actors, pharmaceutical industry employees, and external contractors.
Keywords: commissioning and qualification, pharmaceutical industry.

INTRODUCTION

Qualification of pharmaceutical plants is an indispensable part of good manufacturing practice [1] and is a basic component for ensuring the quality, integrity, safety, and efficiency of pharmaceutical plants. The set of qualification activities includes analytical planning and rigorous implementation of all necessary phases, in order to meet pharmaceutical standards and ensure specific requirements defined by regulatory authorities, which immediately meet the highest quality criteria.
Commissioning refers to systematic planning, verification, and documentation, to ensure that all systems and installed equipment are tested and ready for operational use, as per designed specifications and functional requirements. This process includes a series of activities and tests that confirm that the installed equipment meets all operational and safety standards before entering the formal qualification and validation phases, thus creating a solid basis for further work and quality assurance in pharmaceutical production, [2].
According to [2], qualification is a structured and documented process that confirms that equipment, systems, or plants are capable of functioning in accordance with the defined specifications and performances, as well as regulatory requirements. This process is a key part of validation, and it includes stages such as installation qualification (IQ), operational qualification (OQ), and performance qualification (PQ), to ensure that manufacturing processes in the pharmaceutical industry continuously meet the set quality and safety standards.
Commissioning is a contract between the supplier and the customer, and the documents necessary for its execution can be created without considering the quality process but instead focusing on the functionality of the equipment considered as a "stand-alone" system. Qualification documents have to be much more strictly regulated and adapted to the entire pharmaceutical process because they must be presented to regulatory departments of institutions. In theory, qualification should refer only to the stages that must guarantee the quality of the final pharmaceutical product throughout the entire process, [3].

[1] Corresponding author ORCID: https://orcid.org/0009-0002-7867-2758
[2] ORCID: https://orcid.org/0000-0002-5589-9127
[3] ORCID: https://orcid.org/0000-0002-7039-0783

Commissioning and qualification activities can be documented in a single document, depending on the corporate philosophy and complexity of the system. Commissioning is considered an engineering activity, which aims to implement the design and functionality of the system. Qualification, on the other hand, is a good manufacturing practice activity that focus on elements and systems that have a direct impact on product quality and must follow a rigorous approach to documentation, relative to commissioning, [4].
In paper [5], it is argued that a well-designed commissioning and qualification program reduces time and costs. In the paper, an approach to the management of the life cycle of qualifications is defined, by considering the entire process, specification, design, installation, commissioning, and qualification (4QS modes, DQ - IQ - OQ - PQ), as well as maintenance, provided that all listed activities are based on risk management.
Based on the conducted case study, as well as by sending a questionnaire to contractors and pharmaceutical companies, paper [6] concludes that there are huge differences in the understanding of the term "quality", because managers of contractors understand quality as a measure of production, whereas managers of pharmaceutical companies observe it as regulatory compliance.
Commissioning documentation and qualification documentation, if properly implemented, have a symbiotic relationship, because qualification helps define what is important to emphasize during commissioning, while commissioning minimizes qualification efforts and acts as support to its success, [7].
Commissioning is crucial, as it ensures that systems in new and existing facilities are properly installed, functionally tested, and ready to operate in accordance with the requirements and defined design. Putting more focus on documented commissioning can increase costs and timelines. However, since qualification usually costs at least twice as much as commissioning, a shift in priority to a documented version of commissioning can reduce the overall cost of qualification, as many qualification problems would be solved upfront, [8].

METHODS

The authors publish the results of the survey, which was taken from the doctoral dissertation [9], through paper [10]. The questionnaire consisted of 63 questions, which were related to the qualification of pharmaceutical facilities. The study concluded that the criteria by which the success of the project can be assessed are time, price, and quality. Additionally, the first two criteria can be easily measured, while quality is a very specific concept, which is at the root of the problem of successful qualification. Through the questionnaire, different views on the meaning of quality were determined. The results of the survey helped shape the key aspects of designing a cybernetic model for the qualification of pharmaceutical plants [11], providing a deeper understanding of the various challenges that arise when installing BMS and HVAC systems. The analysis of these results revealed new information that was essential for the development of the following questionnaire, which is described in detail below.
Aiming to improve the process carried out in the previous survey, additional research was conducted in the form of another survey, using a carefully designed questionnaire. A total of 16 questions were taken from [9], while the remaining 10 questions were conceptualized based on long-term research experience, project management in the pharmaceutical industry, the conclusions drawn from a previous study [10], and the results of a case study, which is shown in (MDPI). This in turn ensured the relevance and continuity of the research.
The aim of the conducted survey presented in the paper was to collect and analyze the views of employees and contractors in the pharmaceutical industry, on key aspects related to their professional engagement.
The design of the survey was such that 24 questions were formed based on the Likert scale, which allows respondents to answer with one of the five clearly defined options: **SA** - Strongly agree; **A** - Agree; **N** - Neither agree nor disagree; **D** - Disagree; **SD** - Strongly disagree. 2 additional questions allowed for qualitative conclusions to be made and 3

questions were related to the title, number of years in the pharmaceutical industry, as well as the number of years of involvement in qualification activities. The approach using a Likert scale, provides a sophisticated methodology for assessing respondents' attitudes and opinions, enabling statistical analysis in a wide range of research, while the neutral category allows for a more subtle interpretation of undecided responses, thus achieving a balance between precision and flexibility in the interpretation of results.

Data collection was done through online platforms or in person. The questions were explained live to each respondent, and the average time required to fill out the questionnaire was ~ 28 minutes. Having filled out the questionnaire, the respondents sent the completed surveys to the email address of the author, after which the results were summarized and analyzed. Out of a total of 60 respondents, who are exclusively experts from the pharmaceutical industry, 48 completed the procedure, which amounts to 80%. The questionnaire was primarily aimed at employees of pharmaceutical companies, contractors in this industry, Good Manufacturing Practice (GMP) inspectors, regulatory authorities, consultants specializing in the pharmaceutical industry, and professors who teach in this field. The questions asked in the questionnaire were rather specific and closely related to the topic of qualification of pharmaceutical plants. It was therefore challenging to find respondents with the required level of expertise and knowledge. Part of the results of this survey contributed to the development of a cybernetic model for the qualification of pharmaceutical plants, which is shown in [11].

Data processing and analysis were performed using quantitative methods, including analysis of frequencies and percentages for each of the given answers on a Likert scale. Additionally, a descriptive statistical analysis was performed to identify the basic tendencies in the respondents' attitudes. The following steps were taken:

- Categorization of answers according to the degree of agreement or disagreement with the statements;
- Calculation of mean values to identify dominant tendencies;
- Analysis of correlations between respondents (years of experience, industry) and responses to survey questions.

The research was conducted in accordance with ethical standards for data collection, with confidentiality and anonymity of responses clearly ensured. Respondents were informed in advance about the purpose of the research, the time frame for completing the survey, and the way in which the collected data will be analyzed and interpreted.

RESULTS AND DISCUSSION

The original questionnaire has been submitted as an attachment. The diagram in Fig. 1 shows the respondents' field of work, more specifically, whether they are contractors, employees in the pharmaceutical industry, professors, or inspectors. In addition to this, the number of years spent working in this profession was also defined as an additional question, which was published in [11]. By analyzing the answers concerning the field of work, conclusions were drawn about each question, and differences were determined, which helped in understanding the problems faced by the participants during commissioning and qualification activities.

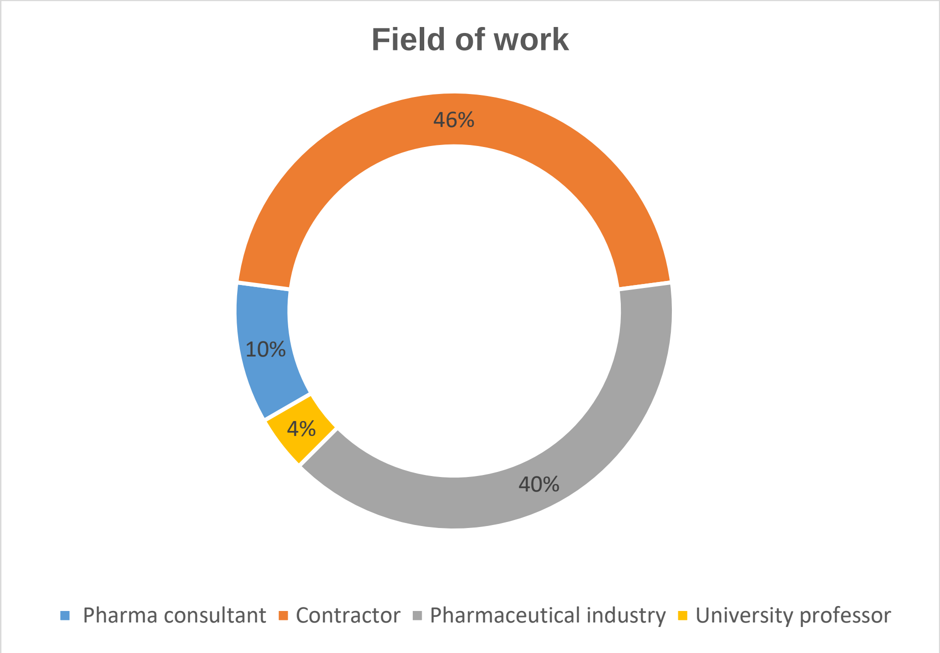

Fig. 1. *Respondents' field of work*

During the execution of works and the actual installation of the system, there are certain challenges faced by the contractors, which, if not solved immediately, are transferred to the commissioning activities and the qualifications themselves. Based on the case study, which is presented in (MDPI), potential problems during the mentioned activities are defined. In the diagram in Fig. 2, the answers related to the most frequent problems are analyzed.

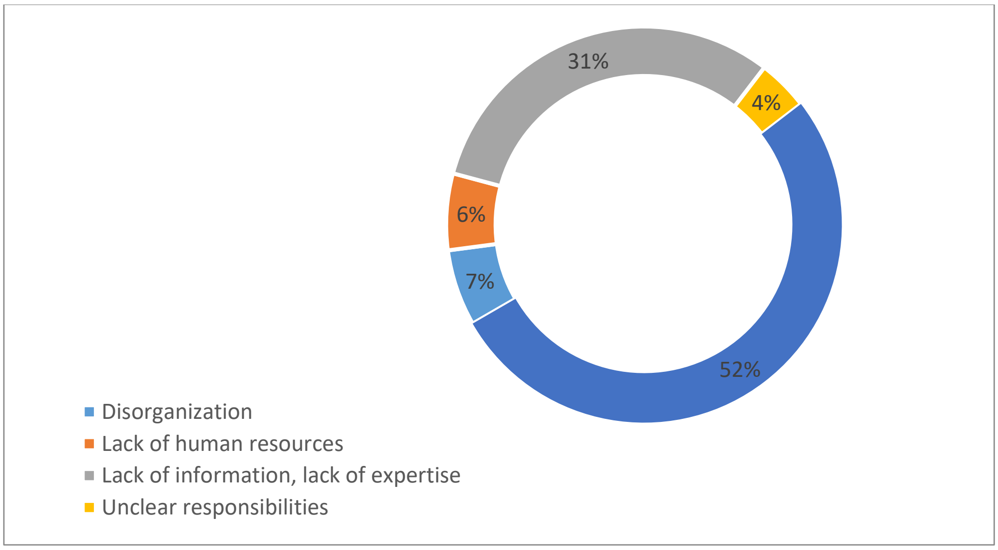

Fig. 2. *Additional question: The main source of problems during project implementation*

As confirmed in practice by the case study, the biggest problem during commissioning and qualification activities is unrealistic deadlines. Pharmaceutical companies aim to start production activities as soon as possible, and qualifications are the last in the series. [12] comes to the same conclusion back in 1998. He concludes that there are too often delays in design and/or construction, and since commissioning is the last stage, the commissioning time is arbitrarily reduced, to keep the completion date of the project intact and not to delay the process of production activities.
The next question can be defined as the best indicator of the problem. Fig. 3 shows the results related to the understanding of pharmaceutical standards, regulatory requirements,

guidelines, and recommendations in the qualification of pharmaceutical facilities, which additionally indicates how challenging and complex the area in question is. The authors determine that the main shortcomings in commissioning and qualifications are sampled by insufficient knowledge of technical literature, regulatory requirements, standards, and GMP itself because a high degree of technical and professional knowledge is required, as well as a careful analysis in order to implement the activities correctly, especially since regulations and standards are constantly being updated, in order to follow technological and scientific trends.

Similar conclusions are given in [13] where it is confirmed with the study that pharmaceutical companies failed to identify the importance and necessity of training programs for their employees. What is more, they do not even assess the level of training before assigning them specific responsibilities.

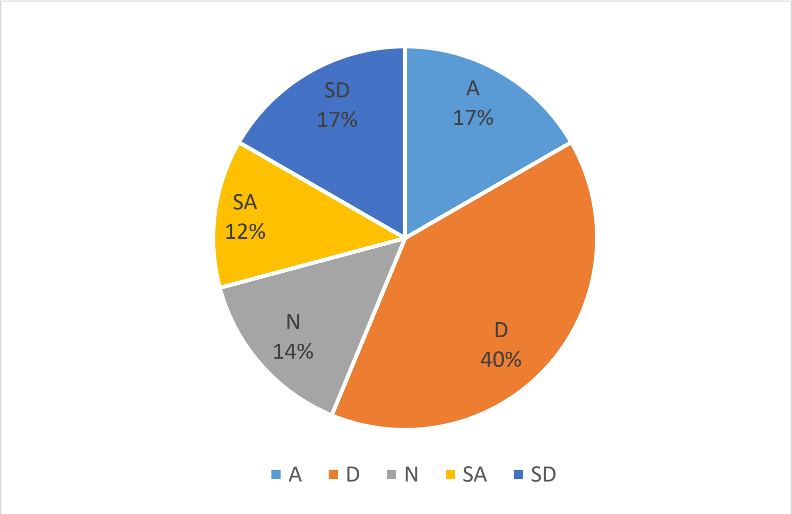

Fig. 3. *Question 3: Regulations for the qualification of pharmaceutical facilities are general, difficult to understand, and insufficiently detailed.*

The question shown in Fig. 4 refers to the responsibility for the execution of qualification activities. The diagram shows extremely varied responses, which leads to the conclusion that this is not defined by the contractual obligation and/or standard. It is very important to follow the entire process, from the initiation of change control and the creation of the URS to the completion of all qualification activities. If all the above steps are carried out, as shown in Fig 5, commissioning and qualifications will meet all regulations, guidelines, and standards, and obligations and responsibilities will be clearly defined. By accepting the plant, the pharmaceutical industry assumes full responsibility for all processes, and all documentation before the regulatory authorities.

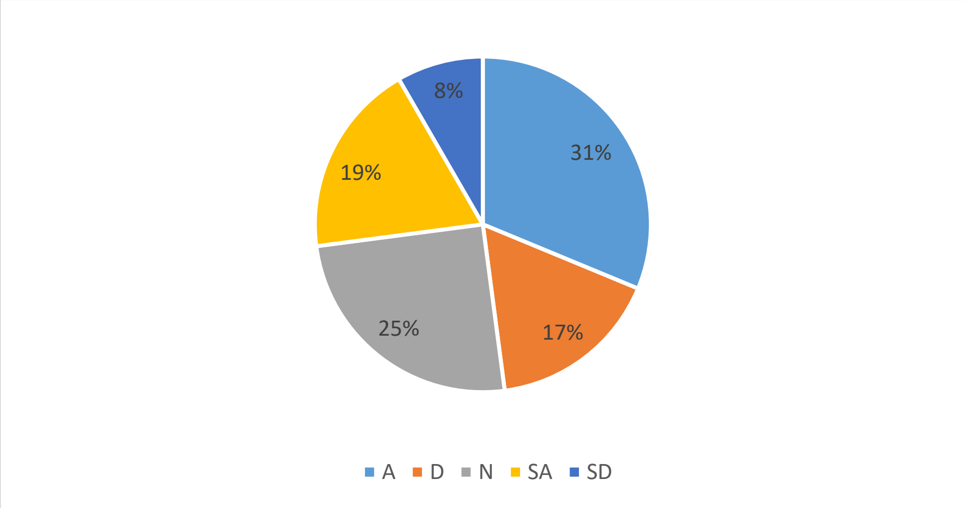

Fig. 4. *Question 8: Qualifications of pharmaceutical facilities should be left to pharmaceutical clients.*

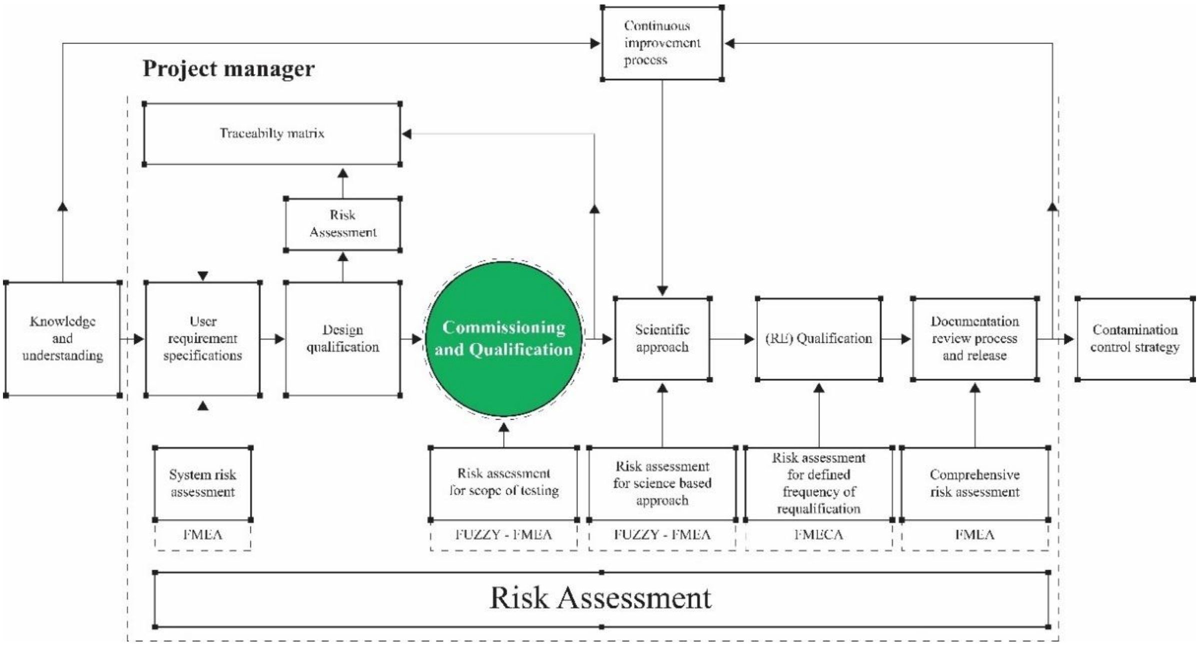

Fig. 5. *Cybernetic model for the qualification of pharmaceutical facilities (MDPI)*

The study conducted by sending a questionnaire to the respondents, who are experts in the field of C&Q, was confirmed to be expedient. By summarizing and analyzing the results, conclusions were made, and key factors were defined that influenced the problems of commissioning and qualification. Not only was the research completed by finding challenges and problems, but a model was created, and a system was implemented that improves processes and gives recommendations on how to overcome challenges. The questions shown in Fig. 2 and Fig. 3 are explained and clarified, and the risk of these situations is reduced to a minimum, by implementing the field "knowledge and understanding" in the model, which conditions all participants to training and full understanding of the entire process. As an additional check, a field has been introduced that has a risk-based principle, as well as a scientific approach, with feedback loops, which will control the entire process. Problems that may arise due to disorganization, irresponsibility, and undefined responsibilities are reduced by introducing the fields in the model: "URS", "DQ", and "Project manager". It is essential to properly define the URS, as well as the responsibilities for the execution of the works, and to have a person in charge of managing this complex system (project manager).

CONCLUSION

Without adequate commissioning and qualification of a pharmaceutical plant, there are huge risks of system failures, product contamination, downtime in production activities, and non-compliance with regulatory requirements. The aim of this research was to identify the challenges and problems encountered during the commissioning and qualification of pharmaceutical plants through a questionnaire distributed to C&Q experts. The scientific contribution of the work is reflected in a systematic approach and analysis of the current situation, taking care to examine all participants and interested parties, contractors, employees in the pharmaceutical industry, consultants, and inspectors. From a regulatory point of view, the paper provides recommendations that can serve to improve existing guidelines. The implementation of the proposed solutions has the potential to minimize regulatory risks and facilitate the process of compliance with regulatory requirements. Timely management of the mentioned critical factors reduces the project completion time, costs, and the start of production activities. Therefore, C&Qs serve not only to ensure compliance but also to preserve the integrity of pharmaceutical products, ultimately protecting patient health and maintaining confidence in the pharmaceutical industry.

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CIRCULAR ECONOMY IN THE CONSTRUCTION SECTOR: THE SITUATION IN CROATIA

Review paper

Držislav Vidaković[1*], Marijana Hadzima-Nyarko[2], Laura Šoja[3]
[1,2]Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture Osijek, Osijek, Croatia
[3]Josip Juraj Strossmayer University of Osijek, Faculty of Economics and Business, Osijek, Croatia

Abstract: This work represents a review of the principles and practices of circular economy in the construction sector. Construction waste is an increasing global problem, with the construction economy being the biggest consumer of raw materials. Many studies have explored the possibilities of reducing waste and recycling materials used in construction. European Union (EU) has defined the concept and goal for reducing and reusing construction waste, which member states achieve with different success. This work presents experiences in this area in Croatia and identifies the problems in practice that need to be solved in order to achieve better results.
Keywords: construction waste, circular economy processes, recycled materials, practical problems

INTRODUCTION

Because of the increasing urbanization and changes in living standards (such as housing style, etc.), which reduce the lifespan of buildings and other structures, the generation and disposal of construction waste has become a global problem because of pollution and the large volumes of waste in landfills. With the continuous increase in the value and scope of construction work, the amount of construction waste is also rising. For example, in Croatia, from 2015 to 2022, the increase in generated construction waste was nearly 46 % [1], and projections for this decade indicate that this growth will continue at a rate of 1.5 % per year [2].
The construction sector produces about 30 % of the total waste in the world and around 37 % of the total waste at the EU level [1]. Thus, the European Commission has included the construction sector as one of the seven key areas that can be used to achieve a circular economy [3]. EU policies focus on making it a world leader in recycling and green technologies, which is tied to the growth of knowledge. Apart from contributing to a cleaner and healthier environment, it increases job opportunities and reinforces local economies [4]. The framework directive 2008/98/EZ set a goal for EU countries to achieve a minimum of 70 % of construction waste by 2020 through preparing for recovery, recycling and recovering other materials (including backfilling with waste replacing other materials), excluding soil and stones. Some countries have done much better than this, but the results are very different from one member state to another and the ways they achieved them. Comparing the results is problematic because there is no consensus on what is included in construction waste, and not all countries classify landfilling similarly (as recovery or disposal). Additionally, illegal dumping is not included in the reports (data on this is not available) [5]. However, the analysis shows that construction waste recovery in Croatia and the EU mainly relies on low-value methods, like filling holes at construction sites or using recycled (crushed) concrete for building roads [6].

CONSTRUCTION WASTE

Waste is any substance or object that the owner discards, intends to discard, or is required to discard. Construction waste is considered a particular type of waste and is defined as waste generated from construction and demolition activities which is not reused at the construction site where it is produced [7]. When demolishing or removing buildings, more significant amounts of waste are typically generated (where different materials are combined, such as

[1] Corresponding author, dvidak@gfos.hr, ORCID: https://orcid.org/0000-0002-7376-0364
[2] mhadzima@gfos.hr, ORCID: https://orcid.org/0000-0002-9500-7285
[3] laurasoja35@gmail.com

reinforcement and concrete) than during new construction and maintenance work. In Croatia, in 2022, the highest amount (almost 40 %) of reported construction waste came from civil engineering, while only 4 % was generated from building construction [1].

As long as the materials from demolition, reconstruction, or construction are separated at the construction site, do not possess any dangerous characteristics, and can be reused for construction purposes at that site, they are not considered waste. Excavation is not considered waste if used in its natural form at the same construction site where it was dug up or if it is a raw mineral material.

In the Croatian Ordinance on Waste Management (2022), aligned with the Commission Decision on the European Waste Catalogue (2000), category 17 refers to construction waste and waste from the demolition of buildings. This waste category has subgroups: concrete, bricks, tiles, and ceramics (17 01), wood, glass and plastics (17 02), bituminous mixtures, coal tar and products containing tar (17 03), metals and their alloys (17 04), soil (including excavated soil from contaminated sites), stone and dredging waste (17 05), insulating materials and construction materials containing asbestos (17 06), gypsum-based construction materials (17 08) and other construction waste and waste from the demolition of buildings (17 09) [8]. For the year 2022, it was estimated that 1,735,581 tons of construction waste were generated in Croatia. Like in previous years, the majority comprises soil, stone and dredging waste. Fig. 1. shows the estimated quantities of construction waste by subgroups.

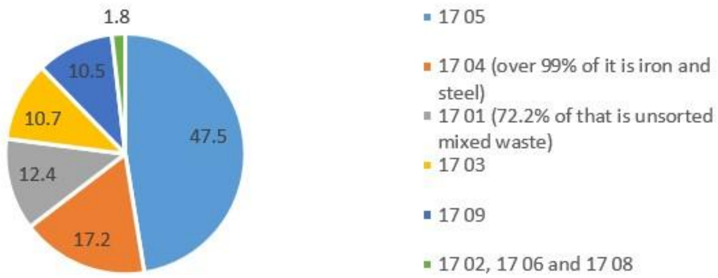

Fig. 1. *The shares of subgroups of construction waste in Croatia in 2022 (according to date from [1])*

Waste generated during construction or demolition must not be left in the environment or thrown into municipal waste. It is estimated that about 95 % of construction waste can be recycled [5]. Most construction waste contains few biodegradable components and can be temporarily stored without significant issues. It is then gradually processed mechanically before being recycled [9].

Recycling and the possibility of using processed construction waste depend on its characteristics. Construction waste can be:

- non-hazardous waste,
- inert waste (does not have significant physical, chemical or biological changes, can not be dissolved, not flammable, does not react physically or chemically in any other way, it is not biodegradable and does not negatively affect human health, animal and plant life, or the environment), and
- hazardous waste (possesses one or more hazardous properties, such as asbestos, tar and polychlorinated biphenyls).

Hazardous waste (in 2022, less than 1 % of such construction waste in Croatia [1]) must be separated, treated and disposed of according to specific guidelines with specific requirements for procedures. Specific requirements for procedures, management conditions, storage and record keeping are set for waste that contains asbestos. For hazardous waste, decontamination is required to stop contamination of other recycled materials.

Large amounts of non-hazardous mineral construction waste (mainly concrete, bricks, tiles, ceramics and their mixtures) are generated in Croatia, which has great potential for reuse and recycling.

In 2022, 52.4 % of the construction waste generated in Croatia was processed through recovery methods (including backfilling), with almost the same percentage processed the year before. In 2021, 27.2 % of construction waste was disposed and 8.8 % was used for backfilling, while in 2022, 31.5 % was disposed and 3 % was used for backfilling. No recovery or disposal method was defined for 11.1 % of the construction waste generated in 2021 and 13 % in 2022. Since soil and stone are the most significant parts of construction waste in Croatia, this subgroup is the most processed (about 50 % of the total waste processed). Over two-thirds of that was disposed of in landfills, and just under 30 % was processed by crushers [1]. It is also believed that some of the waste reported as recovered by crushers was used for backfilling. Fig. 2. shows the recovery rate of construction waste in Croatia from 2015 – 2022, calculated with Annex III Decision 2011/753/EU. (During this period, two different methods were used in Croatia to estimate the amount of generated construction waste.)

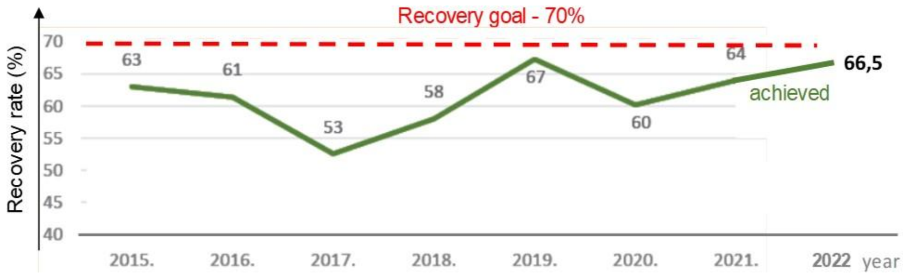

Fig. 2. *The recovery rate of construction waste in Croatia (according to [1])*

The recorded recovery was influenced by the amount of waste from the Zagreb earthquake in 2020, the COVID-19 pandemic and improvements in the quality of reported data in the Waste Management Information System. The calculation of the rate for 2021 was not influenced by the management of mineral materials generated as a result of the earthquake in the Sisak-Moslavina county because they were received at temporary storage facilities for further use and were not declared waste, considered like prevented waste [3].

IMPLEMENTATION OF CIRCULAR ECONOMY IN THE CONSTRUCTION SECTOR

Construction waste handling

A circular economy leads to a reduction in waste generation and reducing the use of primary resources [10]. Papadaki et al. (2022) found that the transition to recycled materials (such as recycled cement, metal, concrete or glass) during the construction phase, along with changes in disposal and recycling methods, can reduce the negative environmental impact by 65 % [11].

Processes of circular waste management include all stages of construction projects (from design and planning to construction, use, reconstruction and demolition). All project participants (from investors and designers to contractors) should be involved, along with material producers, suppliers and local and national authorities.

In the pursuit of reducing construction waste, in accordance with the principles of circular economy, the Construction law (2013) in Croatia mandates the sustainable use of natural resources as one of the fundamental requirements for buildings. This requirement implies that buildings must be designed, constructed and deconstructed to ensure the sustainable use of natural resources. In this regard, it is essential to ensure [12]:

- the reuse or recyclability of the building, its materials and components after deconstruction
- the durability of the building and
- the use of environmentally acceptable raw materials and secondary materials in construction.

The EU aims for a circular economy, and the basic concept of 3R (Reduce + Reuse + Recycle) is being expanded to 5R (with the additional measures of Refuse and Repurpose).
These principles and their measures are not equally helpful or affordable for all types of waste (for example, some are better suited for food waste, clothing, technical devices, etc.) as well as for all subgroups of construction waste.
The circular economy measures for the construction sector are explained in Table 1. It is important to note that in construction, the term 'product' (which later becomes waste) includes materials and equipment used in buildings, and the building itself is also a product of the construction process.

Table 1. *Basic measures of the 5R concept with application for dealing with construction waste*

"R" measures	Application in construction
Reduce	Reduction of waste generation through the design (e.g. more suitable for disassembly and recycling) and longevity of the products installed, as well as through the construction project and better planning, storage and skilful, rational use of materials and supervision in construction production. In addition, proper maintenance of buildings is also essential.
Reuse	Reuse is all procedures that enable the reuse of products, which extends their useful life, thus reducing waste generation and saving energy. In construction, these can be materials such as stone, bricks, wooden beams, windows and doors, etc. (For reuse, inspection, cleaning, repair, and restoration of entire products or consumable parts are required.)
Recycle	Recycling is any recovery process by which waste materials are processed into products, materials, or substances for their original or other purpose other than the use of waste for energy purposes or processing into material used as fuel or for filling. In Croatia, the Law on Waste Management defines waste recovery procedures (R1 - R13), including waste storage before any recovery procedure. More than 60 % of construction waste was recovered through the process of recycling/restoration of other waste inorganic materials (R5). In addition, recycling/restoration of waste metals and metal compounds (R4) and separation, sorting, crushing, compaction, shredding, fitting or mixing, etc. (R12) are also widely used [1]. It is also possible to use construction waste as fuel (R1), although most of it has little potential for this.
Refuse	The refuse represents an extension of the waste reduction measure, primarily by banning or reducing interest in particular products that are not environmentally acceptable. In construction, this can be done mainly through designers and investors who decide on the new building's location, construction and materials.
Repurpose	Repurpose is a subcategory of reuse as a measure by which used products are creatively given new life or used for a new purpose. This can also apply to the buildings themselves, which, after their original purpose, instead of being demolished, can have a new purpose (e.g., in recent times, they often get a cultural one instead of an industrial one).

The model of an integrated approach to construction waste management, as proposed by Manoharan et al. in 2020, requires interaction between all involved facilities, as well as the transport system, and from the moment of waste generation to its disposal, it includes four stages [13]:

- o waste reduction system,
- o sorting system,
- o system for recovery of raw materials and energy, and
- o disposal system.

Hierarchy of procedures in circular management

The Law on Waste Management (2021) determines the system of waste management, including the order of priority, method of waste management, planning documents, competences and obligations, locations and buildings for waste management, cross-border

transport of waste, information system of waste management and administrative and inspection supervision over waste management [7].
The priority order of waste management should always start with measures to prevent and reduce waste generation [1] because that is the most desirable. Prevention starts with extended producer responsibility for their products. Informing customers and labelling packaging and products facilitates the subsequent process of separating construction waste and not mixing it with municipal waste [14].
After preventing waste generation, the waste management protocol (defined within the project [15]) dictates the sequence of procedures as shown in Fig. 3. Disposal is in last place as the least preferred option. Dumping is still allowed, although it does not follow the principles of circular management, which requires the flow of materials in a closed loop.

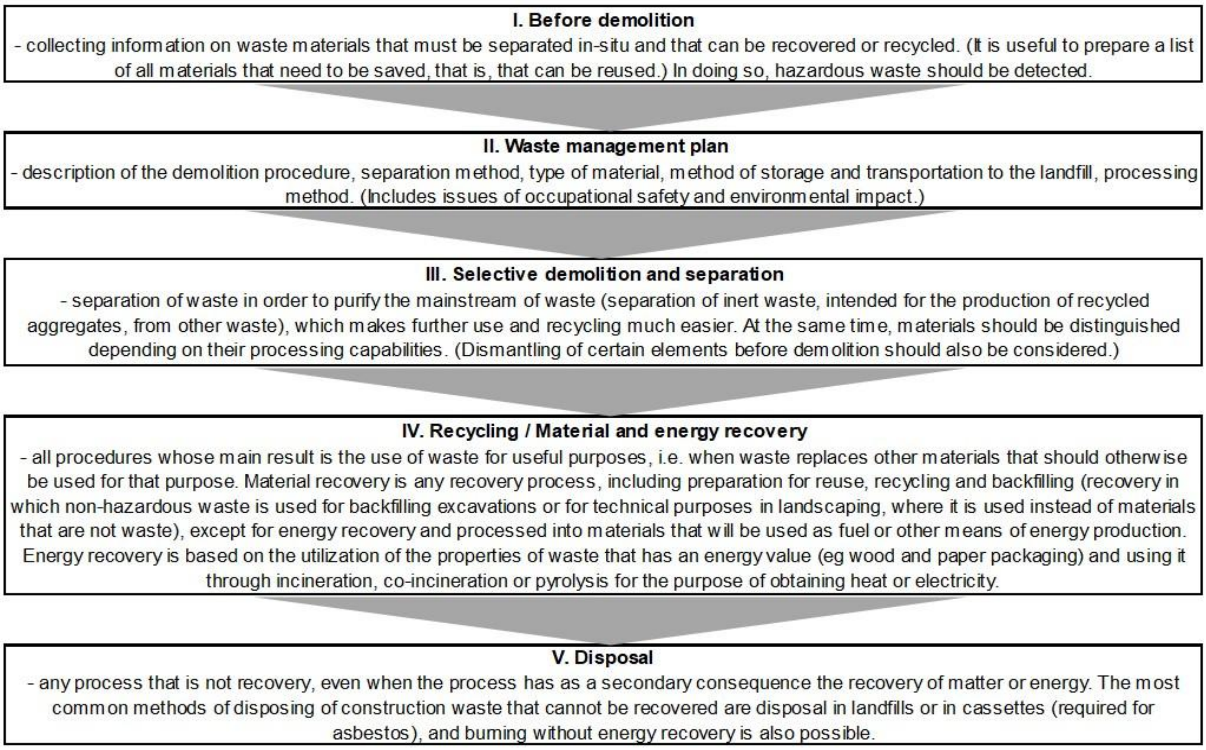

Fig. 3. *Hierarchy of procedures in construction waste management*

Application of recycled waste in construction

When a material is declared as waste and taken from the construction site to a recycling yard or landfill that accepts construction waste, its waste status should be revoked for reuse before recovery or recycling [14].
The reuse of recycled materials is insufficiently practised in the Croatian construction industry. There is little interest and limited possibilities for recycling and reusing materials containing gypsum, insulating materials containing bitumen, shingles, plastic and wooden carpentry, and wood treated with paints and varnishes. The share of difficult-to-use mixed waste in the total construction waste in Croatia is much higher than in some other, more advanced countries in this field [1], [3]. Waste materials are mainly used for backfilling, and in addition, the use of waste for the production of new concrete or asphalt mixtures is quite frequent. Recycled concrete or recycled bricks are mainly used in concrete, which can replace a certain amount of new aggregate, and a part of recycled asphalt is added to asphalt mixtures in addition to new aggregate [14].
However, the decreasing availability of natural resources raises the value of recycled materials. Recycling can be for the same purpose (e.g. metals, paper, glass, gypsum and asphalt) or a different one (e.g. aggregate and wood for chipboard production). As part of the

CONWAS project at the Faculty of Civil Engineering in Zagreb, an analysis of the state of the construction waste management system was carried out, a pilot project for its recycling was formed, and measures for optimal management of construction waste were defined [16]. Table 2 shows the possibilities of using construction waste according to data from that project and supplemented with other sources ([17], [18], [19]) and observations from practice.

Table 2. *Overview of the possibilities of using processed, waste materials in construction*

Type of waste/material	Application in construction
Crushed bricks and demolition waste with crushed bricks	Additional material for the production of masonry and concrete elements, for stabilization, drainage layers, filling, filling the final layers of floors
Mineral waste	Filling and construction of sports fields (drainage)
Recycled sand	Substrate for pipes when installing infrastructure (water, gas, etc.), for unbound and bound bearing layers (upper and lower), construction of agricultural roads and additional material for asphalt production
Different inert waste (recycled)	Replacement for natural aggregate when making concrete (with special properties)
Recycled concrete aggregates	For unbonded and bonded bearing layers (upper and lower), additional material for concrete production, drainage layers, construction of embankments (from larger pieces) and gabion filling
Mixed asphalt / recycled concrete aggregates	For unbound and bonded bearing layers (upper and lower) and the construction of agricultural roads
Glass fibre-reinforced polymer (e.g. from pipelines)	Aggregate for concrete or resin additive in the production of plate-reinforced polymer (with worse characteristics than the original)
PVC (e.g. carpentry)	Plastic, i.e. plastic elements (significantly lower quality)
Glass	Installation in asphalt or reflective paint for roads

In addition to the use of recycled construction waste for the preparation of new construction materials, waste and by-products from other activities, industry and agriculture can also be used for construction (e.g. plastic bottles and ash obtained from the combustion of harvest residues and wood biomass, fly ash, sewage sludge water, etc.), but also some processed construction waste is used in other activities, i.e. industry [18]. In production processes, in addition to products, i.e. what is intentionally produced, substances/materials are created that are not the primary goal of the production process and whose creation cannot be avoided. Of the total amount of by-products in Croatia in 2021, 11.1 % were materials for use in construction. These by-products were used as aggregates in construction, road construction and filling processes, as other building materials and in the cement production process [1]. To place recycled materials on the market, the manufacturer must evaluate and verify the constancy of their properties (they must be certified).

Although some construction materials made with processed waste can be of the same or even better quality than conventional raw materials (such as some concrete), in the construction sector, there is often low confidence in the quality of recycled materials from waste, affecting their use. The EU Protocol for the Management of Construction Waste and Demolition Waste (2016) aims to increase confidence in the management process of construction waste and demolition waste, as well as confidence in the quality of recycled materials from construction waste and demolition waste [20].

POSSIBLE IMPROVEMENTS AND PROBLEMS IN PRACTICE

Research conducted in Australia in 2024 by Amarasinghe et al. [21] determined that financial savings are the most encouraging factor in adopting the circularity of materials in construction, while the most significant obstacle to this is the underdeveloped market for secondary products. The results of the study provided in the UK in 2008 by Osmani et al. [22] showed that waste management is not a priority in the design phase because the prevailing attitude among architects is that waste is mainly generated during construction work, and

that design rarely has an impact on it. However, it was found that 33 % of the waste on the construction site is due to inappropriate reduction measures that were not applied during the design phase. Reducing the amount of waste is included in a sustainable building project through Building Information Modeling (BIM), while it is still only within the scope of activity of investors and designers. However, despite research efforts to minimize construction waste, BIM integration in demolition waste management is still low [23].
Better preparation (planning) of the performance, adequate procurement of materials and organization on the construction site are required from the contractor for waste reduction. Lean business minimizes the loss of time and materials in various industries, including construction. Well-organized storage of materials (without excessive accumulation, but also without shortages) and workplaces where materials are installed to avoid damage and otherwise excessive conversion to waste can be achieved with Lean methods such as organizing workplaces ("5S" method), a system of material procurement and visualization and spotting problems on the ground ("*Gemba*" method) [18]. For seven methods of reducing construction waste (appropriate storage, training of employees in the field of waste management, use of monitoring systems, proper transport and unloading of products, appropriate involvement of subcontractors, use of prefabricated elements, and reuse of products on the construction site) Białko and Hoła (2021) determined that they are used more often the larger the companies are [24]. (Small and medium-sized companies predominate in Croatian construction.)
A lot can be learned from other people's positive and negative experiences, but adopting a successful waste management model from one environment does not guarantee that it will give equally good results in another environment [4].
The management of construction waste in Croatia is negatively affected by the lack of financial incentives from the state (e.g. for the use of recycled materials) and low awareness of the importance of reusing materials from construction or demolition [14]. Also, the lack of labour, especially experienced, quality craftsmen, and the increase in the price of their hourly work leads to an increase in the loss of materials during the execution of works and lower profitability of separating, repairing and reusing materials on the construction site.
The total capacities for the recovery of construction waste, as seen at Croatia's level, are sufficient. However, in about 50 % of the counties, there is a lack of these capacities, and this is a problem considering the costs of transporting this type of waste. One of the key elements of construction waste management is recording and monitoring its flow and supervision after disposal [25]. However, there is no control over how and where construction waste is disposed of by natural persons [14].

CONCLUSION

A large amount of construction waste offers the possibility that, through its recovery, part of the material and even energy needs of the economy, which in Croatia and the EU is mainly dependent on their import, can be met. Construction waste can be an opportunity to make money, but in addition to economic goals, the environmental impact should always be considered. Ecologically responsible waste management raises the company's reputation. Before discarding waste, it is necessary to exhaust all possibilities of reuse. If waste is disposed of, it should be done legally as specified in the regulations. The prevention of waste generation and the potential of reuse in the construction sector are primarily determined in the design phase, which is why university and professional education on this is required.
There is obviously much thought about the circular economy, and in the future, it can be expected that goals related to it will grow. European and national legislation determines obligations and regulates waste management in the construction sector, but the data show that the situation in practice is not yet satisfactory. In order to improve waste management, recycling capacities should be strengthened in areas where they are lacking. Also, more should be invested in researching innovative waste reduction and reuse solutions and changing people's awareness of construction waste.

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INTRODUCING ISO 22301 INTO AN ESTABLISHED INTEGRATED MANAGEMENT SYSTEM (IMS)

Research paper

Marija Perović[1*], Marija Todorović[1]
[1] Jaroslav Černi Water Institute, Belgrade, Serbia

Abstract: Presented research highlights the critical role of standardization in enhancing efficiency, productivity, and compliance in Industrial Engineering and Environmental Protection. Standardization optimizes processes, ensuring consistent quality, interoperability, and cost reduction, while also facilitating regulatory compliance. The advantages of an Integrated Management System (IMS), which combines frameworks such as ISO 9001, ISO 14001, and ISO 45001, are reflected in streamlining processes, aligning organizational objectives, and enhancing risk management, leading to improved performance and compliance. Furthermore, the manuscript discusses the integration of the international standard for Business Continuity Management (BCM), ISO 22301 into an existing IMS, supported by a comparative analysis to ensure a smooth incorporation into already established management system. Results detail the methodology, challenges, and benefits of this integration, emphasizing how the process can be streamlined due to the pre-existing IMS, thereby reducing the effort required. The study also offers valuable insights into strengthening organizational resilience, highlighting key overlaps and differences between standards, and providing practical tools to help organizations anticipate and achieve desired outcomes with minimized effort.
Key words: Integrated Management System, Business Continuity Management, organizational resilience, risk management

INTRODUCTION

Enhancing Efficiency and Compliance Through Standardization

Standardization is crucial for companies, particularly in the field of Industrial Engineering and Environmental Protection (Fig. 1). In the area of Industrial Engineering, it enhances efficiency and productivity. Standardization optimizes processes by establishing consistent methods and practices. This reduces variability, minimizes errors, and enhances productivity. Consistent procedures allow for smoother workflow, better resource management, and improved operational efficiency. Standards ensure that products and services meet defined quality benchmarks. This fosters customer trust and satisfaction, as consistent quality is maintained. Standardization also simplifies quality control processes, enabling easier identification and correction of deviations. In industrial engineering, interoperability between systems and components is vital. Standards ensure that different parts and systems can work together seamlessly, reducing the need for custom solutions and facilitating easier integration of new technologies [1,2]. By adhering to standardized practices, companies can reduce costs associated with custom designs, trial-and-error approaches, and inefficient processes. Standardization also enables bulk purchasing of standardized materials and components, further driving down costs. Many industries have stringent regulatory requirements. Standardization helps companies ensure compliance with relevant laws and regulations, avoiding legal issues and potential penalties. It also facilitates easier updates to comply with new regulations [1-5].
In the area of Environmental Protection Environmental standards, such as ISO 14001, guide companies in adopting sustainable practices [1]. This includes efficient use of resources, waste reduction, and minimizing environmental impact [1]. Standardization in environmental management ensures that companies contribute positively to environmental sustainability. Standards provide frameworks for monitoring and controlling pollution levels. This includes setting limits for emissions, waste management practices, and pollution prevention strategies. Adhering to these standards helps companies mitigate their environmental

[1] Corresponding author, marija.perovic@jcerni.rs, ORCID: https://orcid.org/0000-0003-2045-001X

footprint. Environmental standards help companies identify and manage environmental risks. This includes potential impacts on air, water, and soil quality. Effective risk management protects the company from environmental incidents that could result in costly cleanups, legal liabilities, and damage to reputation. Companies that follow environmental standards demonstrate their commitment to corporate social responsibility. This enhances their reputation among stakeholders, including customers, investors, and the community. A strong reputation for environmental responsibility can also provide a competitive advantage. Standardization encourages continuous improvement and innovation. Companies are motivated to develop new technologies and processes that meet or exceed environmental standards. This leads to advancements in cleaner production methods, energy efficiency, and overall environmental performance.

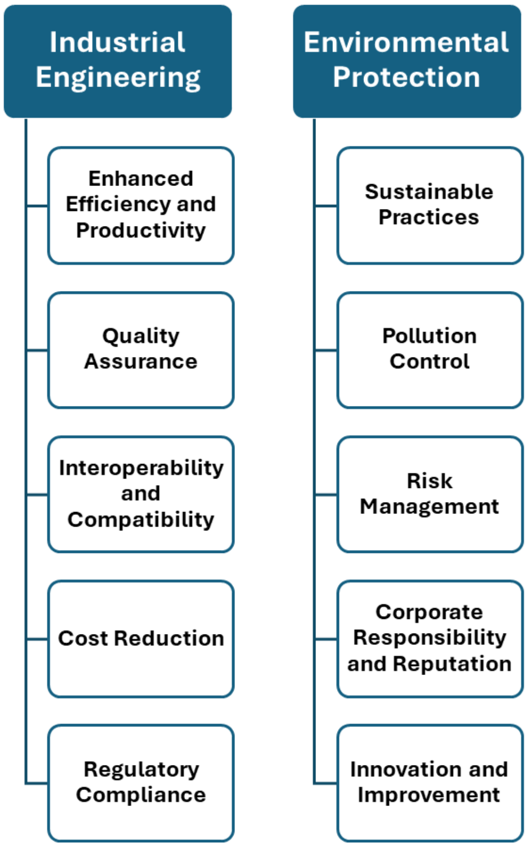

Fig. 1. *The advantages of standardization in the field of Industrial Engineering and Environmental Protection*

The advantages of the Integrated Management System

IMS seamlessly combines various management frameworks, such as quality (ISO 9001), environmental (ISO 14001), and occupational health and safety (ISO 45001), into a unified structure [4,5]. This integrated approach ensures that all aspects of an organization are harmoniously aligned and managed, removing redundancies and streamlining processes. By reducing administrative burdens and saving time and resources, IMS enables organizations to focus more effectively on their core activities. The alignment of management objectives and policies through IMS fosters consistency across the organization, helping to achieve strategic goals and ensuring that every department works towards common objectives. This integrated framework also facilitates compliance with multiple regulatory requirements, thereby minimizing the risk of non-compliance and its associated legal and financial repercussions. IMS takes a comprehensive approach to risk management, identifying, assessing, and managing risks across various functions. This forward-looking approach enhances organizational resilience and reduces the likelihood of disruptions. Additionally, by consolidating data from different management areas, IMS provides a complete overview of organizational performance, supporting informed and strategic decision-making. The continuous improvement of culture promoted by IMS ensures that organizations consistently enhance their performance, quality, and sustainability [4,5]. Demonstrating high standards through IMS builds trust among stakeholders, including customers, employees, regulators, and investors—leading to increased business opportunities and a stronger reputation. Furthermore, IMS optimizes resource utilization across the organization, reducing waste and boosting overall productivity. Integrated audits of multiple management systems are more efficient and less disruptive compared to separate audits, streamlining the auditing process and offering a more thorough evaluation of compliance and performance.

The framework established by ISO 9001 helps organizations consistently deliver quality products and services, emphasizing customer satisfaction, continuous improvement, and process management. Through a systematic approach, ISO 14001 manages environmental responsibilities, aiming to minimize environmental impact and ensure regulatory compliance. The focus of ISO 45001 is on maintaining a safe and healthy work environment by identifying hazards, managing risks, and adhering to occupational health and safety regulations. Meanwhile, ISO 22301 enhances organizational resilience by developing strategies to maintain and recover critical operations during and after disruptions. To facilitate the integration of ISO 22301 into an existing IMS that includes ISO 9001, ISO 14001, and ISO 45001, a comparative analysis was conducted to identify key differences and ensure smooth incorporation.

MATERIAL AND METHODS

ISO 22301 is specifically focused on Business Continuity Management (BCM) to ensure that an organization can continue operating and recover effectively in the event of disruption. It concentrates on the development, implementation, and maintenance of a business continuity plan to protect against and respond to potential disruptions.
The Annex SL framework, which is a common structure adopted by ISO for management system standards, helps to align the structure and language of different ISO standards, making it easier to integrate them into an IMS. The Annex SL framework helps to standardize the structure and terminology of various ISO standards, making it easier to integrate them into an IMS. However, while IMS provides a unified approach to managing multiple standards, the specific requirements of each standard, including ISO 22301, will still need to be addressed individually within the IMS framework. In essence, Annex SL facilitates integration but does not eliminate the need to meet the distinct requirements of each individual standard within the IMS.
It outlines a common structure starting with understanding the organization's context and stakeholder needs, defining the scope, and establishing leadership and policy. Planning involves addressing risks, setting objectives, and planning changes. Support covers resources, competence, awareness, communication, and documented information. Operations are managed through planning and control of processes. Performance evaluation includes monitoring, internal audits, and management reviews. Lastly, improvement focuses on addressing nonconformities and continual enhancement of the system. Each standard applies this framework to its specific focus—quality, environmental, occupational health and safety, or business continuity—ensuring consistency while addressing distinct requirements.
The methodology of the conducted research was based on comparing the requirements of the standards according to the clauses of Annex SL, resulting in a detailed listing of the differences in these requirements. As a result, the necessary time for implementing ISO 22301 into an Integrated Management System is significantly reduced.

RESULTS AND DISCUSSION

The alignment of standard clauses across four major ISO standards: ISO 9001, ISO 45001, ISO 14001, and ISO 22301 is outlined in Table 1. Each standard follows a similar structure, with clauses covering scope, normative references, terms and definitions, and the context of the organization. For example, Clause 4 in all standards addresses the context of the organization, but with specific focuses related to quality, occupational health and safety, environmental management, and business continuity, respectively. Additionally, while the core structure remains consistent, ISO 22301 introduces unique elements in Clause 8, such as business impact analysis, continuity strategies, business continuity plans and procedures and evaluation of business continuity capabilities, reflecting its specialized focus on organizational resilience. This structured approach facilitates easier integration of ISO 22301 into existing management systems, significantly reducing the time required for implementation by utilizing commonalities and clearly identifying areas of divergence. Table 1 provides an overview of the examined standard requirements.
In addition to highlighting the structural similarities across ISO 9001, ISO 45001, ISO 14001, and ISO 22301, Table 1 reveals how these standards address specific organizational needs through their unique clauses. For instance, while all four standards emphasize leadership and commitment under Clause 5, ISO 45001 includes an additional focus on the consultation and participation of workers, reflecting its priority on occupational health and safety.
Furthermore, Clause 6, which covers planning, is tailored to each standard's specific objectives. For example, ISO 22301 incorporates planning for business continuity objectives, emphasizing the importance of preparing for potential disruptions. This clause also introduces the planning of changes specifically related to the business continuity management system, which is not present in the other standards.
Clause 8, focused on operation, diverges significantly among the standards, particularly with ISO 22301. While ISO 9001, ISO 45001, and ISO 14001 emphasize operational planning and control, ISO 22301 expands this to include business impact analysis, continuity strategies, business continuity plans and procedures and the evaluation of business continuity documentation. These elements are crucial for ensuring that organizations are not only operationally efficient but also resilient in the face of disruptions.
This detailed comparison underscores the tailored approach of each ISO standard to its specific focus area, while also demonstrating the potential for seamless integration within an organization's existing management system. By understanding these nuances, organizations can more effectively implement ISO 22301 alongside other standards, ensuring comprehensive management that addresses both operational excellence and continuity.

ISO 22301 introduces several unique requirements that set it apart from other management standards within an Integrated Management System. Central to ISO 22301 is the development of a comprehensive Business Continuity Management Policy, which establishes the framework for managing continuity. It requires conducting a Business Impact Analysis (BIA) to identify critical functions and assess the potential impact of disruptions. Risk assessment and treatment are essential, involving the identification and mitigation of risks to ensure continuous operations. The standard emphasizes setting clear business continuity objectives and developing strategies and solutions to maintain critical functions during disruptions. Detailed business continuity plans and procedures must be documented, regularly tested, and exercised. Effective communication and awareness programs are necessary to ensure that all stakeholders understand their roles. Performance evaluation and continual improvement are integral, requiring regular monitoring, reviews, and updates to the BCM system. Additionally, ISO 22301 mandates coordinated incident response and recovery processes to minimize operational impact during and after disruptions. These specific requirements focus on ensuring organizational resilience and continuity, distinguishing ISO 22301 from other standards like ISO 9001, ISO 14001, and ISO 45001.

Table 1 *The cross-section of requirements of different standards: ISO 9001, ISO 14001; ISO 45001; ISO 22301*

ISO 9001		**ISO 45001**		**ISO 14001**		**ISO 22301**	
Standard Clause		Standard Clause		Standard Clause		Standard Clause	
1	Scope	1	Scope	1	Scope	1	Scope
2	Normative references	2	Normative references	2	Normative references	2	Normative references
3	Terms and definitions	3	Terms and definitions	3	Terms and definitions	3	Terms and definitions
4	Context of the organization	4	Context of the organization	4	Context of the organization	4	Context of the organization
4.1	Understanding the organization and its context	4.1	Understanding the organization and its context	4.1	Understanding the organization and its context	4.1	Understanding the organization and its context
4.2	Understanding the needs and expectations of interested parties	4.2	Understanding the needs and expectations of workers and other interested parties	4.2	Understanding the needs and expectations of interested parties	4.2	Understanding the needs and expectations of interested parties
4.3	Determining the scope of the quality management system	4.3	Determining the scope of the OH&S management system	4.3	Determining the scope of the environmental management system	4.3	Determining the scope of the business continuity management system
4.4	Quality management system and its processes	4.4	OH&S management system	4.4	Environmental management system	4.4	Business continuity management system
5	Leadership	5	Leadership	5	Leadership	5	Leadership
5.1	Leadership and commitment	5.1	Leadership and commitment	5.1	Leadership and commitment	5.1	Leadership and commitment
5.2	Policy	5.2	OH&S policy	5.2	Environmental policy	5.2	Policy
5.3	Organization roles, responsibilities and authorities	5.3	Organization roles, responsibilities and authorities	5.3	Organization roles, responsibilities and authorities	5.3	Roles, responsibilities and authorities
		5.4	Consultation and participation of workers		/		/
6	Planning	6	Planning	6	Planning	6	Planning
6.1	Actions to address risks and opportunities	6.1	Actions to address risks and opportunities	6.1	Actions to address risks and opportunities	6.1	Actions to address risks and opportunities
6.2	Quality objectives and planning to achieve them	6.2	OH&S objectives and planning to achieve them	6.2	Environmental objectives and planning to achieve them	6.2	Business continuity objectives and planning to achieve them
6.3	Planning of changes		/		/	6.3	Planning changes to the business continuity management system
7	Support	7	Support	7	Support	7	Support
7.1	Resources	7.1	Resources	7.1	Resources	7.1	Resources
7.2	Competence	7.2	Competence	7.2	Competence	7.2	Competence
7.3	Awareness	7.3	Awareness	7.3	Awareness	7.3	Awareness
7.4	Communication	7.4	Communication	7.4	Communication	7.4	Communication
7.5	Documented information	7.5	Documented information	7.5	Documented information	7.5	Documented information
8	Operation	8	Operation	8	Operation	8	Operation
8.1	Operational planning and control	8.1	Operational planning and control	8.1	Operational planning and control	8.1	Operational planning and control
8.2	Requirements for products and services	8.2	Emergency preparedness and response	8.2	Emergency preparedness and response	8.2	Bussiness impact analysis and risk assessment
8.3	Design and development of products and services		/		/	8.3	Bussiness continuity strategies and solutions
8.4	Control of externally provided processes, products and services		/		/	8.4	Bussiness continuity plans and procedures
8.5	Production and service provision		/		/	8.5	Exercise programme
8.6	Release of products and services		/		/	8.6	Evaluation of business continuity documentation and capabilities

ISO 9001		**ISO 45001**		**ISO 14001**		**ISO 22301**	
Standard Clause		Standard Clause		Standard Clause		Standard Clause	
8.7	Control of nonconforming outputs		/		/		/
9	Performance evaluation	9	Performance evaluation	9	Performance evaluation	9	Performance evaluation
9.1	Monitoring, measurement, analysis and evaluation	9.1	Monitoring, measurement, analysis and evaluation	9.1	Monitoring, measurement, analysis and evaluation	9.1	Monitoring, measurement, analysis and evaluation
9.2	Internal audit	9.2	Internal audit	9.2	Internal audit	9.2	Internal audit
9.3	Management review	9.3	Management review	9.3	Management review	9.3	Management review
10	Improvement	10	Improvement	10	Improvement	10	Improvement
10.	General	10	General	10.1	General	10.1	Nonconformity and corrective action
10.	Nonconformity and corrective action	10	Incident, nonconformity and corrective action	10.2	Nonconformity and corrective action	10.2	Continual improvement
10.	Continual improvement	10	Continual improvement	10.3	Continual improvement		/

CONCLUSION

Standardization in Industrial Engineering and Environmental Protection is vital for ensuring efficiency, quality, compliance, and sustainability. It enables companies to operate more effectively, reduce costs, manage risks, and fulfill their environmental responsibilities. Ultimately, standardization supports long-term success and resilience in an increasingly competitive and environmentally conscious market. IMS integrates multiple management systems into a single framework, focusing on streamlining operations and eliminating redundancies across various management areas.

While ISO 22301 offers a targeted framework for business continuity, IMS provides a broader, more holistic approach to managing various aspects of organizational performance. IMS integrates multiple management standards into a unified system, enabling organizations to streamline their processes and achieve greater efficiency across different domains, such as quality, environmental management, and occupational health and safety. The IMS framework utilizes common elements from various standards to create a cohesive management approach, facilitating easier compliance and more effective oversight.

Both approaches are complementary but serve distinct functions. ISO 22301 focuses specifically on maintaining business operations during disruptions, ensuring that organizations are prepared to handle and recover from incidents with minimal operational impact. In contrast, IMS provides a comprehensive management structure that integrates various standards, addressing a broader range of organizational needs. Together, these approaches enable organizations to not only safeguard their continuity in the face of challenges but also enhance overall management practices, driving operational excellence and resilience across all aspects of their operations.

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Session 6

Health and Environmental Protection

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VALIDATION OF SOME AIR POLLUTANT DISTRIBUTION MODELS

Stevo K. Jaćimovski[1], Dane Subošić[2], Jovan P. Šetrajčić[3]
[1,2]University of Criminalistic and Police Studies, Zemun – Belgrade, Serbia;
[3]Academy of Sciences and Arts of the Republic of Srpska, Banja Luka, B&H;

Abstract: By air pollution we usually mean the presence of a certain concentration of gaseous and particulate pollutants in the atmosphere. The presence of airborne pollutants in the atmosphere is continuously measured with the aim of protecting human health and the environment in general. Modeling the distribution process of air pollutants is an important tool in researching the impact of pollution on the natural environment. There are different approaches to modeling air pollution. The paper analyzes mathematical modeling where the distribution of air pollutants is found by solving the equation of advective diffusion by analytical and numerical methods. The results of these two procedures are compared with the results of measurements in the experiment, and based on certain parameters, it is determined which model gives more valid results. The parameters necessary for specific calculations are adopted from available literature data.
Key words: Pollutant distribution, analytical model, numerical model, turbulent diffusion, atmospheric stability.

INTRODUCTION

There is growing concern in the world about the increasing global environmental pollution, especially due to the increased number of incidents resulting in air, soil and water pollution in crowded cities around the world. Due to the realization of the importance of studying and preventing environmental pollution, information about pollutants and their impact on the living world is becoming more and more available.

The problem of air pollution is a global problem because it affects practically all countries in the world, i.e. all their regions, settlements, socioeconomic and age groups. There are important geographic differences in exposure to air pollution. Residents of Africa, Asia and the Middle East inhale much higher concentrations of pollutants than the rest of the world.

According to the World Health Organization, air pollution is the biggest threat to the preservation of the environment and is annually responsible for one in nine deaths, which are about 3 million people every year. Only one in ten people live in cities that meet air quality standards. Therefore, the world population is faced with the existence of a large number of people suffering from chronic non-infectious diseases (heart and respiratory diseases), which affect the quality of life of people, but also the economic development of society. It can be said that air quality is a marker of sustainable development of society [1].

Atmospheric pollution is global, because not only those who cause pollution suffer from it, but also other entities and other countries due to the admixture of carcinogenic substances over long distances. The influence of the anthropogenic factor on the appearance of impurities in the atmosphere is decisive for all components and tends to increase.

The impurities they deliver to the atmosphere are gaseous, solid and liquid substances in their structure. Of these, gaseous substances (CO, CO_2, sulfur compounds, nitrogen oxides, organic compounds) account for 90% of impurities. The mass of solid substances in impurities is 10% (dust, heavy metals, radioactive substances, minerals and organic compounds). Liquid admixtures (sulfuric acid) are few in comparison to gaseous and solid admixtures.

Of the physic-chemical impurities, oxides of sulfur and nitrogen play a special role, because their existence is the cause of the creation of the so-called acid rain. The processes by which these oxides are released into the atmosphere are very complex and depend on many factors, including meteorological conditions, surface relief, sedimentation, etc.

When we talk about air pollution that is dangerous for people, we usually mean the existence of illegal concentrations of particulate matter in the air. The most important components of

[1]Corresponding author, stevo.jacimovski@kpu.edu.rs, ORCID: https://orcid.org/0000-0002-4074-662X
[2]dane.subosic@kpu.edu.rs, ORCID: https://orcid.org/0000-0002-2797-8952
[3]jovan.setrajcic@gmail.com, ORCID: https://orcid.org/0000-0002-6903-2882

particulate matter are sulfates, nitrates, ammonia, sodium chloride, coal dust, mineral dust and water.

Particles of small dimensions have a great influence on the health of the living world and in small concentrations have a negative effect on human health. These particles are introduced into the body mainly through the respiratory system or through food intake. Among them, particles whose dimensions are less than 2,5 μm are particularly significant, and their concentration is most often used as a representative indicator of exposure to air pollution ($PM_{2.5}$). The respiratory organs suffer immediately, because about 50% of particles with a radius 0,01 – 0,1 μm penetrate into the lungs and settle there. One of the main sources of radioactive particles are nuclear power plants. The greatest danger is represented by ^{90}Sr and ^{137}Cs. Thanks to its chemical similarity with calcium, ^{90}Sr easily penetrates the bones of the irradiated, and ^{137}Cs accumulates in muscle tissues replacing potassium.

Monitoring of air quality in major cities of the world, which was carried out in the period from 2008 to 2013, indicated an increase in the concentration of $PM_{2.5}$ particles by 8% [1]. In addition to improving the network of air monitoring stations, researchers, scientists and international organizations are joining efforts to develop the most accurate mathematical models for calculating the concentrations and exposure of the population primarily to particulate pollution.

The very idea of modeling the spread of pollutants originated in the twenties of the 20th century. The main objective was to assess the spread of chemical warfare agents used on the battlefields during the First World War. The idea was later transferred to the assessment of the impact of the spread of pollutants in industrial areas of developed countries.

Interest in dealing with the problem of pollution is constantly growing, especially when it comes to human safety. The problems of environmental pollution after the occurrence of natural disasters or disasters during the transport of radio-nucleotides or biological and chemical agents are very current [2].

MODELING OF THE AIR POLLUTION PROCESS

Measurements of pollutant concentrations provide important quantitative information about the state of air quality at specific locations at a specific time. They cannot point to the reasons that led to the air quality problems.

The physics of particle transport or dispersion is a complex field that encompasses and mathematically describes the distribution of pollutant particle concentrations due to advection and turbulent diffusion processes that govern air masses near the ground. It represents the basis for modeling the process of the spread of pollutants.

Air pollution modeling provides a complete deterministic description of the origin of air pollution problems, including the analysis of cause-and-effect relationships between various parameters (number and distribution of pollutant emission sources, topography of the terrain around the source, meteorological conditions such as wind direction and speed, atmospheric stability and temperature gradients, physics-chemical changes of pollutants, etc.), as well as some guidelines on the implementation of measures to mitigate the consequences of pollution.

The results of the applied model can also serve us to evaluate suitable locations for setting up measuring stations, for various legal, research or forensic applications [3,4].

Currently, there are many models for calculating surface concentrations of air pollution in areas affected by industrial sources. In total, there are about 120 models of different levels of complexity and purpose. Some of them have a normative character, and others have a scientific research character.

Models of spatial-temporal distribution of air pollution are divided in different ways, most often into physical models and mathematical models. In physical models, the actual process is simulated on a smaller scale in the laboratory using a physical experiment, which models important features of the original process under study. The advantage of physical models is that the geometry of the scale model, as well as the fluid flow rate and other important variables can be easily changed and controlled.

Mathematical models are divided into statistical and deterministic. In the case of statistical models, the concentration in the ambient air is calculated using the methods of mathematical statistics using the empirically established statistical relationship between meteorological and other parameters on the other hand. Only semi-quantitative conclusions can be drawn on some specific air quality issues. The statistical model is very useful for short-term forecasting of concentrations. The advantage of such models is that they require a small computational effort that simulates the measured concentration in a single point or concentration field of pollutants.

Deterministic models are based on mathematical equations and express the laws of conservation of mass, momentum and energy. They are divided into Lagrangian, Euler and Gaussian models. The Gaussian model is mostly used in practice, because of its simplicity and the relatively good results it gives. Between the Lagrangian and Euler models, the Euler approach has the advantage, because the quantities contained in the Euler model are easier to measure than those from the Lagrangian model.

The analysis of the problem of atmospheric distribution of pollutants using Euler's method leads to the solution of turbulent diffusion equations with the use of numerous semi-empirical methods to obtain a closed system of equations that describe the transport and diffusion of impurities in a turbulent environment.

ADVECTIVE DIFFUSION EQUATION (ADE)

The use of partial differential equations to formulate certain physical phenomena is well known, such as in the modeling of heat and mass transfer, and especially in the context of air pollution modeling [5]. The spatial-temporal distribution of pollutant concentration is described by a partial differential equation of the parabolic type known as the equation of advective diffusion. This equation is of the form:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(k_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial C}{\partial z}\right)+R+S. \qquad (1)$$

Here C [kg/m^3] is the concentration of impurities in the atmosphere, u [m/s], v [m/s] and w [m/s] are the components of the wind speed in the x, y and z directions, and k_x [m^2/s], k_y [m^2/s] and k_z [m^2/s] are coefficients of turbulent diffusion of pollutants. The term R characterizes chemical processes if the admixture participates in chemical reactions during transport (non-conservative admixture). If the admixture does not participate in chemical processes, it is called conservative and then the term is equal to: $R=0$. The term S characterizes the properties of the source that emits impurities into the atmosphere.

When analyzing the appropriate model, in Euler's approach, it is necessary to solve this equation analytically or numerically. For a more complete understanding of this model, it is necessary to define the basic concepts, elements and parameters that describes in models of this type, and this is done in the following text. Since a few years ago, we have also been actively involved in solving this problem [6,7]. Here we will show what we did in the analytical and numerical analysis of equation (1) in the presence of conditions of turbulent spread of air pollution.

Wind speed and turbulence

For dispersion of air pollution, pollutant speed and wind speed play an important role. By wind, generally speaking, of all three components, we consider the horizontal component of the wind. With the help of the wind direction at the source, the initial direction of transport of pollutants from their source can be determined. Due to the effect of friction on the wind from the earth's surface and roughness elements on the surface, the wind slows down at near-ground levels.

Turbulence can be created thermally and mechanically. Thermally generated turbulence is created by the heating of the Earth's surface, which leads to thrust-induced air convection. With strong surface heating, thermal turbulence will increase. Winds moving past different elements of vegetation or urban structures create mechanical turbulence. The stronger the wind, the greater the degree of mechanical turbulence created. Also, the greater the elements of roughness (relief structures, vegetation) on the Earth's surface, the greater will be the mechanical turbulence.

Advection

Advection is the process of transport of pollutants together with the mean volume flow of air. Advection is sometimes referred to as wind-driven flow transport.

Diffusion

The basic process of mixing polluted air with clean air is called diffusion. It is usually implemented in two ways:
– molecular diffusion, which occurs due to the chaotic movement of molecules in the air and
– turbulent or vortex diffusion, which occurs due to turbulent air currents.

Both of the above diffusions are responsible for mixing polluted air with clean air. Diffusion differs from advection in that it is realized in a random manner.

Dry deposition

Dry deposition describes how particles and gases are deposited from the air near the ground. Particles larger than 1 μm are deposited by gravity. For dry deposition to occur, the gas must first be transported to the surface layer by turbulence. All depositions depend on the wind speed and the roughness of the surface on which the gas or particle is deposited.

Stability of the atmosphere

Atmospheric stability is the tendency of the atmosphere to resist changes and increases in vertical air movement. When the atmosphere is stable, there is practically no air mixing. An unstable atmosphere is marked by a high degree of turbulence, so the air from different altitudes is thoroughly mixed, which is a very favorable condition for the dispersion of air pollutants in the atmosphere.

The most commonly used method of categorizing the amount of atmospheric turbulence is the method given by Pasquill in [8]:

A = extremely unstable, B = unstable, C = slightly unstable,

D = neutral, E = slightly stable and F = stable.

ANALYTICAL SOLUTION OF ADE

The analysis of the problem of atmospheric diffusion of impurities using Euler's method leads to the solution of turbulent diffusion equations with the use of numerous semi-empirical methods to obtain a closed system of equations that describe the transport and diffusion of impurities in a turbulent environment.

The assumptions for the ADE solution are as follows:

- the stationary case is considered, i.e. $\frac{\partial C}{\partial t} = 0$;
- the vertical component of velocity w is neglected in relation to the horizontal components of velocity u and v;
- the x axis is oriented along the wind, i.e. $u = U$ and $v = 0$;
- diffusion along the wind is negligibly small compared to advection, i.e.

$$u\frac{\partial C_y(x,z)}{\partial x} = k(x)\frac{\partial^2 C_y(x,z)}{\partial z^2}\ ; \qquad \left|u\frac{\partial C}{\partial x}\right| \gg \left|\frac{\partial}{\partial x}\left(k_x\frac{\partial C}{\partial x}\right)\right|. \tag{2}$$

Applying these assumptions to AED in the case that pollutants do not participate in reactions in the atmosphere leads to the following equation:

$$u\frac{\partial C}{\partial x} = \frac{\partial}{\partial y}\left(k_y\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z\frac{\partial C}{\partial z}\right). \tag{3}$$

It will be assumed that $k_y = k(x)$ and $k_z = k(x)$, as well as $k_y = k_z$. Then we integrate equation (3) as follows:

$$u\frac{\partial}{\partial x}\int_{-\infty}^{\infty} C\,dy = \int_{-\infty}^{\infty}\frac{\partial}{\partial y}\left(k_y\frac{\partial C}{\partial y}\right)dy + \int_{-\infty}^{\infty}\frac{\partial}{\partial z}\left(k_z\frac{\partial C}{\partial z}\right)dy, \tag{4}$$

$$u\frac{\partial}{\partial x}\int_{-\infty}^{\infty} C\,dy = k_y\frac{\partial C}{\partial y}\bigg|_{-\infty}^{\infty} + k(x)\frac{\partial^2}{\partial z^2}\int_{-\infty}^{\infty} C\,dy,$$
$$\int_{-\infty}^{\infty} C\,dy = C_y(x,z);\quad k_y\frac{\partial C}{\partial y}\bigg|_{-\infty}^{\infty} = 0. \tag{5}$$

From this follows the two-dimensional equation that will most often be solved when modeling the spread of pollutants:

$$u\frac{\partial C_y(x,z)}{\partial x} = k(x)\frac{\partial^2 C_y(x,z)}{\partial z^2}. \tag{6}$$

Boundary and initial conditions essentially determine the shape of the ADE solution. The following boundary conditions will be used in the work:

1) $k\frac{\partial C_y(x,z)}{\partial z} = -w_g C_y(x,z),\quad z=0,$ (7)

where w_g - speed of gravitational settling of heavy particles;

2) $k\frac{\partial C_y(x,z)}{\partial z} = 0,\quad z=H,$ (8)

pollutant flux at the mixing height H (H represents the inversion layer height and is often called the mixing height);

3) $u\,C_y(x,z) = Q\,\delta(z-H),\quad x=0,$ (9)

this is the mass continuity equation, Q is the source strength, and the δ is Dirac function;

4) $C_y(x,z) = 0,\quad z=\infty.$ (10)

this means that the concentration of pollutants tends to zero at long distances.

The height of the mixing layer H depends on the stability of the atmosphere. Table 1 shows characteristic values of the height of the mixing layer for individual stability classes.

Table 1. *Mixing layer heights for individual stability classes*

Stability class	**A**	**B**	**C**	**D**	**E**	**F**
***H* [m]**	1.300	900	850	800	400	100

The analytical solution of ADE, for the given boundary conditions, is [9]:

$$C_y(x,y) = \frac{Q}{4\pi kx}\left[\begin{array}{l}\exp\left(-(z-H)^2 u/4kx\right)+\exp\left(-(z+H)^2 u/4kx\right)-\\ -\frac{2w_g\sqrt{\pi x}}{\sqrt{ku}}\exp\left(\frac{w_g(z+H)}{k}+\frac{w_g^2 x}{ku}\right)Erfc\left(\frac{(z+H)\sqrt{u}}{2\sqrt{kx}}+\frac{w_g\sqrt{x}}{\sqrt{ku}}\right)\end{array}\right]. \tag{11}$$

Here, $Erfc(x)$ is the error function [10]. Also $u \equiv u_{115} = u_{10}(z/10)^p$ is the wind speed that changes with height. Wind speed is measured at $z = 10$ m and is calculated according to atmospheric stability classes and whether it is an urban or rural environment. For the urban environment, values for p according to stability classes are given in table 2.

Table 2. *Values of the parameter p for different classes of atmospheric stability [11]*

Stability class	**A**	**B**	**C**	**D**	**E**	**F**
p for the urban environment	0,19	0,21	032	0,30	0,36	0,46

NUMERICAL SOLUTION OF ADE

The JAD solution, for the given boundary conditions, can also be obtained numerically, solving equation (3), e.g. Adomain decomposition method [12]:

$$C_y(x,z) = \frac{Qw_g}{u(Hw_g - k)} \exp\left(\frac{2\left[\frac{udk}{kdx} - w_g\right]x}{\frac{u}{k}H(Hw_g - 2x)}\right) \sum_{i=1}^{\infty}\left[\frac{2\left(\frac{u}{k}H\frac{dk}{dx} - w_g\right)x}{H(Hw_g - 2x)}\right]\left[\frac{-kz^{2i}}{w_g(2i)!} + \frac{z^{2i+1}}{(2i+1)!}\right]. \quad (12)$$

The values of the turbulent diffusion coefficient k will be taken as: $k = 0{,}04\ u\ x$ (from [13]).

COMPARISON OF MEASURED AND CALCULATED VALUES OF AIR POLLUTANT CONCENTRATIONS

An experiment was conducted in Copenhagen in 1987 in which SF_6 concentration values were measured over a certain period of time for different classes of atmospheric stability [14]. The measurement results are, through the so-called normalized concentrations of *C/Q* expressed in units: $10^{-4}\,s\,m^{-2}$], given in table 3. Also, there are given normalized concentration values calculated according to the analytical solution and according to the numerical solution of JAD, for the same conditions as in the experiment.

Table 3. *Comparative values of measured and calculated normalized concentrations of C/Q according to the analytical and numerical solution of ADE*

x **[m]**	**Stability class**	**Airflow speed** u_{10} **[m/s]**	**Airflow speed** u_{115} **[m/s]**	**Measured values** ***C/Q*** **[$10^{-4}\,s\,m^{-2}$]**	**Analytical calculated values** ***C/Q*** **[$10^{-4}\,s\,m^{-2}$]**	**Numerically calculated values** ***C/Q*** **[$10^{-4}\,s\,m^{-2}$]**
1.900	**A**	2,1	3,34	6,48	1,75	2,89
3.700	**A**	2,1	3,34	2,31	3,90	1,48
2.100	**C**	4,9	10,71	5,38	3,02	3,99
4.200	**C**	4,9	10,71	2,95	1,62	1,98
1.900	**B**	2,4	4,01	8,2	6,7	4,17
3.700	**B**	2,4	4,01	6,22	4,94	2,13
5.400	**B**	2,4	4,01	4,3	2,82	1,45
2.100	**C**	3,1	4,93	6,72	6,52	3,99
4.200	**C**	3,1	4,93	5,84	4,50	1,98
6.100	**C**	3,1	4,93	4,97	1,89	1,36
2.000	**C**	7,2	11,45	3,96	2,80	4,19
4.200	**C**	7,2	11,45	2,22	1,52	1,98
5.900	**C**	7,2	11,45	1,83	0,87	1,40
2.000	**B**	4,1	6,85	6,7	4,07	3,96
4.100	**B**	4,1	6,85	3,25	2,54	1,91
5.300	**B**	4,1	6,85	2,23	1,71	1,48
1.900	**D**	4,2	8,74	4,16	4,15	4,69
3.600	**D**	4,2	8,74	2,02	2,56	2,46
5.300	**D**	4,2	8,74	1,52	1,40	1,66
2.100	**C**	5,1	11,14	4,58	2,90	3,99
4.200	**C**	5,1	11,14	3,11	1,56	1,98
6.000	**C**	5,1	11,14	2,59	0,87	1,38

Figure 1 shows a graphic representation of the normalized values of the concentration of pollutants whose values are given in table 3. From that table you can find statistical indicators of the difference between the measured and predicted values of the normalized concentration, such as mean square error, correlation coefficient, etc. According to Hanna

[15], the statistical parameters necessary to compare the quality of the model with the experimentally determined normalized concentrations are:

- Normalized mean square error: $NMSE = \frac{\overline{(C_M - C_G)^2}}{\overline{C_M}\,\overline{C_G}}$, (13)
- Correlation coefficient: $R = \frac{\overline{\left(C_M - \overline{C_M}\right)\left(C_R - \overline{C_R}\right)}}{\sigma_{C_M}\sigma_{C_R}}$ (14)
- Concentration ratio: $FAC2: \quad 0,5 \leq \frac{C_R}{C_M} \leq 2,0$ (15)
- Fractional tendency: $FB = \frac{\left(\overline{C_M} - \overline{C_R}\right)}{0,5\left(\overline{C_M} + \overline{C_R}\right)}$ (16)

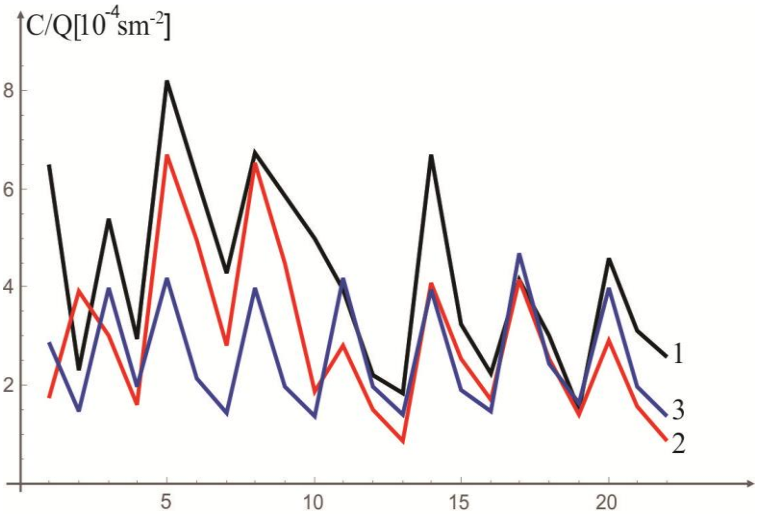

Fig. 1. *Normalized values of the concentration of pollutants: 1- experimentally measured, 2 - calculated from the analytical solution of ADE and 3 - calculated from the numerical solution of ADE*

If the model were perfect, i.e. gave results identical to the measured values, the *R* and *FAC2* parameters should have a value of 1,0, and the *NMSE* and *FB* parameters should have a value of 0,0. Due to the influence of randomness on atmospheric processes, no model is perfect and the mentioned parameters never reach ideal values. Table 4 gives the values of these parameters for the case when the dispersions are determined based on the analytical solution of ADE and the numerical solution of ADE.

Table 4. *Table caption (10 pt, italic, centered)*

Case	Models	*NMSE*	*R*	*FAC2*	*FB*
The equation of advective diffusion (ADE)	**Analytical solution**	0,21	0,76	0,70	0,36
	Numerical solution	0,40	0,60	0,61	0,48

Table 4 shows that the calculation of the normalized concentration of pollutants in the analytical solution, according to all parameters, is more consistent with the experimentally measured data. This means that analytical solutions are preferable, if they can be found. Numerical solutions have the advantage of saving time.

CONCLUSION

The paper highlights the problem of air pollution as one of the key problems we face today and which affects many aspects of modern life. Modeling and based on it the prediction of the spread of air pollution was mentioned as one of the ways to protect against air pollution.

The models used are very diverse and many of them are incorporated into software packages used in practice. The basis of most models is Euler's approach, in which the equation of advective diffusion needs to be solved for different initial and boundary conditions. It should be said that the Gaussian model also follows from Euler's approach by solving ADE for constant coefficients of turbulent diffusion and corresponding boundary conditions. Solutions that are used in practice are obtained in analytical form or numerically. During the analytical solution, a functional connection is found between the parameters that characterize the distribution of air pollution of the corresponding type of pollutants. In the numerical approach, the solution is found approximately, by solving the ADE using potential series, the Adomian decomposition method or numerical methods of solving partial differential equations such as the finite element method, etc. The paper uses a statistical method to compare these two approaches with experimentally measured values. It has been shown that the analytical method gives results that are more consistent with the experimentally determined values of air pollution. However, due to the complexity of the air pollution problem, due to the variability of the parameters that affect air pollution, it is very difficult to find an analytical solution for many practical situations. Therefore, a combination of both approaches is resorted to in order to determine the spread of air pollution as precisely as possible and thereby reduce the risk to the population and nature.

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EXPERIMENTAL STUDY OF FIRE HAZARDS FROM SMALL-SCALE METHANE FIRES

Research paper

Milan Protić[1]*, Nikola Mišić[2], Ana Vukadinović[3], Jasmina Radosavljević[4], Miomir Raos[5]
[1,2,3,4,5] University of Niš, Faculty of Occupational Safety, Niš, Serbia

Abstract: This paper presents an experimental study on the flame dynamics and radiation properties of small-scale methane fires, with a focus on safety implications in laboratory settings. The experiments were conducted using a methane sand burner to simulate various heat release rates (HRR) ranging from 3 kW to 10 kW. Key parameters, such as flame height and total heat flux, were measured and compared with estimations derived from the Heskestad and McCaffrey models. The results demonstrated good agreement between the experimental measurements and model predictions up to 8 kW, with significant discrepancies arising beyond this point. The study also highlights the nonlinear relationship between HRR and measured incident total heat flux, with the largest increases observed between 3–5 kW and 7–8 kW. The findings should be interpreted with caution due to external influences, such as flame tilting caused by minor airflow in the laboratory. Obtained results provide valuable insights for assessing fire hazards in small-scale methane fires and improving safety protocols.
Key words: pool fires, methane, flame length, incident thermal radiation

INTRODUCTION

Despite efforts toward transitioning to cleaner energy, fossil fuels, including oil and natural gas, still account for a significant portion of global energy consumption. Hydrocarbon use remains a dominant force in global energy markets, influencing both economic and environmental outcomes. United States, China, and other leading industrial nations account for half of global oil use, with much of the world's oil being traded between regions rather than consumed at the source [1]. The reliance on hydrocarbons adversely affects environmental sustainability and calls for the urgent need for energy transition strategies [2]. These insights reflect the complex balance between the economic benefits of hydrocarbons and the environmental challenges they pose, emphasizing the importance of integrating sustainable energy practices.

Safety incidents involving hydrocarbon fuels in the process industry come in various forms. Each of these incidents has distinct radiation characteristics, but they share the common factor of having devastating effects on nearby people and property. Tayab et al. (2023) provided a detailed analysis of over 50 process safety events, showing that failures in risk identification and asset integrity contributed to many incidents [3]. Similarly, Aslam et al. (2023) analyzed the effects of human factors, noting that over 30% of storage tank incidents are linked to human errors, particularly during critical activities such as flushing and purging hydrocarbon systems [4]. Study by Nolan (2011), showed that large incidents often escalate when hydrocarbons cannot be isolated from the source [5]. The integration of updated safety practices, continuous training, and better leadership during crises are critical to reducing the frequency and severity of incidents in the hydrocarbon industry.

Hydrocarbon events in the process industry are categorized based on the nature of the release and subsequent events such as fires, explosions, or toxic releases. These events often originate from the release of hydrocarbons in gaseous, liquid, or mist form, with gas

[1] Corresponding author, milan.protic@znrfak.ni.ac.rs, ORCID: https://orcid.org/0000-0003-4957-7882
[2] nikola.misic@znrfak.ni.ac.rs, ORCID: https://orcid.org/0000-0003-2314-4851
[3] ana.vukadinovic@znrfak.ni.ac.rs, ORCID: https://orcid.org/0000-0002-6228-1077
[4] jasmina.radosavljevic@znrfak.ni.ac.rs, ORCID: https://orcid.org/0000-0001-8545-2265
[5] miomir.raos@znrfak.ni.ac.rs, ORCID: https://orcid.org/0000-0001-5586-0276

releases posing the highest risk due to their potential to create vapor clouds that can lead to explosions or jet fires.
Pool fires are one of the most common fire hazards in the process industry, particularly in chemical and hydrocarbon processing facilities. Pool fires are a type of diffusion flame, where fuel and oxidizer mix at the onset of flame. In pool fires, fuel is vaporized from a liquid pool and then combusted in the air, creating a diffusion flame characterized by its dependence on heat and mass transfer processes.
The aim of this paper is to investigate the flame dynamics and radiation properties of methane flames in a laboratory setting, with a focus on safety considerations. Methane flames are not typically categorized as pool fires since pool fires usually involve liquid fuels that evaporate and burn as diffusion flames above the liquid surface. Methane, being a gas at standard conditions, does not form a liquid pool like hydrocarbons such as gasoline or heptane. However, under certain conditions, methane flames can be considered comparable to pool fires, particularly when examining combustion characteristics, heat transfer, and flame dynamics.

MATERIAL AND METHODS

Experiments were performed with calibration burner used for ISO 13927 [6]. Burner design is shown on the Fig. 1 [6].

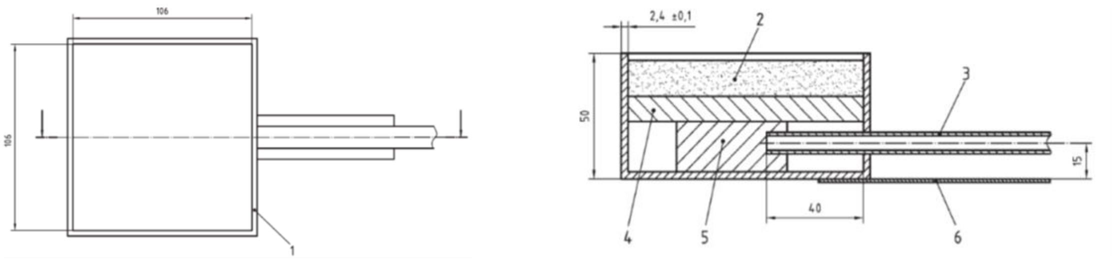

Fig. 1. *Methane burner used for performing experiments [6]*

where: 1. is square stainless-steel pan, 2 sand (with grain size approximately 1 mm to 2 mm), 3. is the stainless steel tube for methane conduit (inner diameter 8 mm), 4 and 5 are isolating ceramic-fiber blankets and 6. is handle for manipulation of burner.
The burner was connected to double rotameters (Influx, UK) calibrated for methane flow and then to a methane cylinder (250 bar). The cylinder was equipped with a double regulator. For safety reasons, a double flame arrestor system was used. One rotameter had a flow range between 0-18 l/min, while the other had a range of 0-2.8 l/min. A three-way valve was used to direct the methane flow from the gas cylinder to either of the flowmeters. For the experiments, only the flow meter with a higher range was used. According to the producer's recommendation, the flow through the flowmeters was limited to 2 bar. The configuration is shown in Fig. 2.

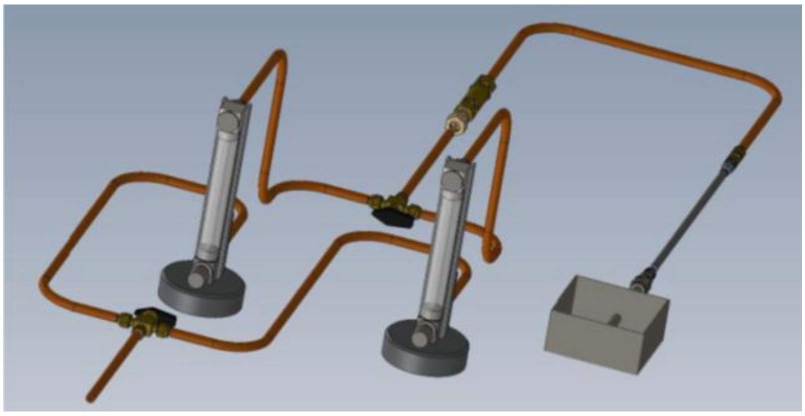

Fig. 2. *System for conveying methane to the burner* [7]

Experiment was performed for heat release values from 3 kW to 10 kW. The relationship between the heat release rate and the corresponding methane flow is shown in the Fig. 3.

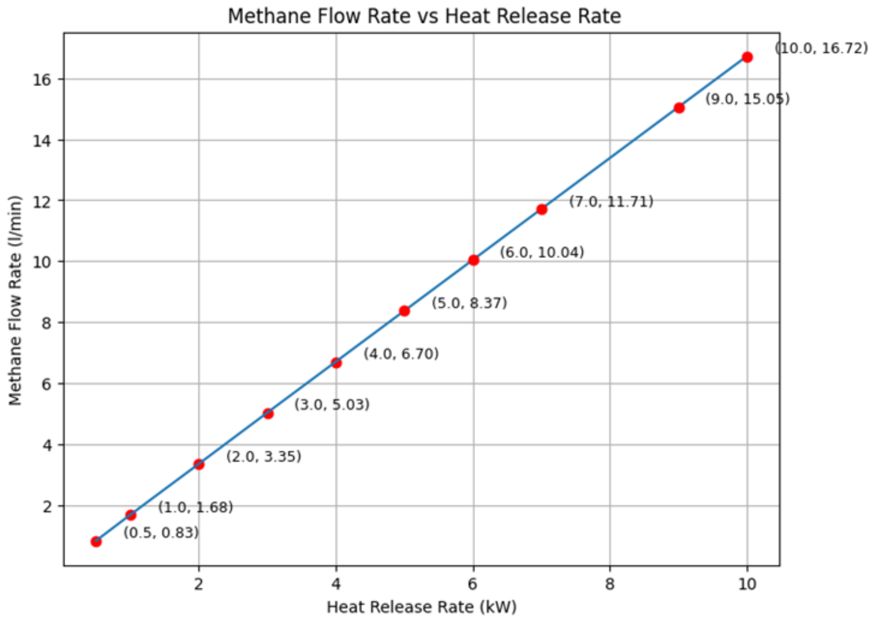

Fig. 3. *Methane flow rate vs Heat release rate*

For heat flux measurement, a calibrated water-cooled Schmidt-Boelter (thermopile type) heat flux meter (Medtherm, USA) was used. The measurement range of the heat flux meter is set to 100 kW/m². The heat flux meter was connected to a data processing device and then to a computer, allowing for immediate readings of the incoming thermal radiation. Data were displayed at a frequency of 1 Hz. The instrument was zeroed to show 0 kW/m² for ambient thermal radiation. The heat flux meter was continuously cooled through 6 mm barbs. Demineralized water with a flow rate in the range of 200-300 ml/min was used for cooling. The cooling loop of the heat flux meter was closed with an appropriate immersion pump. The heat flux meter was clamped to a vertical holder. This allowed the adjustment of the heat flux meter by height. The height of the heat flux meter could be adjusted, and for the experiments in this study, the thermopile part of the flux meter was set at a height of 15 cm, measured from the edge of the burner and at distance of 17 cm. The installation during the experiment is shown in Fig. 4. This configuration enabled continuous measurement of incoming thermal radiation.

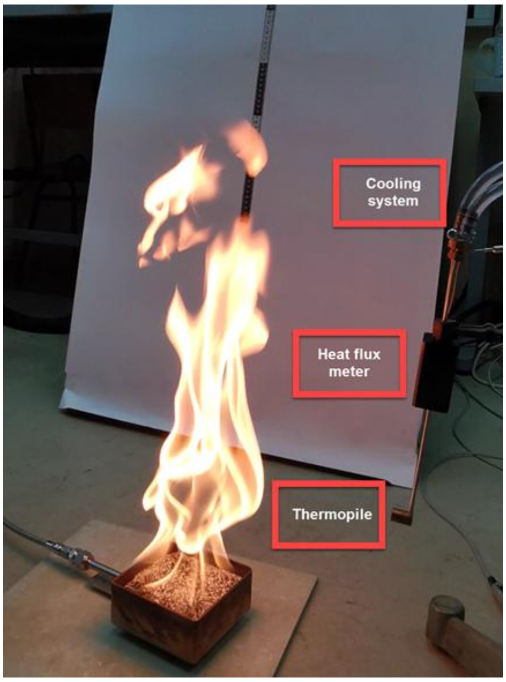

Fig. 4. *Installation used for heat flux measurement*

An aluminum meter was used to measure the flame length. It was attached to the back side of the sand burner.

RESULTS AND DISCUSSION

Flame height

Flame height is defined as the distance from the burner to the flame tip. From the very beginning, it was clear that measuring the flame height would be a very difficult task. A methane diffusion flame has a complex morphology dictated by turbulence. The flame has an irregular shape, with numerous small flames detaching from the main flame vertically and laterally. This is especially noticeable at higher fuel flow rates. See Fig. 4.

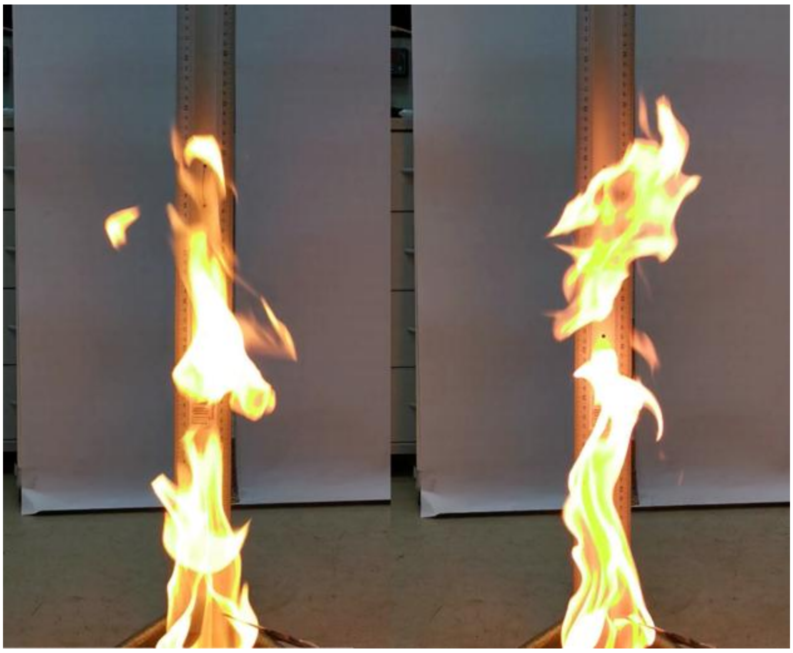

Fig. 5. *Two frames for the same HRR illustrating the pulsating nature of the turbulent methane flame*

Due to the pulsatory nature of the flame, it was difficult to precisely measure the flame height. Therefore, multiple measurements were collected for each heat release rate, and the results are reported in a normalized box plot Fig. 5. Mean values are indicated on the right side of the Gaussian distribution curve for each of the tested heat release rates.

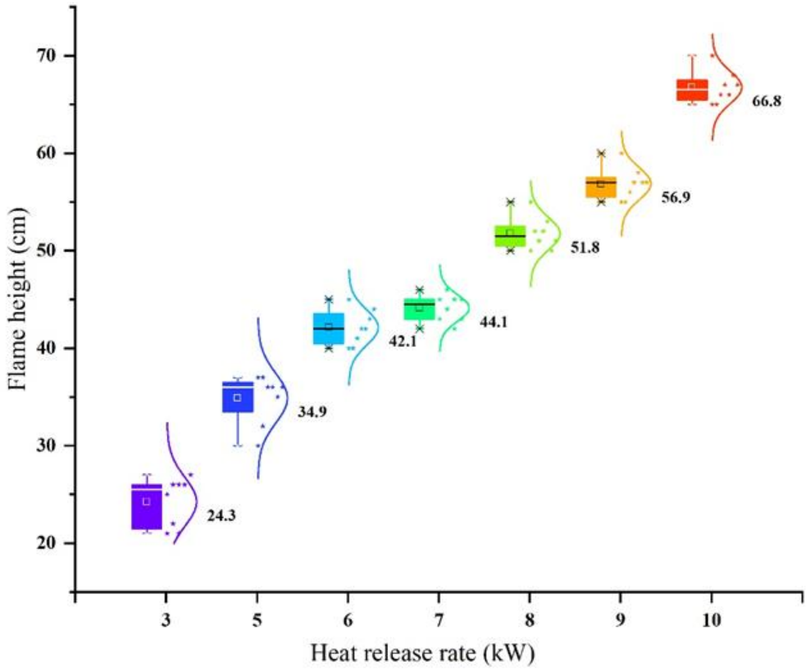

Fig. 6. *Measured flame height and corresponding HRR*

In the next step, the obtained values were compared with those derived from models found in the literature. For the comparison, the following two models were used: the Heskestad virtual origin model [8], and the model developed by McCaffrey [9].
Both models require the perimeter of the pool as an input, as they are used to describe pool fires. In the experiments, as previously mentioned, a square burner was used. Therefore, the equivalent diameter was calculated using the following formula:

$$D_{eq} = \sqrt{\frac{4A}{\pi}} \quad (1)$$

where: D_{eq} is the equivalent diameter (m) and A is the area of the burner (m²). Hence, for the square burner used (10 x 10 cm), the following equivalent diameter was applied for further calculations:

$$D_{eq} = \sqrt{\frac{4 \times 0.01}{\pi}} = \sqrt{\frac{0.04}{3.14159}} \approx \sqrt{0.01273} \approx 0.113\,\mathrm{m} \quad (2)$$

Heskestad's model [8] is based on the concept of a "virtual origin" of the flame, which adjusts the flame height based on the heat release rate and the plume's behavior near the flame base. According to this model, the flame height is given by:

$$h_f = 0.235 \cdot Q^{2/5} - 1.02 \cdot D \quad (3)$$

where: h_f is the flame height, Q is the heat release rate and D is the diameter of the fire source.

The McCaffrey model divides the flame into three distinct regions: continuous flame, intermittent flame, and buoyant plume, each with different behaviors. When predicting the flame height for a highly turbulent fire from the onset, like it is the case in this study, it is essential to account for both the continuous flame region and the intermittent region. Thus, for highly turbulent flames starting from the sand burner head, the intermittent region's equation:

$$h_f = C \cdot Q^{2/5} \tag{4}$$

where C is an empirical constant, gives the prediction for the flame height before transitioning into the buoyant plume.

Experimentally obtained results were compared with the estimations from the two aforementioned models. The results are summarized in Fig. 6.

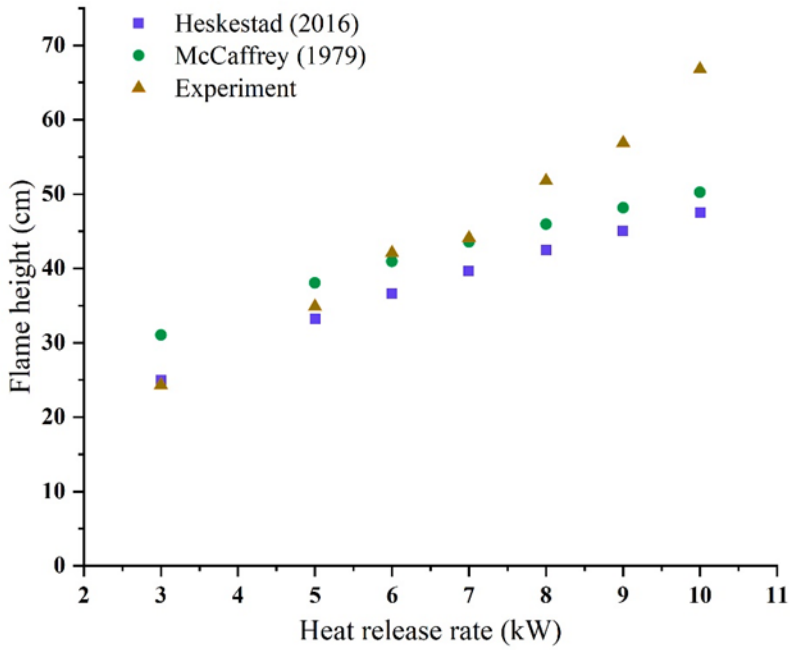

Fig. 7. *Flame height vs. HRR: experimental results and model estimates*

As can be seen from the figure, there was good agreement between the experimental results and the models up to a heat release rate of 8 kW. For heat release values of 6 and 7 kW, the experimental results were almost identical to the McCaffrey model. However, for a heat release rate of 7 kW, the experimentally obtained values began to diverge, and the difference between the models and experimental results increased. Therefore, for HRR values in the range between 3 and 8 kW, both models provided a reasonable estimate for flame height. For lower HRR values (3 to 5 kW), the Heskestad model provided accurate estimates, while for higher HRR values, the McCaffrey model performed better. For all tested HRR values, the intermodel agreement was satisfactory, with a decreasing trend in differences as the tested HRR increased.

Thermal radiation hazard

Measured thermal radiation values are presented as box normal plot in Fig. 7.

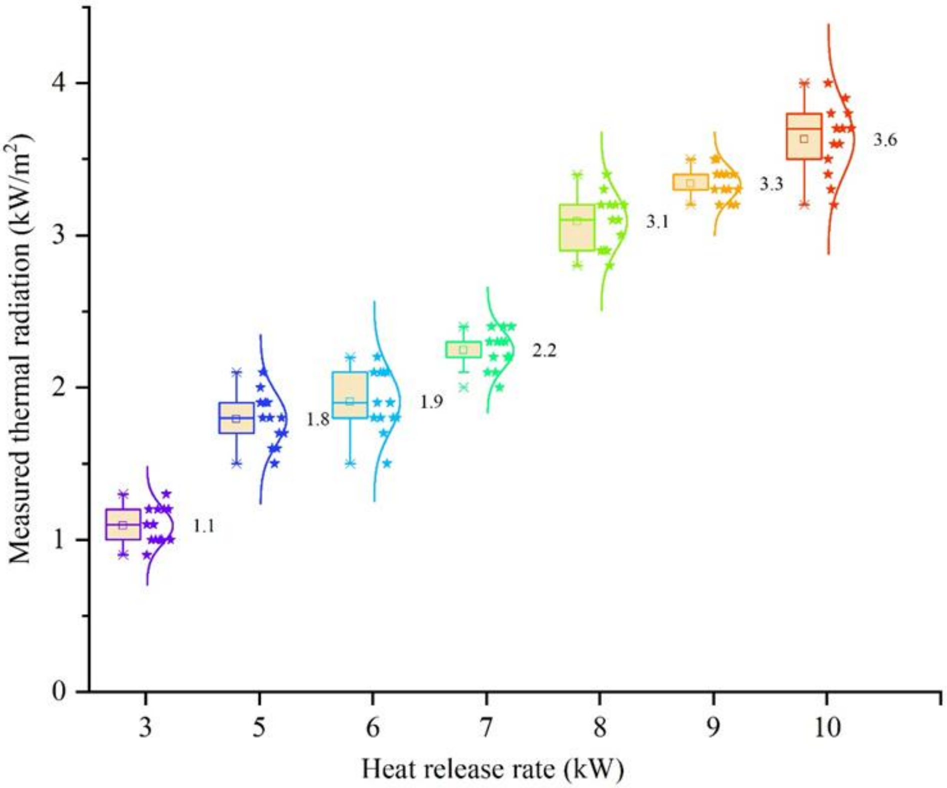

Fig. 8. *Measured total heat flux from flame vs. HRR*

As was expected, the measured total heat flux increased with increasing HRR. However, this increase was not regular. The largest changes in the measured total heat flux occurred between an HRR of 3 and 5 kW, and between 7 and 8 kW. The obtained values should be interpreted with caution due to the pulsating nature of the flame and flame tilting, which may have potentially affected the measurement process.

According to the NFPA 59A Standard [10], a heat flux level of 5 kW/m² is often used to determine hazard distances for human exposure to radiant heat from fires. In the European Union, the permissible exposing heat flux levels for radiant heat from fires are primarily outlined in the EN 1473 standard [11]. According to EN 1473, 1.5 kW/m² is threshold set for unshielded areas of critical importance where individuals without protective clothing may be exposed. The obtained results comply with NFPA 59A but not with the regulations outlined in EN 1473. However, it is important to note that distance from the direct flame significantly affects human thermal exposure. Therefore, while exposure at higher HRR may exceed the threshold set by EN 1473, the incident radiation at greater distances is considerably lower and considered acceptable. The main hazard from this type of laboratory flame arises from the stochastic nature of the flame. This includes highly unpredictable flame morphology (such as flame detachment) and, in particular, flame tilt, which can be induced by even minor disturbances in the surrounding airflow. These adverse events, especially at higher methane flow rates, should be regarded as primary safety concerns.

CONCLUSION

This experimental study examined the flame dynamics and thermal radiation properties of small-scale methane fires. The results demonstrated that both the Heskestad and McCaffrey models provide reasonable estimates of flame height for heat release rates (HRR) ranging between 3 and 8 kW. For lower HRR values, the Heskestad model was more accurate, while the McCaffrey model performed better at higher HRR values. Beyond 8 kW, the experimental values began to diverge from the model predictions. This can be attributed to the complexity of flame behavior at elevated fuel flow rates.

Additionally, the thermal radiation measurements showed an expected increase in total incident heat flux with higher HRR. However, the increase was nonlinear, with significant changes observed between 3 and 5 kW, and 7 and 8 kW. Although the obtained heat flux values complied with the NFPA 59A standard, they exceeded the limits outlined in EN 1473. However, the incident radiation at greater distances from the flame is expected to be significantly lower, reducing the overall hazard.

The study emphasized the importance of considering flame morphology, particularly the stochastic behavior and flame tilting caused by minor airflow disturbances, as critical safety concerns in laboratory settings. These findings contribute valuable insights for improving safety protocols in handling flammable gas fires and assessing fire hazards in controlled environments.

ACKNOWLEDGEMENT

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INTEGRATION OF CIRCULAR ECONOMY AND INDUSTRIAL ECOLOGY: PATHWAYS TO SUSTAINABLE INDUSTRIAL DEVELOPMENT

Review paper

Vesna Drakulović[1]*, Višnja Mihajlović[2], Bogdana Vujić[3], Mića Đurđev[4], Milan Marković[5]

Abstract: This paper explores the integration of Circular Economy (CE) principles and Industrial Ecology (IE) practices as a means to enhance sustainability and resource efficiency across various industries. The circular economy shifts away from the traditional linear model of "take, make, dispose," promoting a closed-loop approach that minimizes waste and prolongs the lifecycle of products through reuse, recycling, and remanufacturing. Industrial ecology, on the other hand, emphasizes industrial symbiosis, where waste or by-products from one process serve as inputs for another, mimicking natural ecosystems. The study employs a qualitative methodology, analysing secondary data from industries such as automotive, energy, and electronics, revealing how CE and IE practices lead to significant reductions in resource use, waste generation, and carbon emissions. Results show that industries adopting CE and IE principles achieve improved efficiency and environmental sustainability, with specific examples of resource savings and reductions in CO2 emissions. Despite challenges in implementation, this research highlights the potential of CE and IE to foster innovation, economic growth, and environmental resilience. The paper concludes by stressing the importance of collaboration between governments, businesses, and academia to advance these concepts and address the environmental challenges of the 21st century.
Key words: circular economy, eco-innovation, industrial ecology

INTRODUCTION

The circular economy presents a systematic shift from the traditional linear economy model, charaterized by the "take, make, dispose" paradigm. Environmental problems, such as biodiversity loss, water, air, and soil pollution, resource depletion, and excessive land use are increasingly jeopardising the earth's life-support systems.[1] The concept of the circular economy (CE) is actively supported by the European Union, numerous national governments such as China, Japan, the United Kingdom, France, Canada, the Netherlands, Sweden, and Finland, as well as growing number of businesses worldwide. Transition to a circular economy necessitates eco-innovations that close the loop in product life cycle, repurpose waste into valuable products for others, and address the need for environmental resilience, all white balancing the pressures of continued economic growth. [2] In the literature, the term eco-innovation is generally understood to mean "the production, application or exploitation of a good, service, production process, organizational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use (including energy use) compared to relevant alternatives" [3]. The circular economy plays a significant role in driving economic growth, which can be measured through indicators like GDP (Gross Domestic Product) and GNP (Gross National Product). As a result, it creates various opportunities for industries, businesses, governments (policymakers), and society by promoting cost savings, generating new jobs, fostering modernization, and encouraging renewal and innovation. By adopting a circular economy, Europe stands to achieve significant economic benefits, with estimated savings of EUR 1.8 trillion by 2030. In contrast, if Europe continues along its current linear economic trajectory, it could experience a reduction of EUR 0.9 trillion in potential economic gains. This shift towards a circular economy not only brings financial savings but also promotes more sustainable economic

[1] Corresponding author, vesna.drakulovic@tfzr.rs, ORCID: https://orcid.org/0009-0007-1796-7946
[2] visnja.mihajlovic@tfzr.rs, ORCID: https://orcid.org/0000-0002-9750-1076
[3] bogdana.vujic@tfzr.rs, ORCID: https://orcid.org/0000-0001-5249-8021
[4] mica.djurdjev@tfzr.rs, ORCID: https://orcid.org/0000-0002-1825-2754
[5] milan.markovic@tfzr.rs, ORCID: https://orcid.org/0009-0007-8130-7467

growth. Research suggests that such a transition could lead to a 7% increase in GDP growth, driven by improved resource efficiency, innovation, and the development of new business models. Additionally, the circular economy could positively impact labor markets by creating new employment opportunities across various sectors, from recycling and waste management to the design and production of sustainable products. Overall, the adoption of circular economy principles is expected to foster a more resilient, inclusive, and environmentally sustainable economy, strengthening Europe’s long-term economic prospects while addressing key social and environmental challenges [4].

The research employed a qualitative methodology to explore the integration of circular economy (CE) principles and industrial ecology (IE) practices across different industries. The study focused on analyzing case secondary data sources to investigate how industries are adopting circular economy and industrial ecology to enhance sustainability and resource efficiency. Data were gathered from multiple sources, including academic journals, reports from government and international organizations (such as the Ellen MacArthur Foundation and the European Commission), as well as industry reports from companies actively engaged in CE and IE practices.

LITERATURE REVIEW

The literature on circular economy and industrial ecology explores how these concepts intersect to provide solutions for sustainable industrial systems. As we have seen CE focuses on closing the loop of material and energy flows, reducing waste, and maximizing resource efficiency. In contrast, IE emphasizes the symbiotic relationships between industrial activities and ecosystems, wherein the waste from one process becomes the input for another, mimicking natural systems. Early studies by Frosch and Gallopoulos (1989) introduced the idea of an industrial ecosystem, laying the groundwork for the concept of IE. [5] The Ellen MacArthur Foundation (2013) later expanded the idea with a focus on CE, advocating for systemic redesign and innovation across supply chains. More recent research has demonstrated that the integration of CE and IE can lead to significant reductions in carbon emissions, waste generation, and resource extraction, especially in energy-intensive industries such as steel manufacturing, electronics, and chemical processing. [4]

The role of governments and businesses in promoting these concepts has also been extensively examined. European Union directives such as the Circular Economy Action Plan (2020) encourage industries to adopt sustainable practices, and countries like China have integrated CE principles into their national strategies. This literature highlights the synergies between policy, technological innovation, and industrial collaboration as key drivers of CE and IE success.[6]

THEORETICAL FRAMEWORK

Circular economy (CE) framework

The development of the circular economy concept is relatively recent. Originally, this concept emerged from the field of industrial ecology, which focuses on fostering material symbiosis between different companies and diverse production processes. Industrial ecology aims to mimic natural ecosystems, where waste and by-products from one process can serve as valuable inputs for another, CE is grounded in principles such as maintaining the value of products, materials, and resources for as long as possible and reducing waste to a minimum. The CE framework is often structured around the "3Rs"—Reduce, Reuse, and Recycle—which emphasize minimizing resource inputs and managing waste sustainably. Additionally,, CE promotes the concept of product life cycle extension through repair, refurbishment, and remanufacturing.[7] Through the lens of industrial ecology, the circular economy offers a transformative model that challenges the traditional linear economic paradigm by encouraging industries to collaborate in resource-sharing networks, innovate in product lifecycle management, and design processes that prioritize regeneration and environmental stewardship.[8] Circular economy could result in a reduction of primary material consumption by 32% by 2030 and 53% by 2050.

Fig 1. *Circluar economy* [9]

INDUSTRIAL ECOLOGY (IE) FRAMEWORK

IE focuses on understanding material and energy flows within industrial systems and designing these systems to be more like natural ecosystems. IE involves the practice of industrial symbiosis, where companies in close proximity exchange by-products, energy, or materials, reducing overall waste and improving efficiency. This concept is key to achieving closed-loop systems and reducing environmental impact. Currently, there is no universally accepted definition of industrial ecology. However, to prevent any misunderstanding, it is important to clarify the terms "industrial metabolism" and "industrial ecology" as used in this context. "Industrial metabolism" refers to the materials and energy flows of the industrial system. It is studied with an essentially analytical and descriptive approach (basically an application of materials-balance principles), aimed at understanding the circulation of the materials and energy flows (and stocks) linked to human activity, from their initial extraction to their inevitable re-integration, sooner or later, into the overall bio-geochemical cycles.[10] "Industrial ecology" goes further: the idea is first to understand how the industrial system works, how it is regulated, and its interactions with the Biosphere; then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function.[11,12,13,14,15]

The results from the case studies indicate that industries adopting both CE and IE principles achieve significantly improved resource efficiency and reduced environmental impacts. For example, in the automotive sector, implementing CE strategies such as material recycling and remanufacturing components extended product life cycles by an average of 30%, while industrial symbiosis reduced the amount of virgin raw materials required for production. In the energy sector, industries that utilized waste heat recovery and renewable energy integration within industrial symbiosis networks achieved reductions in CO2 emissions of up to 40%. Similarly, in the electronics industry, the combination of CE and IE practices facilitated the recovery of rare earth materials from electronic waste, reducing the need for environmentally damaging mining activities. Levický el. al. assess 169 micro-enterprises in Slovakia to analyze the implementation of circular economy whereas over 26% of SMEs do not implement any form of circular economy principles in their business process but, over 46% of medium-sized enterprises carry out 3 to 5 activities associated with a circular economy [16]. However, some studies found that transitioning from linear to circular economy face several obstacles. Different perceptions of managers what are the benefits of implementation of CE, particularly financial indicators of CE, knowledge gaps and convincing actors of the benefits of CE, and difficulties in overcoming existing 'linear' mindsets [17]

POTENTIAL FUTURE RESEARCH IN THIS DOMAIN

While the integration of Circular Economy (CE) and Industrial Ecology (IE) shows promising results, several areas of future research could further enhance the understanding and application of these concepts. Potential research directions include:

1. **Quantitative Evaluation of CE and IE Impacts:** While the current study provides qualitative insights into the benefits of CE and IE, future research could focus on developing more comprehensive quantitative models to measure the environmental, economic, and social impacts of these practices across different sectors. This could include developing standardized metrics for assessing resource efficiency, carbon emissions, and lifecycle impacts.
2. **Barriers to Implementation**: Research could investigate the organizational, financial, and policy barriers that prevent industries from fully adopting CE and IE practices. Understanding these obstacles, particularly in small and medium-sized enterprises (SMEs), could lead to the development of tailored solutions, such as financial incentives, policy frameworks, or technological innovations that facilitate the transition.
3. **Technological Innovations and Digitalization:** Exploring how emerging technologies such as blockchain, artificial intelligence (AI), and the Internet of Things (IoT) can support CE and IE practices could be a valuable area of research. These technologies have the potential to optimize resource use, monitor waste flows, and enhance transparency in industrial symbiosis networks

CONCLUSION

The integration of circular economy and industrial ecology offers a promising pathway for achieving sustainable industrial development. By closing the loop on material and energy flows, industries can significantly reduce waste and environmental impacts, while simultaneously creating new opportunities for innovation and economic growth. Although challenges persist in implementation, particularly in terms of cost and coordination, the long-term benefits for both industries and the environment make CE and IE critical components of future industrial strategies.

Governments, businesses, and academic institutions must continue to collaborate on developing policies, technologies, and frameworks that support the widespread adoption of CE and IE. With the growing global focus on sustainability and climate resilience, the integration of these concepts into industrial practice will be essential for addressing the pressing environmental challenges of the 21st century.

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METHODOLOGY OF DETERMINATION OF FIRE HAZARD ZONES IN THE HIGH-BAY WAREHOUSES

Research paper

Goran Bošković[1*], Višnja Mihajlović[2], Nikola Karanović[3], Natalija Nikolić[4], Zoran Čepić[5]
[1]Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Kraljevo, Serbia
[2]Technical Faculty "Mihajlo Pupin", University of Novi Sad, Zrenjanin, Serbia
[3]University of Aveiro, Portugal
[4]Faculty of Sciences, University of Novi Sad, Novi Sad, Serbia
[5]Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Abstract: Searching relevant literature sourcesit was found that the determination of fire hazard zones in warehouses is not sufficiently researched and studied. This paper aims to present a new methodological approach concerning the mentioned issue. Based on the COPRAS multi-criteria decision-making method, a new method was developed for the precise determination of potential zones where there is a risk of fire. The advantage of the described method is that it enables quick and easy determination of all orientation zones of fire risk in a quick and simple way. The method requires fewer hardware resources compared to the existing ones and enables the display of the warehouse space in the form of a 3D model with calculated fire hazard zones. The mentioned procedure represents the first step when planning the layout and arrangement in the warehouse itself. The effectiveness of the proposed method was confirmed through a suitable numerical example.
Keywords: warehouse; fire risk zones; COPRAS method

INTRODUCTION

Fire represents a serious threat to the aspect of safety of people and property, regardless of whether it is about residential buildings, storage facilities, or industrial facilities, therefore managing the risk of fire outbreaks is a big challenge in urban and rural environments [1]. In comparison with other places of fire origin, fires in warehouses have a small share in the total number of fires. Still, in terms of heat release, the size of the area affected by the fire, the degree of damage to the building itself, and material damage, these fires have significant consequences compared to fires in other types of buildings.

Warehouses, as the main factors of logistics and distribution, are often exposed to various improvements and corrections in the development phase, for the sake of better performance, capacity and efficiency of the warehouses themselves.The aforementioned improvements result in larger and higher warehouses, the use of automated systems for storage and retrieval of storage units (AS/RS systems), increased storage density, and placement of storage units at higher heights [2]. With the increase in the height and density of storage, the possibility of the spreading and growth of flames in the case of fire increases, thereby reducing the possibility of a quick detection and localization of the fire, as well as increasing emissions of smoke and harmful substances, which significantly affects the health and safety of employees It is known that most deaths in fires are the result of inhalation of toxic gases (CO, CO2,...), thick smoke, and insufficient amount of oxygen [3]. The fire that occurred in August 2015 in the warehouse of the port of Tianjin in North China, due to the large number of victims and caused material damage, pointed out the importance of the issue of fire protection in warehouses. In this event, 173 people died, and several hundred were injured [4]. At least 49 people, including nine firefighters, were killed in a major fire in 2022 at a container warehouse near a port city in southeastern Bangladesh [5], and more than 100 people were injured in total. Based on the large number of fires in warehouses, which by their scope and consequences can sometimes be considered catastrophic and which occurred around the world at the end end of the last century and during this century a large number of research related to this topic was initiated.

[1] Corresponding author, boskovic.g@mfkv.kg.ac.rs, ORCID: https://orcid.org/0000-0002-4597-922X
[2] visnja.mihajlovic@tfzr.rs, ORCID: https://orcid.org/0000-0002-9750-1076
[3] nikolakaranovic@ua.pt, ORCID: https://orcid.org/0000-0002-7498-6103
[4] nacanikolic@gmail.com
[5] zorancepic@uns.ac.rs, ORCID: https://orcid.org/0000-0001-5853-4767

The primary goal of these investigations consisted of answering questions related to risk assessment, safe evacuation from the warehouse, effective fire extinguishing and localization, as well as reducing the risk of the fire itself.

MATERIAL AND METHODS

The method presented in this paper consists of four parts. The first part refers to the selection of parameters used in fire risk assessment methods, needed to obtain the weighting coefficients necessary for determining fire hazard zones using multi-criteria decision-making procedures [6]. In the second part, the COPRAS method is presented, which was selected as relevant for obtaining the weighting coefficients necessary for further calculation, as in the paper. The third part describes the characteristics and advantages of the three-dimensional method for determining the parameters related to the contents placed in the warehouse necessary for calculations, fire risk assessment, and the determination of fire hazard zones. In the last, fourth part, the 3D COG method (center of gravity method) is presented, which is used to determine locations within the warehouse that are considered potential risk zones in case of fire.

Selection of Parameters for Multi-Criteria Analysis

The basic concept in the development of the method was to combine factors related to the emission of harmful substances due to the frequency of poisoning in fires, as well as factors related to the process of burning materials in a fire. To determine potential fire risk zones in warehouses based on data sources [7], 7 different parameters were selected: the concentration of CO [mg/g], the concentration of CO2 [mg/g], smoke density [kg/m3], ignition temperature [°C], thermal conductivity [W/mK], specific heat capacity [J/(kg K)], and calorific value [MJ/kg].

Determination of Simulation Parameters Using the COPRAS Method

The COPRAS method [8] has a very wide field of applications. It was used for risk assessment in the construction industry, in the selection of materials for solar panels, in the selection of mechanical processing of composite materials, in the selection of the type of robotization in production, etc. In this paper, the COPRAS method was used to determine the weighting coefficients, which also represent input parameters for risk assessment in the case of a high-bay warehouse, as the authors presented in the paper.

Three-Dimensional Method for Determining Storage Parameters

To determine the most precise parameters related to the locations of transport units and flexibility in terms of the configuration of the layout within the facility itself, a procedure was developed for the formation of a three-dimensional model of the warehouse with associated elements. The proposed structure of the procedure for determining the parameters of the warehouse, as shown in Figure 2, includes three main phases for the calculation and determination of the necessary parameters related to the storage of materials inside the warehouse.

The Procedure for Determining the Coordinates of Potential Hazard Zones

The classical approach to the method of determining the center of gravity (COG method) used in logistics enables the determination of optimal locations in the two-dimensional coordinate system *XoY*. To assess potential fire hazard zones and their coordinates, an improved version of the COG method will be used to determine the center of gravity in a three-dimensional coordinate system, which has found application in medicine, electrical engineering, mechanics, and other fields.

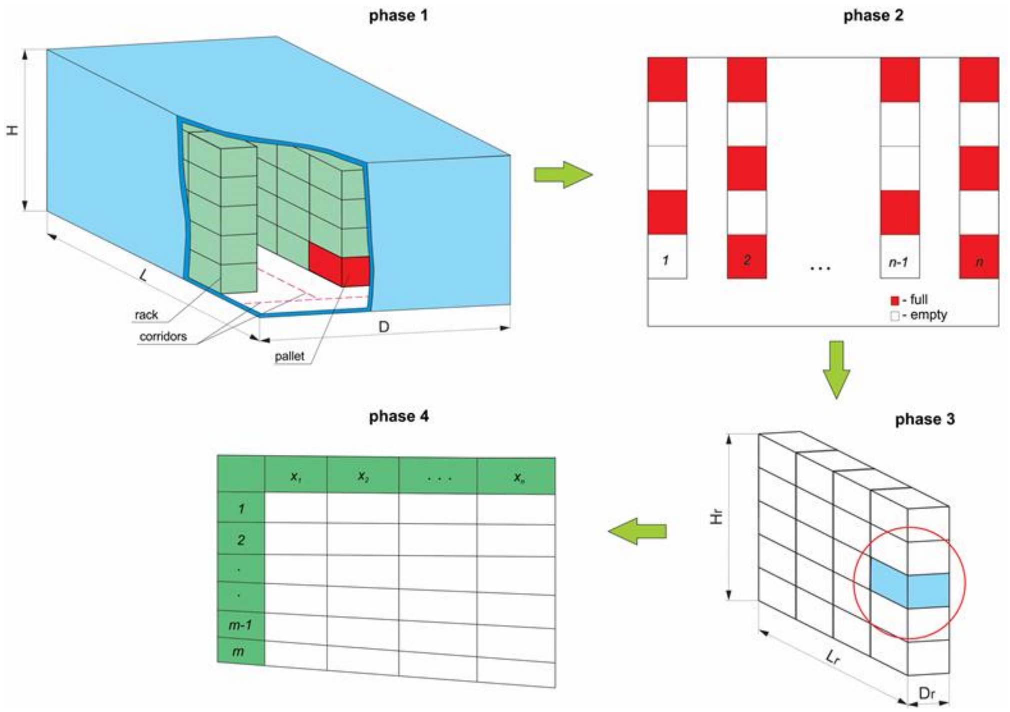

Fig. 1. *Schematic representation of the formation of a three-dimensional warehouse model and the procedure for obtaining the relevant parameters.*

NUMERICAL EXAMPLE

In the numerical example shown in this section, the parameters of the high-bay warehouse related to dimensions and layout (see Figure 2). Based on the considerations presented in the previous section, to obtain the most accurate data needed for further simulation, it was decided to select five types of solid materials (wood, cardboard, chipboard, PVC plastic, and rubber) as alternatives in the multi-criteria decision-making process.

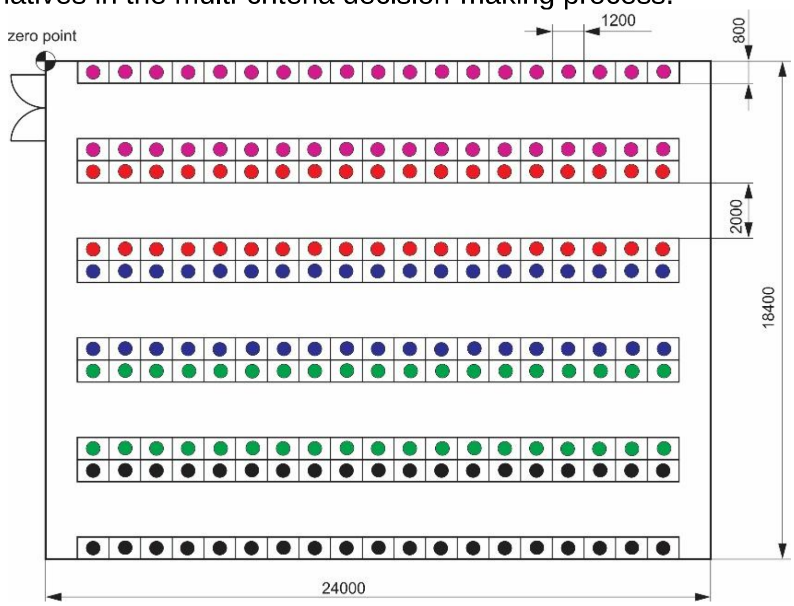

Fig. 2. Layout of a high-bay warehouse with associated dimensions and materials (• wood, • cardboard, • chipboard, • PVC, and • rubber).

The list of materials and the numerical values of the seven selected parameters are given in Table 1. The listed characteristics of materials related to combustion shown in the mentioned table represent criteria in the multi-criteria decision-making process and are taken from the literature.

Table 1. *Input parameters in the procedure of determining the weighting coefficients required for the simulation*

Material	CO [mg/g]	CO_2 [mg/g]	Smoke Density [kg/m^3]	Ignition Temperature [°C]	Thermal Conductivity [W/mK]	Specific Heat Capacity [J/(kg K)]	Calorific Value [MJ/kg]
Wood	6	1696	100	350	0.15	1360	14.4
Cardboard	0.1	1450	39.8	427	0.061	1400	13.5
Plywood	6	1774	400	150	0.13	2500	17
PVC	71	657	55.03	391	0.185	900	41
Rubber (tire)	600	1911	8000	315	1.85	1880	35

Table 1 presents the criteria in the order shown in the previous Section. C1, C2, and C3 are considered useful because they take into account the emission of harmful gases that affect human health. In contrast, the other criteria, C4, C5, C6, and C7, which take combustion into account, are declared useless in the first case. Alternatives related to materials are marked with *Aj* (*j = 1, …,5*). After converting the qualitative attributes into quantitative ones, the decision matrix with assigned weighting coefficients is shown in Table 2.

Table 2. Decision matrix (CASE 1)

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Unit of measure	**[mg/g]**	**[mg/g]**	**[kg/m^3]**	**[°C]**	**[W/mK]**	**[J/(kg K)]**	**[MJ/kg]**
Goal	**min**	**min**	**min**	**max**	**min**	**max**	**min**
	Beneficial			**Non-Beneficial**			
Weights	0.2	0.2	0.2	0.1	0.1	0.1	0.1
A1	6	1696	100	350	14.4	1360	0.15
A2	0.1	1450	3.8	427	13.5	1400	0.061
A3	6	1774	400	150	17	2500	0.13
A4	71	657	55.03	391	41	900	0.185
A5	600	1911	8000	315	35	1880	1.85

Identically, the parameters for case 2 can be determined when the decision matrix is replaced, so parameters C4, C5, C6, and C7 are considered useful, and the other criteria, C1, C2, and C3, are considered useless.

Table 3. Tubular representation of obtained weight coefficients w_{ei} and w_{ci}

Case 1			**Case 2**	
w_{ei}	**Rank**		w_{ci}	**Rank**
0.14821	3		0.19179	4
0.13642	4		0.20419	3
0.15195	2		0.21666	2
0.11238	5		0.23213	1
0.45105	1		0.15523	5

RESULTS AND DISCUSSION

Each of the materials presented in Table 1 occupies two racks, so the total number of racks in the warehouse is 10; that is, there can be a maximum of 1200 transport units in the warehouse. In practice, it is rarely the case that the warehouse is filled to 100%, and so testing the effectiveness of the proposed method is carried by varying the layout of the transport units in the racks so that the total percentage of the warehouse is filled to a maximum of 70%, with the rule that the percentage share of each of material should be equal, i.e., 20% of the total number of transport units. In this way, each rack contains 168 transport units.

To confirm the functionality of the method and the comparative presentation of the results, the coordinates X, Y, Z, and the vector r were calculated for the following variants of warehouse filling:
- Variant 1: The first three racks on the left side of the warehouse are completely emptied and the filling of the warehouse with the remaining 840 transport units starts from rack number 4;
- Variant 2: The last three racks on the right side of the warehouse are completely emptied and the filling of the warehouse with the remaining 840 transport units starts from rack number 1;
- Variant 3: The content of each of the racks on the upper front side is reduced by 30%;
- Variant 4: The content of each of the racks on the lower front side is reduced by 30%;
- Variant 5: The content of each of the racks in the uppermost rows is reduced by 30%;
- Variant 6: The content of each of the racks is reduced by 30% in the initial lower rows;
- Variant 7: The content of each of the racks is reduced by 30% and the arrangement of transport units within the racks is carried out randomly.

Based on the obtained coordinates and using a three-dimensional model of a high-bay warehouse, two spheres that define potential fire risk zones were generated (Figure 3). The mentioned spheres represent the space that is considered vulnerable in terms of fire and which includes normal and random variants of material distribution within the space of the observed high-bay warehouse.

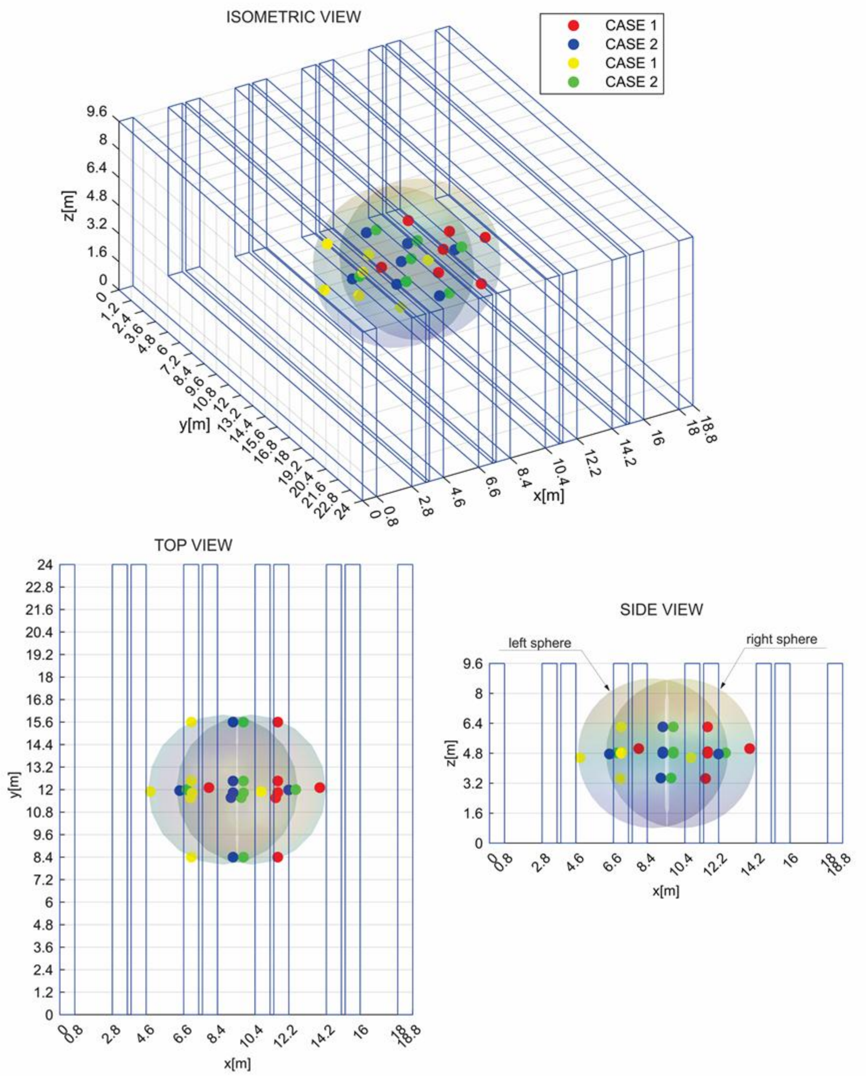

Fig. 3. Graphic representation of the fire risk zones in the warehouse with isometric view, top view, and side view.

CONCLUSION

A method for risk assessment and the determination of potential fire hazard zones in high-bay warehouses is presented in this paper. Concerning existing methods related to risk assessment in warehouses, the proposed method is based on weight coefficients related to the type of material being stored, the percentage share of storage units, as well as parameters related to the structure and configuration of the warehouse. Weight coefficients related to the type of material represent input parameters in the process of simulation and the determination of potential fire hazard zones. They are determined by a multi-criteria decision-making process using the COPRAS method.
Compared to other, mostly two-dimensional methods, this method enables simple data acquisition in the form of data tables and the generation of a three-dimensional model of the warehouse, which contains spatial points that define potential risk zones. By incorporating the mentioned spatial points within the 3D model of the high-bay warehouse, a sphere is obtained, whose radius represents the critical area of the risk of fire. The results obtained by the proposed method can be a good basis during the planning and design of the warehouse, the layout of the objects, and also when designing the appropriate fire protection and evacuation systems in the warehouse.

ACKNOWLEDGEMENT

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GIS AND REMOTE SENSING IN FOREST FIRE ANALYSIS IN SERBIA

Review paper

Natalija Nikolić[1] Jovana Čugalj[2*], Vesna Drakulović[2]
[1]Faculty of Sciences, University of Novi Sad, Novi Sad, Serbia
[2] Technical Faculty "Mihajlo Pupin" Zrenjanin, University of Novi Sad, Serbia

Abstract: This paper represents a review of papers that analyze forest fires in Serbia via GIS and remote sensing data. Forest fires are a hazard that could threat to the environment, and especially protected areas. GIS has great possibilities for analyzing spatial data, such as satellite images obtained by remote sensing methods. By using different data, it is possible to get more information about the extent of damage caused by forest fires, but also data about which areas are more threatened by forest fires than others. This shows the importance of GIS in forest fire analysis and that research on this topic should be continued.
Key words: forest fire, hazards, gis, remote sensing, serbia

INTRODUCTION

Since ancient times, human kind has begun to modify space according to its needs. In recent history, this process has been further accelerated by intensive industrialization, urbanization and deforestation. All this has led to changes in the Earth's climate. The humanity is now struggling with various challenges, which have arisen as a consequence of overexploitation of the planet's resources - droughts, forest fires, flash floods, landslides [1]...

Forest fires, also known as wildfires, are uncontrolled fires that spread rapidly across forested landscapes, often fueled by dry vegetation, strong winds, and extreme weather conditions. These fires play a complex role in ecosystems, acting both as a natural disturbance that can facilitate ecological renewal and as a destructive force that threatens biodiversity, air quality, and human settlements. The frequency and intensity of forest fires have increased in recent decades, largely due to climate change and anthropogenic factors, such as deforestation and land use changes [2].

Many research show that forest fire will become more frequent and more severe in Mediterranean region, including the Balkan penninsula and Serbia [3-5]. Around the third of Serbia is covered in forests - 31.1%. During the heatwaves from 2007 to 2012 more than 1000 wildfires were recorded [2]. From 2012 to 2016, there were 414 wildfires recorded [6]. The average annual temperature in Serbia is estimated to rise for 1℃ in the near future (until 2035). Along with that, drought periods will become longer and the risk from forest fires occuring will increase [7].

The consequences of forest fires can be fatal for the environment. Protected areas are especially at risk, given that they are often the habitats of a large number of living creatures. After a fire, it is necessary to invest a lot of financial resources and time to restore the destroyed ecosystem. Oftenly these processes are not carried out and nature is left to restore itself over time. Losses are often irreparable, at least immediately after the fire. Because of this, it is very important to have records on the occurrence of fires in the country, as well as data on the danger of certain areas, especially protected ones [6,7].

In recent times using geographic information systems (GIS) and remote sensing data has become one of the main methods for mapping, modelling and analyzing forest fire patterns, vegetation changes, burn severity, post-fire vegetation recovery time [6]… This paper explores the use of GIS and remote sensing in analyzing forest fires in Serbia in order to determine which areas of Serbia have been covered by research so far and to determine what is yet to be done.

[2] Corresponding author,jovana.cugalj@tfzr.rs, ORCID: https://orcid.org/0009-0002-7257-7936
[3]vesna.drakulovic@tfzr.rs, ORCID: https://orcid.org/0009-0007-1796-7946

BRIEF INTRODUCTION TO GIS AND REMOTE SENSING

GIS can be defined in numerous ways. One of the most comprehensive definitions interprets GIS as a "computerized system capable of assembling, storing, managing, analyzing, modelling and displaying spatial information" [8]. Main components of GIS are hardware, software, data, people and applications/methods. According to [8], the workflow in GIS begins with identifying the geospatial problem. After that, the data is being acquired. That is when remote sensing data, among the other data, is found and used. Remote sensing refers to the science and technology of acquiring information about objects, areas, or phenomena from a distance, typically using sensors mounted on satellites or aircraft. Remote sensing data consists of observations collected by sensors that detect electromagnetic radiation across various wavelengths, such as visible light, infrared, and microwave. This data is typically captured in the form of digital images or spectral signatures, where each pixel represents a measure of energy reflected or emitted from a specific area. One of the most common uses of remote sensing data is for environmental parameter monitoring based on physical models [9]. After acquiring and converting data into a readable format, the data is georeferenced and set in the needed coordinate system. When all the necessary data is gathered, the analyses are determined and then conducted [8]. Schematized remote sensing data acquisition and processing is shown in Fig. 1.

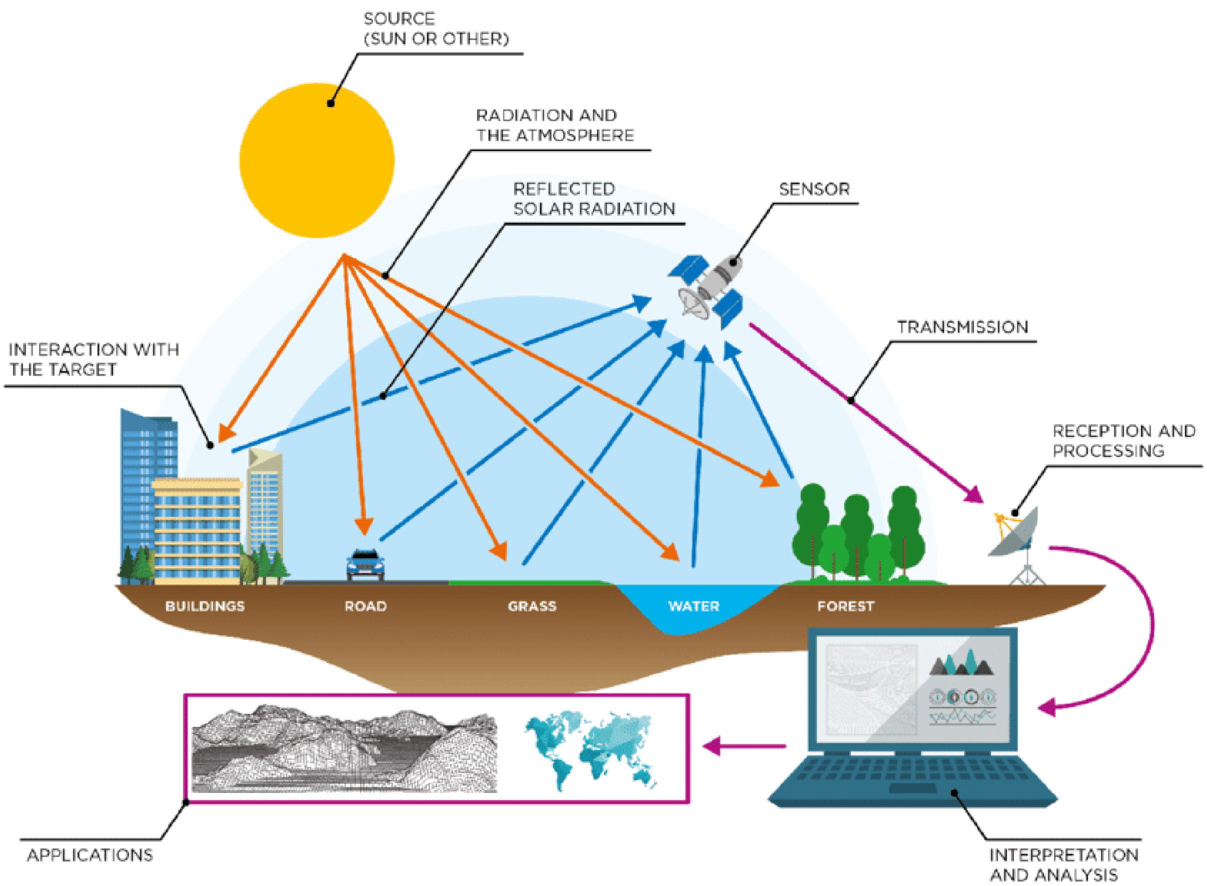

Fig. 1. *Remote sensing and GIS, [10]*

Four main elements of data acquisition in remote sensing are also shown in the Fig. 1. Those are: electromagnetic radiation, light source, sensor and target [10]. Most of the data used in scientific reseach in Serbia was generated by Landsat and Sentinel satellites. Landsat satellites are a series of Earth observation missions jointly managed by NASA and the U.S. Geological Survey, providing long-term, continuous satellite imagery since 1972 for monitoring land use, climate change, and natural resources. Sentinel satellites, part of the European Union's Copernicus program, offer high-resolution imagery and data for environmental monitoring, disaster response, and land management, with a focus on multispectral and radar imaging capabilities. Another frequently used data source is MODIS (Moderate Resolution Imaging Spectroradiometer). It is an advanced sensor aboard NASA's Terra and Aqua satellites, designed to capture data across 36 spectral bands with a wide swath, providing near-global coverage every 1-2 days.

FOREST FIRE ANALYSIS IN SERBIA

Google Scholar search of scientific papers found 11 papers [1,2,6,7,11-17] that use GIS and remote sensing to study forest fires in Serbia. Of these 11, 6 [2,12-15,17] were written and published before 2020, and 5 [1,6,7,11,16] in and after 2020. The oldest paper is from 2013, and the newest from 2022. Three papers [11-13] use a period of 13 or more years for analysis, and two [6,14] use a period of less than 8 years. Three papers [2,15,17] compare data from two different years. Three papers [1,7,16] analyze terrain susceptibility to forest fires and do not use time frames for analysis.
As for the area where the research was conducted, three papers each analyze area of Eastern [1,11,12] and Southwestern [1,2,15] Serbia. Two papers [14,17] were written for the area of the northern province and one paper [16] for the south of Serbia. Two papers [6,13] deal with the study of forest fires for the territory of the entire country. Of all these works, four were done for the area of some protected territory - two for the National Park "Tara" [2,15], one for Nature Park “Golija” [7] and one for the municipality of Beočin, which territorially belongs to the National Park "Fruška gora" [17].
The many studies use Landsat satellite imagery for research purposes [2,11,12,14,17], with only two study use Sentinel imagery [6,7]. Additionally, MODIS and Corine Land Cover (CLC) datasets have been more extensively used [2,11,13]. These datasets, derived from remote sensing technologies, enable the calculation of various indices for environmental and land-use analysis. Some of them are NDVI (Normalized Difference Vegetation Index) [15], NBR (Normalized Burn Ratio) [12,15], dNBR (differenced NBR) [15] and BSI (Bare Soil Index) [7]. NDVI is used to assess vegetation health by comparing the near-infrared (NIR) and red (RED) bands. NBR is applied to detect burned areas and is calculated using the near-infrared (NIR) and shortwave infrared (SWIR) bands. dNBR quantifies the severity of fire damage by calculating the difference between pre- and post-fire NBR values. BSI is used to identify and monitor bare soil areas by utilizing the blue, red, NIR, and SWIR bands.
Other data that was used in these papers depend on the methods that were used to assess the forest fires. Papers that analyze terrain susceptibility to forest fires [1,7,16] also use CLC data, slope and aspect from Digital Elevation Models (DEM), road distance and distance from settlements and buildings. Forest fires susceptibility indes is calculated according to the formula:

$$RC = 7VT + 5(S + A) + 3(DR + DS) \quad (1)$$

where: RC - forest fires susceptibility index, VT - vegetation type index (CLC), S - slope index (DEM), A - aspects index, DR - road distance index and DS - settlements and buildings distance index. This is done by GIS software, by applying the formula on the appropriately made raster files for all of the indices.
Other used methods are: logistic regression [11], random forest method [2,11] and numerous statistical methods (Fire radiative power (FRP), Fire Radiative Energy (FRE), Hot spot analysis (Global Moran’s I, Cluster and Outlier analysis using Anselin Local Moran’s I)) [13]. In GIS, logistic regression is used to model the probability of a spatial event or phenomenon based on spatial predictors, by linking the occurrence of the event to environmental or geographic variables. Random forest is a machine learning technique applied in GIS for tasks such as land cover classification, spatial pattern recognition, and predictive mapping, utilizing an ensemble of decision trees to handle large datasets and complex spatial relationships with high accuracy. In GIS, Fire Radiative Power (FRP) measures the rate at which a fire releases energy into the atmosphere, derived from satellite observations, and is

used to assess fire intensity in near-real-time. Fire Radiative Energy (FRE) represents the total energy emitted by a fire over its duration and is used to estimate the amount of biomass burned and atmospheric emissions. Hot Spot Analysis includes methods like Global Moran's I, which measures the overall spatial autocorrelation of fire events, indicating whether fire occurrences are clustered, dispersed, or randomly distributed. Cluster and Outlier Analysis using Anselin Local Moran's I identifies specific clusters of high or low fire activity and outliers, providing localized patterns of fire occurrences for targeted intervention and analysis.
Two papers use, among other things, data from local governments in order to obtain the most complete situation on the ground. The paper [14] uses precipitation data from the Republic Hydrometeorological Service of Serbia to compare the relationship between droughts and fire risk. The paper [17] compares which types of land cover were covered by fires and to what extent. Data on land cover were obtained from Landsat satellite imagery, and areas where there was a fire from local governments.

DISCUSSION

Based on the previously analyzed scientific works, it can be determined that there are a large number of ways to examine forest fires. Thanks to the achievements of remote sensing, it is possible to study forest fires from a distance, rather than from the field, which significantly reduces the cost and time required for spatial analysis. On the other hand, the accuracy of satellite images depends on which images are used, and for greater accuracy it is necessary to invest a large amount of resources.
In Serbia, initial efforts in the analysis of forest fires have been undertaken, though there remains significant potential for further research. A small number of works have been written about protected areas, which are also the most threatened in the event of forest fires. The increasing risk and vulnerability of landscapes to forest fires, driven by climate change, requires continued study. Developing a comprehensive map of fire-prone areas across the country would be beneficial, followed by the implementation of sensor networks to facilitate rapid detection and response to fire events.

CONCLUSION

Forest fires pose a significant threat to the environment, with climate change exacerbating the risk, particularly in the Balkan region. GIS and remote sensing technologies are increasingly utilized for analyzing both the impacts of forest fires and terrain susceptibility to such events. In Serbia, scientific research on this topic has been conducted, covering extensive areas of the country and employing various methods and data types. However, further research is essential to develop a comprehensive understanding of fire risk across the entire country and to address these challenges in the most efficient manner. Special attention should be paid to protected areas and their best possible protection in the event of a forest fire.

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PTE DISTRIBUTION FACTOR AS AN INDICATOR OF URBAN SOIL POLLUTION

Research paper

Aleksandra Mihailović[1], Jordana Ninkov[2], Selena Samardžić[3], Savka Adamović[4], Robert Lakatoš[5], Sofija M. Forkapić[6], Tomas Nemeš[7]

[1,3,4,5,7]University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia,

[2]Institute of Field and Vegetable Crops, National Institute of the Republic of Serbia Maksima Gorkog 30, Novi Sad, Serbia

[6]University of Novi Sad, Faculty of Sciences, Novi Sad, Serbia

Abstract: This paper examines the distribution of potentially toxic elements (PTEs) among various soil particle sizes, with a focus on Fluvisol soils in Novi Sad, Serbia, which are distinguished for their high sand content. Potentially toxic elements (PTEs), as As, Co, Cr, Cu, Mn, Ni, and Pb were analyzed in urban soil in the vicinity of major roads and distribution factors (DF) were calculated. Urban soil was initially collected as bulk samples and then separated into seven distinct particle size fractions through wet sieving. Based on the obtained results, the highest DF values were observed in the finest fraction (< 25 μm), followed by larger fractions (500-1000 μm), while the lowest values were found in the medium-sized particles (125-250 μm). Considering the predominant presence of sand as larger particle in urban soils worldwide, it is important to include coarser fractions in the risk assessment for the urban environment.

Key words: urban soil, potentially toxic elements, particle size distribution

INTRODUCTION

Potentially toxic elements (PTEs), particularly those from anthropogenic sources, accumulate in fine urban soil fractions, posing health risks through inhalation, ingestion, or skin contact. Various studies have examined PTE content in urban soil or road sediments, [1, 2, 3]. Most research indicates that PTEs preferentially bind to finer soil particles, such as clay minerals, due to their larger surface area per unit mass and negative surface charge, [4, 5]. Li et al., [6] note that the highest bioaccessibility of PTEs is not always observed in the finest soil fractions, as significant variations in pollutant distribution occur across different soil types. The urban soils are under strong anthropogenic influence due to diverse human activities, resulting in a distinct change in their nature characteristics. Major degradation processes affecting urban soils are compaction, sealing, element enrichment, and contamination, [7]. Urban soils typically have a higher proportion of coarser fractions for two main reasons. Large cities historically developed near rivers and coastal regions. These regions, formed from fluvial, beach, and offshore deposits, naturally have a higher sand content due to their geological origins, [8]. Another factor could be the addition of man-made materials, such as concrete and bricks, into urban soils, [7]. While PTEs are known to bind primarily with fine particles, coarser sediment fractions also pose an environmental risk due to their greater mass and prevalence in urban soils. Most research has focused on the risk of PTEs in fine particles from a health perspective, but it's important to consider larger particles as well, as they can diffuse pollutants throughout the urban environment. This study aims to explore PTE distribution in various particle size fractions within Fluvisol soils in Novi Sad, Serbia, particularly near busy roads where elevated PTE concentrations have been previously noted, [9, 10].

[1]Corresponding author, zandra@uns.ac.rs, ORCID: https://orcid.org/0000-0002-8965-1226
[2]jordana.ninkov@nsseme.com, ORCID: https://orcid.org/0000-0003-4148-0453
[3]selena@uns.ac.rs, ORCID: https://orcid.org/0000-0003-2578-7412
[4]adamovicsavka@uns.ac.rs, ORCID: https://orcid.org/0000-0003-1649-4482
[5]laki@uns.ac.rs, ORCID: https://orcid.org/0000-0002-8206-7692
[6]sofija@df.uns.ac.rs, ORCID: https://orcid.org/0000-0001-8066-9852
[7]nemes.tomas@yahoo.com, ORCID: https://orcid.org/0000-0001-8261-5743

MATERIAL AND METHODS

Study area and soil sampling

The study was carried out at four sites within the urban areas of Novi Sad, Serbia. This region is entirely composed of Holocene alluvial deposits from the Danube River's fluvial activity. The native soil type in Novi Sad is classified as Fluvisol according to both the soil map and WRB classification, [11, 12].Composite samples, averaging 10 to 15 individual samples each from a 0-10 cm depth, were collected with a soil probe from an area of about 50 m^2. The study involved analyzing four bulk soil samples, which were divided into seven particle size fractions, resulting in a total of 32 samples analyzed (4 bulk samples plus 28 fractions).

Soil texture and fractionation

Particle size distribution was assessed for the < 2 mm fraction using the pipette method [13]. The size fractions were classified as clay (< 2 µm), silt (2-20 µm), fine sand (20-200 µm), and coarse sand (200-2000 µm). Soil particles were separated into seven fractions from four soil samples using the wet sieving method, based on procedures by Cambardella and Elliot [14] and Six et al. [15]. Initially, 100 g soil samples were immersed in deionized water to separate water-resistant aggregates. The soil was then sieved through mesh sizes of 1000 µm, 500 µm, 250 µm, 125 µm, 50 µm, and 25 µm. The number of sieve immersions decreased from 25 to 15 as the fraction size decreased. The resulting particle sizes were expressed as a percentage of the total aggregate mass.

Measurement of PTE levels

PTE levels were determined in four bulk samples and their seven corresponding fractions, resulting in 32 samples. The total concentrations of As, Co, Cr, Cu, Mn, Ni, Pb and Zn were analysed after microwave digestion of soil samples in concentrated HNO_3 and H_2O_2 (5 HNO_3:1 H_2O_2, and 1:50 solid:solution ratio) by stepwise heating up to 180°C using a Milestone ETHOS1 for 55 min. The concentration of the elements in prepared samples was determined by ICP-OES (Vista Pro-Axial, Varian) by the U.S. EPA Method 200.7:2001.

The distribution factor (DF), as an important contamination index, reveals the proportion of the observed element’s concentration within an individual fraction concerning its concentration in the bulk sample, [16]:

$$DF = \frac{X_{fraction}}{X_{bulk}} \quad (1)$$

where $X_{fraction}$ and X_{bulk} represent element concentrations in mg/kg in the specific fraction and the initial (“bulk”) soil sample, respectively. Values of the factor > 1 indicate enrichment of the particular fraction with the investigated element.

RESULTS AND DISCUSSION

The soil texture of the initial bulk samples reveals a predominance of fine sand, followed by coarse sand (Table 1). These two major fractions together comprise 62 to 88% of the total sample composition, consistent with the typical characteristics of the Fluvisol soil type found in the study area [11, 12].

Table 1. *Soil texture of bulk samples*

Sample	Clay < 2 (μm)	Silt 2 - 20 (μm)	Fine sand 20 - 200 (μm)	Coarse sand 200 - 2000 (μm)
1	16.5	21.8	51.1	10.5
2	9.1	13.2	44.7	33.1
3	10.2	14.7	48.0	27.1
4	3.6	8.3	42.6	45.5
Mean ± SD	9.85 ±5.29	14.50 ±5.58	46.6 ±3.73	29.05 ±14.55

Figure 1 presents the mean mass percentages of various fractions obtained from wet sieving of bulk samples (1-4). The data showed that the particle mass distribution across the seven grain size fractions is similar for samples 2, 3, and 4. The largest mass fractions were found in the 50-125 μm, 125-250 μm, and 250-500 μm ranges, accounting for 65-75% of the total sample mass. These results are consistent with previous research by Luo et al. [16] and Ljung et al. [4], where most of the total mass was also composed of particles within the 50-500 μm range. The smallest mass fractions were observed in the finest (< 25 μm; 25-50 μm) and the coarsest (500-1000 μm; >1000 μm) fractions. Sample 1 exhibits a different particle size distribution compared to the other three samples, with the < 25 μm fraction making up a significant 15%. The highest mass percentage was found in the 50-125 μm fraction, around 20%, while the remaining fractions show a fairly uniform distribution, each ranging between 10-15%. A comparison with the data in Table 1 reveals that sample 1 is characterized by a higher clay content and a lower proportion of coarse sand.

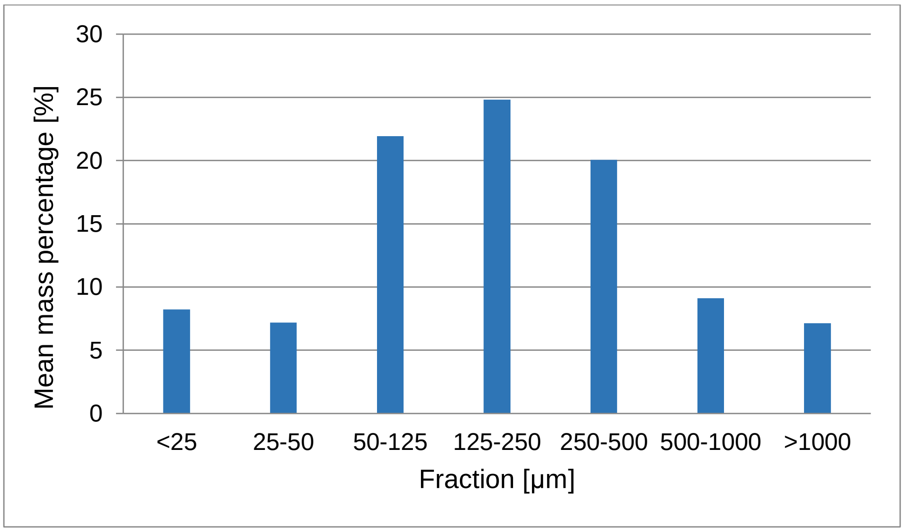

Fig. 1. *Mean mass percentage of fractions in soil samples*

PTE levels within different soil fractions are presented in Table 2. Overall, the element concentrations in these fractions are higher than those in the bulk samples, highlighting the uneven distribution of these elements across various soil fractions. Qin et al. [17] and Gong et al. [18] found that element concentrations generally increase as particle size decreases. Similarly, Luo et al. [16] reported higher PTE levels in the clay (< 2 μm), fine silt (2-10 μm), and fine sand (50-100 μm) fractions of urban soils in Hong Kong compared to bulk samples. In our study, PTEs were most concentrated in the <25 μm fraction, with concentrations decreasing as particle size increased up to 125-250 μm. PTE levels then rose in the 250-500 μm fraction but remained below those in the finest fraction.

In addition to the accumulation of PTEs in the smallest fractions (< 50 μm), a marked increase in concentration is evident in the coarse sand fractions (> 500 μm). This finding aligns with existing literature and is explained by the higher organic matter content in the larger particle sizes [19].This phenomenon can be explained by the accumulation of PTEs in both fine and coarse aggregates, influenced by several complex factors. These include the initial adsorption of newly introduced PTEs by coarse aggregates and the presence of microaggregates within larger particles [20]. From an ecological standpoint, it's important to note that the PTE concentrations in the examined soil samples are lowest in the fractions that account for the largest portion of the total mass.

Table 2. *Concentration of PTEs in mg/kg across soil fractions*

Sample		Bulk	< 25	25-50	50-125	125-250	250-500	500-1000	> 1000
			[μm]						
1	As	9.5	11.6	6.7	4.6	6.9	7.5	7.2	8.0
	Co	11.2	15.0	9.9	8.2	11.1	12.0	11.7	11.5
	Cr	39.6	66.2	33.4	28.5	36.0	40.2	43.7	42.8
	Cu	25.3	58.3	26.5	19.2	25.3	29.7	31.3	28.9
	Mn	531.4	611.7	485.6	399.8	540.5	577.1	556.1	539.3
	Ni	33.2	52.0	29.8	24.2	30.8	35.3	35.0	34.2
	Pb	85.5	56.0	52.9	44.8	66.3	85.3	62.8	54.9
	Zn	94.7	129.2	80.2	65.6	88.4	101.4	113.0	102.4
2	As	5.8	10.9	6.3	5.2	3.9	4.9	6.5	6.3
	Co	6.2	12.4	8.5	7.0	4.9	5.8	8.1	7.1
	Cr	28.1	58.9	38.4	36.2	32.1	31.1	49.8	29.3
	Cu	40.0	72.5	40.2	32.9	19.4	58.4	34.5	27.8
	Mn	417.7	870.9	775.5	680.0	396.9	393.7	587.9	503.5
	Ni	32.4	51.6	34.5	33.2	25.6	31.8	41.1	38.9
	Pb	999.1	1683.0	1580.0	1669.0	1218.0	1568.0	1048.0	768.5
	Zn	125.2	313.7	194.6	163.5	94.6	103.0	111.8	93.4
3	As	6.9	11.8	7.1	5.5	4.5	4.6	10.7	6.3
	Co	7.9	14.4	10.0	8.8	6.7	7.4	13.1	10.1
	Cr	35.5	55.8	37.8	32.0	29.2	36.8	43.1	42.8
	Cu	31.3	88.8	54.1	38.7	25.0	30.6	59.6	95.3
	Mn	414.6	854.9	652.5	568.2	429.1	439.7	919.0	908.7
	Ni	29.5	49.6	34.2	29.4	24.0	28.2	51.1	35.9
	Pb	230.1	408.4	360.3	334.9	273.3	330.4	690.0	485.8
	Zn	134.1	275.4	231.4	125.3	100.5	114.8	244.7	198.3
4	As	6.1	12.6	9.5	5.5	5.2	4.5	8.1	7.9
	Co	6.1	13.2	9.1	6.0	5.3	5.4	8.8	8.5
	Cr	44.8	66.6	55.9	38.7	29.5	29.2	46.2	45.8
	Cu	86.7	221.7	110.2	68.4	46.1	196.1	138.2	74.1
	Mn	328.6	1019.0	730.4	479.9	363.4	341.2	793.2	815.3
	Ni	34.2	58.6	44.3	29.8	50.3	30.4	48.5	47.9
	Pb	318.7	985.6	553.7	416.2	422.0	353.3	455.8	256.5
	Zn	162.7	694.8	356.1	206.6	160.9	183.4	257.6	247.0
Mean	As	7.1	11.7	7.4	5.2	5.1	5.4	8.1	7.1
	Co	7.9	13.8	9.4	7.5	7.0	7.7	10.4	9.3

	Cr	37.0	61.9	41.4	33.9	31.7	34.3	45.7	40.2
	Cu	45.8	110.3	57.8	39.8	29.0	78.7	65.9	56.5
	Mn	423.1	839.1	661.0	532.0	432.5	437.9	714.1	691.7
	Ni	32.3	53.0	35.7	29.2	32.7	31.4	43.9	39.2
	Pb	408.4	783.3	636.7	616.2	494.9	584.3	564.2	391.4
	Zn	129.2	353.3	215.6	140.3	111.1	125.7	181.8	160.3

Based on the distribution factor (DF) of potentially toxic elements, the level of PTE contamination in soil samples across various fractions was assessed. The mean values of DF are graphically represented in Figure 2. The highest DF values, notably > 1, which indicate enrichment of the particular fraction with the investigated element, were observed for the finest soil fraction (< 25 µm) and ranged from 1.64 for Ni to 2.57 Cu. In the following finest fraction (25-50 µm), all calculated DF values were also > 1, ranging from 1.1 for As and Ni to 1.64 for Mn. According to previous research conducted by Luo et al. [16], the accumulation of PTEs was most pronounced in the clay (< 2 µm) and fine silt (2-10 µm) fractions. Similar findings were obtained in the research by Yutong et al. [21]. Conversely, the DF factor values in the coarse silt fraction (10-50 µm) were generally low. Accumulation of PTEs in the soil of urban parks in Murcia (Spain) [22] also revealed accumulation in finer soil fractions with DF factor values ranging from 1.5 to 2.0 for Co, Cr, Cu, Ni, and Zn in the fraction (< 75 µm). The reason for this lies in the larger specific surface area of fine particles and their negative charge on the surface. For instance, Pb and Zn can react with the $(CO3)^{2-}$ ion, forming metal-carbonate complexes on the surface of calcite and dolomite crystals [22].

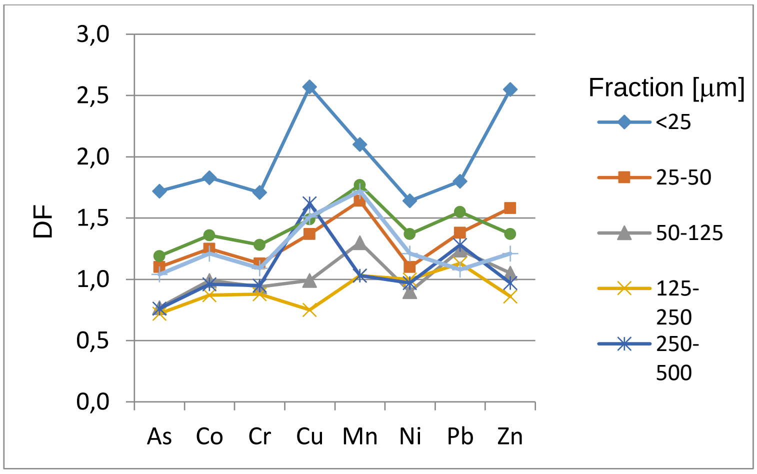

Fig 2. *Mean distribution factor (DF) values across various soil fractions*

In the present study, in the fractions 50-125; 125-250 and 250-500 µm, DF values were dominantly below 1, except for Mn and Pb (in all three fractions) and Cu (in fraction 250-500 µm). In fractions 500-1000 mm, all DF values were notably > 1, ranging from 1.2 for As to 1.8 for Mn. In the coarsest soil fraction > 1000 µm, all calculated DF values ranged from 1.0 for As to 1.7 for Mn. The highest DF values were observed in the finest soil fraction (< 25 µm), followed by the coarse fraction (500-1000 µm), while the lowest values were found in the medium fraction (125-250 µm). Gong et al. (2023) similarly determined that, in addition to the major accumulation of PTEs in the smallest fraction, there was also enrichment of PTEs (DF > 1) in larger particle size fractions for As, Cd, Cr, and Pb at specific places within the research area.

CONCLUSION

The evaluated bulk soil predominantly comprising fine and coarse sand fractions. The analysis of PTE concentrations across different soil particle sizes reveals that the finest soil fraction (< 25 μm) contains the highest concentrations, significantly surpassing those found in the bulk soil samples. bimodal distribution is observed for all elements, with significant PTE accumulation not only in the smallest fractions (< 50 μm) but also in the coarse sand fraction (> 500 μm). The calculated distribution factor (DF) proves the previously observed trend of bimodal accumulation of PTEs across soil particles. Urban soils often contain more coarse particles due to their proximity to rivers or coastal zones, where natural materials contribute to a sand-rich texture. Furthermore, the addition of man-made construction materials intensifies this specific texture in urban soils. Potentially Toxic Elements (PTEs) are typically assessed in finer particles, but our study reveals that PTEs also bind significantly to coarser particles, which pose a considerable ecological risk due to their larger mass and potential for dispersing persistent PTEs in urban environments.

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ASSESSING THE POTENTIAL OF PHOTOVOLTAICS ON AUSTRIAN RAILWAY NOISE BARRIERS: ADVANCING RENEWABLE ENERGY COMMUNITIES AND SUSTAINABLE ENERGY SOLUTIONS

Research paper

Milijana Keseric[1], Momir Tabakovic[2*]
[1] University of Applied Sciences Wiener Neustadt, Wieselburg, Austria
[2] University of Applied Science Technikum Wien, Vienna, Austria

Abstract: This paper examines the potential of utilizing photovoltaic (PV) systems on noise barriers along Austrian railway lines and their possible integration into Renewable Energy Communities. In line with Austria's climate goals to cover the entire electricity consumption from renewable sources by 2030, the study analyzes how existing infrastructures, particularly noise barriers, can be used for solar power generation without the need for additional land. The future expansion of noise barriers, projected to increase by 135 km by 2030, is also considered. Data from the Austrian Federal Railways (ÖBB) and simulations are used to forecast power yields under various geographic and technical conditions. Factors such as the orientation of noise barriers, shading effects, and module efficiency are incorporated into the calculations. The PVGIS simulation tool is utilized to account for regional variations and their impact on solar energy production.
Furthermore, the study investigates how the generated energy could be integrated into existing Renewable Energy Communities to support decentralized and community-based energy supply. A case study of a Renewable Energy Community illustrates how such a concept can be implemented. The analysis also includes a scenario-based approach, evaluating potential electricity generation across different technological development pathways. Depending on the progress of PV technologies and the expansion speed of noise barriers, annual electricity production could range from 50 to 90 GWh. Limiting factors such as physical efficiency constraints and geographical limitations are also analyzed. The study emphasizes the importance of flexible solutions, such as energy storage and optimized grid integration. The results provide a foundation for assessing the potential of PV systems on noise barriers along Austrian railway lines, as well as their integration into existing infrastructures and Renewable Energy Communities, contributing to decentralized energy supply and climate targets.
Key words: Photovoltaic Systems, Renewable Energy Communities, Climate Targets, Solar Energy Integration, Sustainable Energy Solutions, Decentralized Energy Supply

INTRODUCTION

The ongoing climate crisis caused by increased CO_2 emissions and other greenhouse gases is leading to extreme weather events and rising global temperatures, [1].To counteract these developments, urgent measures are needed to reduce CO_2 emissions. The switch to a low-CO_2 energy supply through the increased use of renewable energies plays a central role in this. Austria has set itself the ambitious goal of covering its entire electricity demand from renewable sources by 2030, [2]. A key element in achieving this goal is the expansion of photovoltaics (PV), which is considered a cost-effective and quickly realizable technology. However, there is a tension between the use of agricultural land for energy production and its importance for food production, [3]. It is therefore important to find innovative solutions for PV integration that minimize the need for agricultural land and make optimum use of existing infrastructure areas, such as noise barriers along railway lines.
One promising approach is the installation of PV systems on noise barriers along railway lines. These existing infrastructures offer great potential for converting unused areas into valuable energy generation areas. As there are several hundred kilometers of noise barriers along the Austrian railway network and further expansion is planned in the coming years, this infrastructure could contribute to achieving climate targets. The electricity generated there could be fed directly into the rail network and thus contribute directly to the decarbonization of public transport, [4].

[1]Corresponding author, milijana.keseric@gmail.com
[2]momir.tabakovic@technikum-wien.at, ORCID:https://orcid.org/0000-0002-6684-3858

In addition, the integration of PV systems into noise barriers also offers opportunities for integration into renewable energy communities. These decentralized structures promote local energy production and use, strengthen local communities and help to reduce costs. In such energy communities, residents, companies and public institutions can jointly invest in the regional energy supply, benefit from the energy generated and contribute to energy independence. By integrating PV on noise barriers into renewable energy communities, not only can local added value be increased, but an active contribution can also be made to the energy transition and the reduction of CO_2 emissions.

MATERIAL AND METHODS

The data analysis is based on information from the Austrian Federal Railways (ÖBB) on noise barriers, including length, height, and location, though lacking orientation specifics. The barriers were categorized by region, and their orientation was determined using Geographic Information Systems (GIS) and satellite images. This orientation is crucial, as it significantly impacts solar yields, forming the basis for PV yield simulations. A key component of the methodology is simulating PV yield factors using the internationally recognized PVGIS software, which calculates yields based on historical weather data and solar radiation databases. The simulation considers standard loss values, using crystalline silicon as the PV technology. These yield factors, along with orientation and coverage data, allow for the calculation of the total solar energy potential for each region.
Shading factors were also determined by analyzing five randomly selected barriers for potential obstructions using satellite imagery. A scenario analysis was conducted, assessing three paths (baseline, optimistic, and pessimistic) to predict annual electricity generation based on different technological developments and expansion rates.
Lastly, long-term yield scenarios and potential energy production were evaluated, factoring in a 1.5% annual efficiency increase due to technological advances. This growth is simulated until 2050, while physical efficiency limits are considered. Additionally, the scalability of energy production was analyzed based on potential expansion of noise barrier surfaces by 25%, 50%, and 100%.

Calculation of the effect of the measures on Austria's national climate targets

The effect of photovoltaic (PV) installations on Austria's national climate targets was calculated using Microsoft Excel. The energy generation potential from the PV systems was derived using data from the Austrian Federal Railways (ÖBB) and the software tool PVGIS, which are crucial for determining the solar yield and its contribution to the climate targets.
Step 1 evaluates the energy production potential of PV systems on noise barriers for 2023. The surface area of existing noise barriers is used, and the generated electricity is multiplied by Austria's emission factor to determine the CO2 equivalent savings. This result is then compared to Austria's national target to assess the contribution from the existing installations.
Step 2 extends this evaluation to 2030, accounting for the planned expansion of noise barriers by 135 km. The increase in available surface area for PV installations is applied to forecast the energy generation potential, and the corresponding CO2 savings are calculated using the same method as in step 1. The expansion is prioritized based on regions with the highest energy yield potential.
These calculations are applied to the entire Austrian railway noise barrier infrastructure, considering both current installations and future expansions. Data from ÖBB and projections for future surface area growth were used to determine the scale of PV deployment by 2030 and its impact on national climate goals.

Definition of the Austrian climate targets

As outlined in the introduction, Austria has committed to achieving climate neutrality by 2040. To support this objective, specific targets have been established in the National Energy and Climate Plan (NECP). The plan mandates that Austria's entire electricity consumption must come from renewable sources by 2030, significantly reducing reliance on fossil fuels and cutting greenhouse gas emissions, [5,6].
In line with Austria's contribution to the European Union's Green Deal, the greenhouse gas emissions reduction target for sectors outside the EU Emissions Trading System (EU ETS), such as transport, agriculture, and buildings, has been set to a 36% decrease compared to 2005 levels. The railway sector, being a critical infrastructure for decarbonization, plays a role in this transition, particularly through electrification and renewable energy integration, such as photovoltaic systems on noise barriers, [7].
The NECP and the targets laid out for 2030 are part of Austria's broader effort to reach climate neutrality. One of the central goals is to increase the photovoltaic capacity to 11 GW, which is expected to generate 11 TWh annually. This includes innovative solutions such as using noise barriers for PV installations, which are considered in this paper. Based on projections, the expansion of PV systems on noise barriers contributes to achieving Austria's 2030 climate targets by reducing the dependency on fossil energy and lowering CO2 emissions, [1].
To achieve the NECP goals, Austria must ensure substantial reductions in CO2 emissions across all sectors, with renewable energy technologies like photovoltaic systems playing a pivotal role in the transformation of the energy system. The measures presented in this paper align with Austria's climate targets, contributing to the reduction in greenhouse gas emissions while supporting the expansion of decentralized renewable energy production.

RESULTS AND DISCUSSION

In the basic scenario, an annual electricity production of 66.6 GWh could be achieved. The optimistic scenario, which assumes technological advances such as tandem cells with an efficiency of up to 30 %, forecasts a production of 90 GWh. In the negative scenario, which assumes less progress and limited expansion, the annual yield is 50 GWh. In addition to the electricity generated, the potential share of renewable energy communities is also taken into account. In the base scenario, 50 % of the electricity is utilized in renewable energy communities, in the optimistic scenario 60 %, and in the negative scenario 30 %.
Moreover, to the yield consideration, the contribution to achieving the Austrian climate targets also plays an important role. Depending on the scenario, the plants can cover between 0.45 % and 0.82 % of the national target. The economic dimension is also taken into account. By integrating PV systems into renewable energy communities, economic benefits can be achieved through subsidies and reduced grid costs. Integration into local and regional renewable energy communities not only contributes to the electricity supply, but also offers financial benefits for the actors involved.
The results of the scenarios are visualized in Figure 1, which shows the annual yields of the individual scenarios and illustrates the differences between the scenarios.

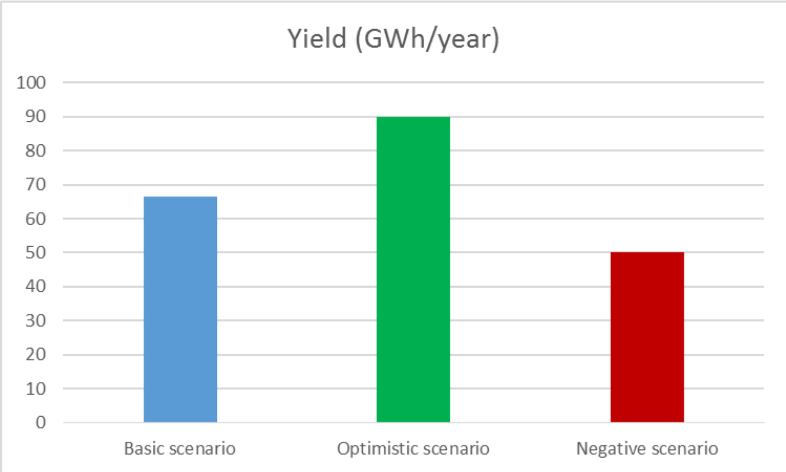

Fig. 1. *Yield (GWh/year) by scenario (own visualization)*

The calculations and visualization show that PV systems on noise barriers offer significant potential for supporting climate targets and decentralized electricity supply. Figure 2 shows the results of the three scenarios analyzed. A comparison shows that the optimistic scenario delivers the highest electricity yield at 90 GWh/year, followed by the base scenario at 66.6 GWh/year and the negative scenario at 50 GWh/year. The share of the renewable energy communities yield also varies accordingly, whereby 54 GWh/year could be fed into the renewable energy communities in the optimistic scenario. The contribution to achieving the national climate target of 11 TWh remains limited in all scenarios, with the optimistic scenario making the largest contribution at 0.82 %. The visualization thus illustrates that technological progress and greater integration into renewable energy communities are decisive factors for maximizing the potential of PV systems on noise barriers.

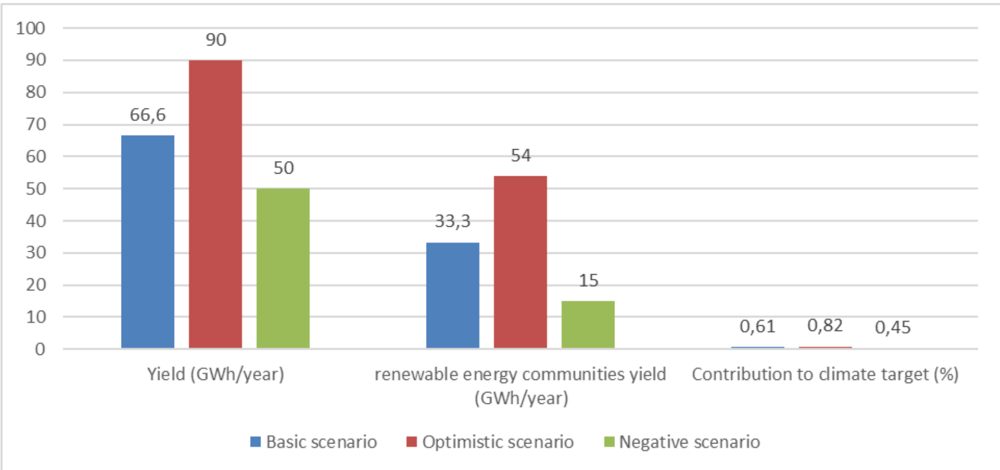

Fig. 2*. Visualization of the scenarios (own illustration)*

This work investigates long-term yield scenarios and the potential for scaling up electricity production from photovoltaic (PV) systems on noise barriers along Austrian railway lines. It acknowledges that technological and physical limits prevent indefinite production increases. Based on 2024 data, with an estimated annual production of 66.6 GWh from PV on noise barriers, a yield scenario was developed for 2050. Calculations assume a 1.5% annual efficiency increase due to technological improvements in module efficiency, reduced degradation, and better system integration. The improvement is visualized in Figure 3.

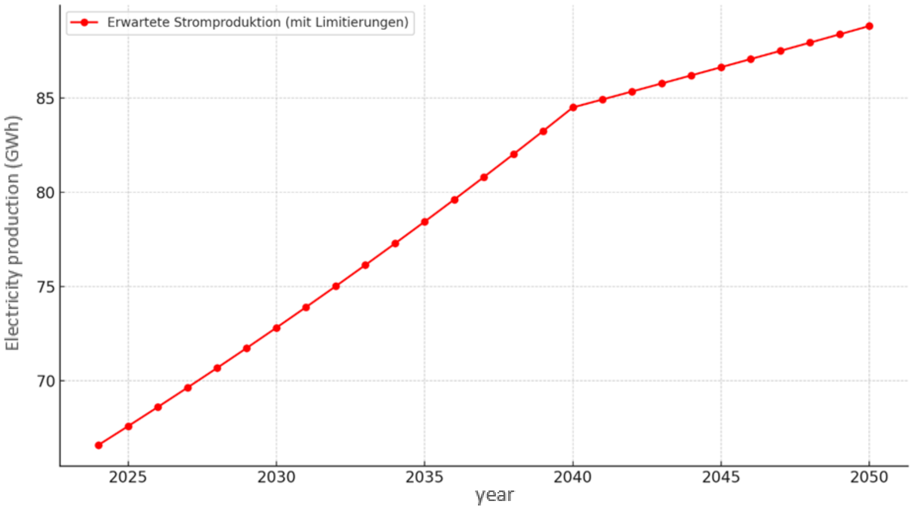

Fig. 3. *Long-term yield scenarios for PV systems on noise barriers (own illustration)*

However, as physical limits, such as the Shockley-Queisser limit (33% efficiency), are approached, the annual production growth will slow. Degradation of modules (0.5–0.8% annually) will further reduce efficiency gains. By 2040, the efficiency increase is expected to slow to 0.5% annually due to these constraints.

In addition to technological improvements, the potential to scale up production by increasing the surface area of noise barriers was analyzed, as shown in Figure 4. Three scenarios were considered: a 25%, 50%, and 100% increase in barrier surface area, corresponding to electricity production increases of 83.3 GWh, 99.9 GWh, and 133.2 GWh, respectively. However, physical and geographical limitations, such as available space and ideal orientation, mean that only 80–90% of the theoretical maximum could realistically be achieved.

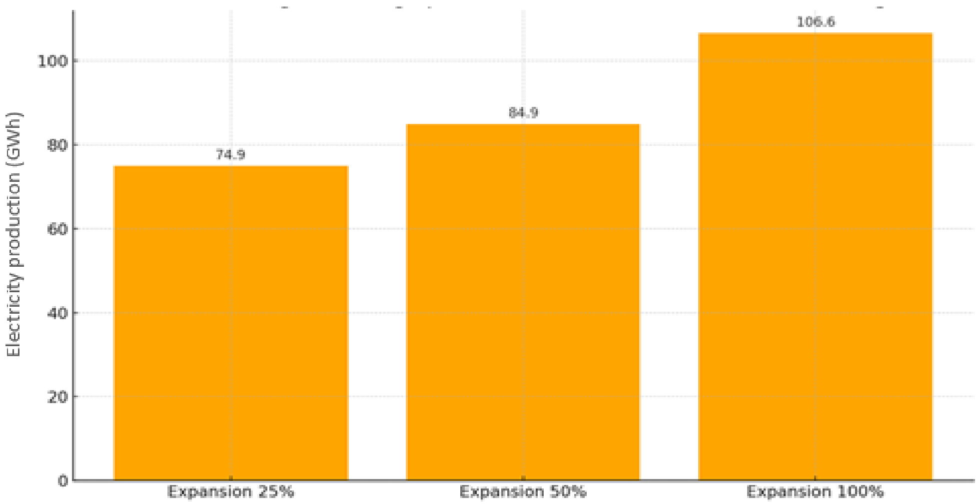

Fig. 4. Upscaling of energy production for Austria (own illustration)

This analysis offers valuable insights for the planning and implementation of Renewable Energy Communities (RECs). While PV systems on noise barriers can make a significant contribution to local energy supply, they also face limitations due to physical and infrastructural factors. Therefore, RECs should adopt strategies that include energy storage systems and optimized grid integration to ensure long-term stability and efficiency, even as growth slows over time. The location and orientation of PV systems are also critical to maximizing long-term success.

CONCLUSION

This study has demonstrated the potential for using photovoltaic (PV) systems on noise barriers along Austrian railway lines, with a particular focus on their integration into Renewable Energy Communities (RECs). By utilizing existing infrastructure, such as noise barriers, the installation of PV systems offers a viable solution to contributing to Austria's ambitious climate targets of achieving 100% renewable electricity consumption by 2030. The projected expansion of noise barriers by 135 km presents a further opportunity to harness renewable energy without the need for additional land use. Through detailed analysis, including simulations using PVGIS, the study identified potential energy yields under varying technological and geographical conditions. Depending on the scenario, annual electricity production from PV systems on noise barriers could range from 50 to 90 GWh, with integration into RECs playing a crucial role in ensuring decentralized energy production and consumption. These systems, however, face limitations such as physical efficiency constraints and geographical restrictions, which must be carefully managed to maximize their potential. The findings highlight the importance of flexible energy solutions, particularly the inclusion of energy storage and optimized grid integration, to ensure long-term stability and sustainability. Furthermore, the study underscores the economic and social benefits of integrating PV systems into RECs, including cost savings through reduced grid dependency and increased local energy independence. This approach not only aligns with Austria's climate goals but also supports the decentralized energy transition and strengthens community involvement in renewable energy production. In conclusion, while the integration of PV systems on noise barriers holds significant promise for contributing to Austria's climate targets, further efforts in technological innovation, policy support, and community engagement will be essential to fully realize their potential.

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GREENWASHING: TRICK OR THREAT

Review paper

Gordana Rendulić Davidović[1] , Milena Damnjanović[2], Nikola Radosavljević[3]
[1,2,3]University of Kragujevac, Faculty of Technical Sciences Čačak, Serbia

Abstract: In recent decades, there has been a notable increase in environmental awareness among consumers. In response to this shift, many companies have pursued to present themselves as environmentally responsible. They have adopted sustainability-focused marketing strategies to highlight their eco-friendly practices and products. However, this trend has also given rise to concerns about greenwashing, where some companies exaggerate their commitment to sustainability without making substantial changes. However, numerous claims made in this context lack validity, giving rise to what is termed greenwashing. This paper examines whether greenwashing poses a significant threat to genuine sustainability efforts or if it is simply a deceptive marketing tactic aimed at manipulating consumer perceptions.
Key words: greenwashing, marketing ethics, green marketing

INTRODUCTION

The growing awareness of environmental issues, the limited nature of natural resources, and the need to preserve the planet for future generations have resulted in the establishment of green marketing. The American Marketing Association (AMA) published one of the first definitions of green marketing, saying that it is a type of activity involving the distribution of products deemed safe for the environment, [1,2]. This is a holistic approach that involves a wide range of activities, including product modifications, adjustments in production processes, changes in packaging, management of storage, and alterations in advertising strategies. All these efforts aim to reduce the negative environmental impacts of business operations, [3]. The primary goal of green marketing is to attract consumers who are conscious of environmental issues and prefer to support products and companies that are eco-friendly. However, adopting green practices can be expensive in the short term, leading some companies to engage in unethical green marketing practices (greenwashing) as a way to expand their market without genuinely pursuing environmental objectives.
Greenwashing is usually understood as a company's attempt to deceive consumers and the public about the ecological attributes of its products, services, or operations. This involves promoting their offerings as environmentally friendly, even though these claims are often exaggerated or false, [4,5]. The term brings attention to the presentation of positive information regarding the environmental performance of a particular organization or product, while negative information is not fully revealed, [6,7].
Given the context, it's important to analize whether greenwashing is simply a strategy for companies to falsely improve their environmental image or if it represents a deeper threat to the integrity of real environmental efforts and consumer trust. Is greenwashing simply a deceptive tactic, or does it pose a broader risk to the effectiveness of green marketing and sustainable practices?

WHAT IS GREENWASHING?

The term "greenwashing" has been known since 1986 when it was first used by environmental activist Jay Westervelt, [4,8,9]. He noticed that many hotels began placing signs in rooms, stimulating guests to reuse towels in order to "save the environment." While these hotels portrayed this practice as an eco-friendly initiative, Westerveld realized that they were not taking meaningful steps to preserve the environment, their true goal was to cut costs. This kind of deceptive environmental claim became symbol of greenwashing. Since then, the topic of greenwashing has become highly relevant, and the number of studies on the subject has grown significantly.

[1]Corresponding author, gordana.rendulic@ftn.kg.ac.rs

Although the term has been in use for a long time, there is no generally accepted definition due to its interdisciplinary nature, [9]. Specifically, greenwashing is associated with corporate sustainability, ecology, social and economic issues.
The Oxford English Dictionary defines greenwashing as "false or incomplete information by an organization to present an environmentally responsible public image", [4,8], and this is one of the most cited definitions. According to Terra Choice, company that specializes in environmental marketing and consulting, greenwashing is is defined as “the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service”, [8]. Furthermore, according to [9] and [4], the understanding of greenwashing is incomplete without considering the role of accusations made by third parties. These accusations often assert that an organization has participated in unlawful or unethical practices.
The phenomenon of greenwashing has been examined by scholars across a wide range of disciplines, including business, economics, social sciences, environmental management, and law [8]. Each field contributes its own perspective and insights, highlighting the complexity and multifaceted nature of greenwashing.
One group of authors [4] describe greenwashing as a type of selective disclosure in which a company strategically withholds negative information about its environmental practices. This involves not revealing or minimizing any negative details regarding the company's environmental impact. Instead, the company highlights and promotes positive aspects of its environmental performance, such as showcasing green initiatives or sustainability efforts. The company aims to create a favorable impression of its environmental responsibility, even though it has not made significant improvements or changes to its actual environmental practices. This selective approach to communication allows the company to project an image of ecological responsibility while concealing undesirable truths about its environmental impact.
Some authors link greenwashing to decoupling behavior, where companies advertise specific actions or initiatives but, in practice, engage in entirely different activities. According to [7] greenwashing involves decoupling behaviors that present symbolic environmental protection actions without actual commitment or action, aimed at reducing public pressure and avoiding conflict with stakeholders.
The third group of researchers highlights that greenwashing is viewed as a pragmatic concept [4], with each stakeholder interpreting it based on the personal advantages they might gain from it. For example, consumers may interpret greenwashing in light of their desire for environmentally friendly products. Investors may look at greenwashing to see how it affects a company's financial health, determining if the company's environmental claims influence its ability to succeed.

Types of greenwashing

According to [4], greenwashing refers to the practice of deceiving consumers by providing false or exaggerated information about a company's environmental practices or sustainability efforts. This misleading behavior can occur at two levels, [4,8]:

- at the organizational level, where the company presents itself as being environmentally responsible without actually making meaningful changes, or
- at the product or service level, where the company overstates the environmental benefits of a particular product or service, giving the impression that it is more eco-friendly than it truly is.

Acording to [4], there is two main types of greenwashing in the literature:

- claim greenwashing and
- executional greenwashing.

Most research focuses on claim greenwashing, which involves misleading claims about the environmental benefits of a product or service. This type of greenwashing is analyzed thoroughly in multiple studies. On the other hand, executional greenwashing, which refers to the actual implementation of environmental practices within a company, has been less frequently studied.

In [4] and [9] autors identify three types of greenwashed advertising:

- false claims - when company provides incorrect information about the environmental advantages of their product or service,
- omissions of important information – when companies withhold key details that would help consumers evaluate the accuracy of their claims, and
- vague or ambiguous terms – when companies use vague or broad language about environmental benefits, misleading consumers about the true eco-friendliness of their product or service.

In [4] autors systematized the literature and identified two typologies of green claims:

- claim type and
- claim deceptiveness.

Each of this two typologies involves five typological categories that is presented in Table 1. This table categorizes different types of deceptive environmental claims made by companies, highlighting how each claim is oriented and the specific form of deception involved. Product-oriented claims often use vague or ambiguous language, while process-oriented claims may omit important details. Image-oriented claims can involve outright falsehoods, and claims labeled as 'environmental facts' frequently combine multiple deceptive strategies. In some cases, a combination of deceptive tactics is deemed acceptable, further complicating the identification of misleading environmental claims.

Table 1. *Typologies of green claims*

Claim type	**Claim deceptiveness**
Product orientation	Vague/ambiguous
Process orientation	Omission
Image orientation	False/outright lie
Environmental fact	Combination two or more of the categories above
Combination two or more of the categories above	Acceptable

Firm-level greenwashing refers to misleading practices at the organizational level, where a company creates a deceptive image of its overall environmental responsibility. This involve, [4,9]:

- practices where companies falsely portray themselves as environmentally responsible while continuing harmful practices,
- exaggerated or inflated environmental claims in advertisements that don't reflect the company's actual practices,
- using environmental issues for political or promotional gains,
- claiming compliance with laws as proof of environmental responsibility, and
- vague or unclear environmental reporting.

GREENWASHING AS THREAT

Greenwashing is a serious threat to both consumers and the community. It impacts economic, social, and environmental aspects of business. This practice questions the transparency and responsibility of companies that promote their products or services as eco-friendly, even though they do not meet real sustainability standards. This practice undermines the transparency and accountability of companies promoting their products or services as eco-friendly, despite failing to meet true sustainability standards. Greenwashing damages consumer trust, affects the market for sustainable products, and harms genuinely sustainable companies, [10]. Greenwashing involves misleading stakeholders about a company's environmental practices. Companies often selectively share positive information while hiding negative details. This can erode employees' trust and decrease their connection to the company, causing negative reactions, [11].

Greenwashing misleads consumers who want to make environmentally responsible choices. Instead of buying products that really help protect the environment, consumers often unknowingly support companies that use unethical practices to appear "green." This deception weakens consumer trust in green initiatives and sustainable products. Misleading eco-advertising confuses consumers and makes it harder for them to make informed buying decisions, [10]. This confusion, lowers consumers' perception of risk but also raises their doubts about real eco-friendly claims.

Greenwashing undermines the market for sustainable products because it allows companies that do not invest in genuine green initiatives to take up market space and resources at the expense of truly sustainable businesses. Autors in [11] emphasize that this practice makes it difficult for consumers to distinguish between products that genuinely contribute to sustainability and those that are the result of deception. When false claims receive the same level of attention as genuine environmental initiatives, it obstructs competition for companies that dedicate resources to real ecological improvements.

Deceptive environmental advertising by corporations is a practice that is widespread among large companies. This practice involves efforts to disguise environmental violations by making claims about eco-friendliness. As a result, there is a disconnect between the positive environmental image that the company presents and its actual poor performance. This discrepancy can create the impression that the company is improving its social reputation. To improve their environmental image, some companies resort to unethical tactics. They may falsify images or forge certifications in order to avoid inspection from environmental regulators. This type of communication is misleading and can deceive stakeholders. Ultimately, it may constitute a form of fake environmental reporting, especially in projects that hold significant importance for the broader community, [11].

Autors in [12] explain that governments and project owners have set high environmental goals. The economic costs of meeting these goals are also very high. Achieving significant environmental objectives can lead to increased costs. This creates a paradox between environmental sustainability and economic success. As a result, company may choose unethical behaviors. They might do this to superficially meet environmental goals while keeping costs low. Such actions can pose potential threats to the environment, as well as to the health and safety of consumers and society.

Greenwashing also poses a serious threat to companies that genuinely work on sustainability. According to [9] these companies may lose their competitive edge as consumers become skeptical of all environmental claims. Greenwashing not only undermines the efforts of these companies but also creates an unfair market competition, as unethical companies benefit from false claims without making real investments in sustainability. In addition to deceiving consumers and undermining the market, greenwashing has broader environmental and social consequences. Corporations that engage in this practice often hide real environmental violations or unethical business practices, which can lead to significant ecological and health impacts on communities. For example, falsifying certificates regarding environmental standards or misrepresenting environmental achievements can jeopardize the health of people and ecosystems, as noted in [10].

Greenwash does not only have a directly negative effect on green purchase intention, but also have an indirectly negative effect on it via green confusion and green perceived risk. This can also affect consumer trust, making it more difficult to distinguish sustainable products from false claims and undermining genuine green initiatives. Companies should decrease their greenwash behaviors and should not only claim their "greenness" but also show the proof of their green products. These policies would reduce customer confusion and risk, [13].

But greenwashing can also have serious consequences for company as loss of consumer trust which is hard to rebuild, lost partnership opportunities after public greenwashing scandal. Brands that misrepresent their sustainability efforts can face "greenwashing litigation," a specific type of false advertising lawsuit, [14]. The financial implications of these lawsuits highlight the importance of accurately representing sustainable practices and corporate social responsibility.

Greenwashing poses a significant threat by misleading consumers and undermines the efforts of genuinely sustainable companies. For consumers, greenwashing can create a false sense of environmental security. When companies misrepresent their sustainability efforts, consumers may unknowingly support businesses that do not align with their ecological values, leading to misplaced trust and dissatisfaction.

GREENWASHING AS TRICK

Greenwashing is a deceptive practice where companies mislead consumers about their environmental efforts. It creates the illusion of sustainability while masking harmful practices.

Consumer behavior refers to the actions exhibited by a consumer at the time of purchase. In today's world, there is an increasing need for consumers to be informed about the sustainable aspects that should be considered when purchasing products labeled as sustainable. Consumers who choose sustainable or eco-friendly options may be influenced by their surroundings or by what is involved in their daily lives.

Organizations often employ "greenwashing" techniques to take advantage of the benefits associated with a green image while lacking ethical practices, [15].

The Terra Choice Group has identified seven distinct categories, or "sins" of greenwashing practices that companies often engage in to mislead consumers about the environmental friendliness of their products or services. These categories are, [4,8]:

- hidden choice - occurs when a product or service is presented as environmentally friendly based on a limited set of attributes, while neglecting other critical environmental factors that are equally important,
- lie - making completely false claims about the environmental benefits of a product or service, deceiving consumers about its true nature,
- no evidence - refers to situations where an environmental claim is made but cannot be easily verified or lacks certification, leaving consumers without the means to validate the claim,
- inaccuracy - poorly defined or overly broad statements regarding a product or service, which can mislead consumers due to their vague nature,
- irrelevance - claim may be technically true but irrelevant to consumers, such as stating that a product does not contain a certain harmful substance when that substance is already banned by law,
- lesser of two evils - occurs when a statement about a product or service is accurate but still results in environmental harm, leading consumers to believe they are making a better choice when they are not,
- false labels - this involves using images, colors, or terminology typically associated with environmental responsibility, such as green hues or the word eco, to suggest that a product or service is more environmentally friendly than it truly is.

These sins range from misleading half-truths to outright lies and highlight common tactics businesses may use to deceive consumers, [16,4,6]. They also simplify the process for consumers to identify instances of greenwashing at the product level, [17].

In addition to these sins, [6] identified seven "varieties of greenwashing" which include concepts such as "selective disclosure", "vague green claims and policies", and "dubious labels and certifications". These categories align with those proposed by the TerraChoice Group [in 4] but also introduce new varieties, which include:

- partnerships and endorsements with NGOs - which may give a false sense of credibility,
- ineffective public volunteer programs - which do little to improve environmental performance,
- false narrative or speech - which misrepresents a company's environmental efforts; and
- misleading visual images - which visually misrepresent the product's environmental impact.

Together, these frameworks provide a comprehensive understanding of how companies engage in greenwashing, emphasizing the importance of transparency and accountability in environmental claims.

CONCLUSION

In recent decades, environmental awareness has increased among consumers and the general public. As a result, companies have pursued to present themselves as environmentally responsible. This shift has led to more marketing strategies focused on sustainability, where businesses highlight their commitment to eco-friendly practices. However, many claims made in these campaigns lack real validity. This practice, known as greenwashing, involves organizations exaggerating or misrepresenting their environmental efforts to gain consumer trust and market share.

The implications of greenwashing are significant and multifaceted. On one hand, it raises questions about the integrity of corporate sustainability claims, undermining the efforts of genuinely committed organizations striving for authentic environmental practices. On the other hand, it can lead consumers to develop skepticism towards all sustainability claims, potentially harming both consumers and truly sustainable businesses.

Greenwashing represents a serious threat as it can deceive consumers into believing that they are supporting environmentally responsible products and companies. Instead of promoting genuine sustainable solutions, businesses often focus on maintaining a favorable image rather than implementing real changes. This approach undermines efforts to genuinely protect the environment. Consequently, greenwashing poses a significant risk to ecological justice and sustainability.

To avoid the practice of greenwashing, it is necessary to ensure transparency in reporting and communication regarding environmental practices at both local and global levels. Consumers need to be informed about how to recognize greenwashing and provided with guidelines for making responsible decisions. Government institutions and authorities should establish clear, strict, and unambiguous regulations regarding environmental claims to ensure corporate accountability.

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PREDICTION OF LANDFILL FIRE AND ENVIRONMENTAL IMPACT HAZARD ZONES: CASE STUDY OF THE SANITARY LANDFILL IN PIROT

Research paper

Lidija Milošević[1], Emina Mihajlović[2], Amelija Đorđević[3], Jelena Malenović Nikolić[4]
[1,2,3,4]University of Niš, Faculty of Occupational safety in Niš, Niš

Abstract: The onset of landfill fires is only possible in the presence of oxygen and an ignition source, as well as flammable material, which is commonly found in the deposited waste and landfill gas. This paper focuses on predicting emissions of methane, one of the dominant flammable components at the regional sanitary landfill in Pirot, Serbia. Based on these predictions, a prediction of hazardous and safe zones during the outbreak of landfill fires and explosions has been made, which is important with regard to occupational safety and health.
Key words: sanitary landfill, landfill fire, methane, hazardous zones

INTRODUCTION

According to 2024 data from the Environmental Protection Agency, there are currently 12 sanitary landfills (10 regional and 2 local), 129 non-sanitary landfills, and 2,526 illegal dumpsites within the Republic of Serbia, [1].
At 11 sanitary landfills, including nine regional and two local landfills, a total of 558,568 tonnes were deposited in 2020, while 2.4 million tonnes of waste were deposited from 2016 to 2020. With the number of sanitary landfills increasing to 12, 1,294,126 tonnes of municipal waste were deposited in 2022, out of the total 3 million tonnes of municipal waste generated, [2,3]. The projected amount of generated municipal waste in 2030 is expected to be around 3.5 million tonnes.
Considering that 50-80% of deposited waste consists of flammable components and landfill gas produced during waste decomposition, which contains 50-60% flammable methane, one of the basic conditions for fire outbreak is constantly fulfilled at landfills. To manage the risk of landfill fires, both sanitary and non-sanitary landfills are monitored for landfill gas emissions and deposited waste. Landfill gas monitoring is conducted using gas wells, with special attention given to monitoring methane alongside other landfill gas components.

MATERIAL AND METHODS

Characteristics of "Muntina Padina" regional sanitary landfill in Pirot

The regional sanitary landfill in Pirot is located on favorable terrain, 4.5 km from Pirot. It is situated in a natural valley, at an altitude of 420-480 meters. The general slope of the terrain is 12.8% in the northeast direction. The landfill complex, which operates since 2013, including access roads, supporting facilities, landfill body, and protective belt, covers an area of 159,897.67 m². The sanitary area for daily waste disposal stretches across 84,160 m², with a landfill capacity of 1,242,710 m³, corresponding to a disposal period of 20 years. The operational platform contains the following facilities: a gate with a ramp, a guardhouse, the staff building, a truck scale, a vehicle washing and disinfection facility, a sand trap with an oil and grease separator, a parking space for dirty vehicles, a parking space for clean vehicles, and a transformer substation. The landfill receives municipal waste with the following composition: 50.96% public area waste, 23.2% organic waste, 6.65% construction waste, 5.78% paper, 2.82% plastic, 2.45% metal, 2.3% textile, 0.95% rubber, 0.56% ash, and 3.20% other waste, [4].

[1]Corresponding author, lidija.milosevic@zrfak.ni.ac.rs, ORCID: 0000-0002-0735-5408
[2] ORCID: https://orcid.org/0000-0003-2279-3462
[3] ORCID: https://orcid.org/0000-0002-3260-2626
[4] ORCID: https://orcid.org/0000-0002-1965-080X

Table 1 shows the amounts of deposited municipal waste for the 2016-2022 period, [3].

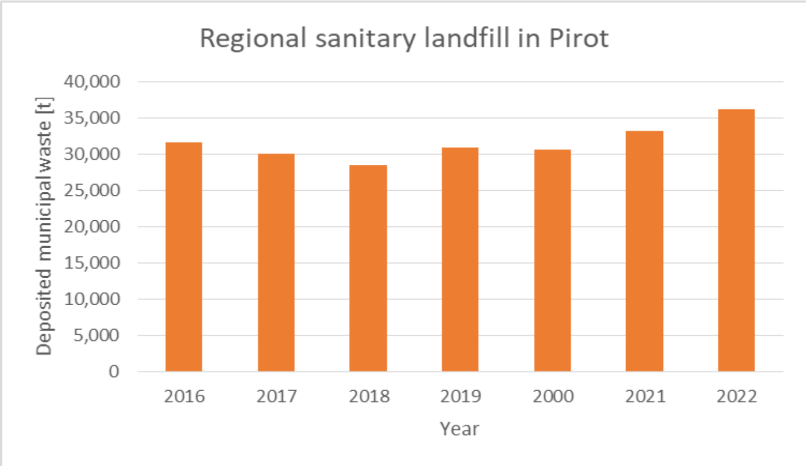

Fig. 1. *Amounts of deposited waste*

The sanitary landfill in Pirot meets all the requirements prescribed by the Regulation on Waste Disposal in Landfills, [5]. At this landfill, the operation is monitored during the active phase of waste deposition through the monitoring of meteorological parameters, surface water, leachate, landfill gas emissions, groundwater, rainfall, landfill body stability, protective layers, and pedological and geological characteristics. Fire prevention measures are implemented throughout the landfill complex, including the facilities and the landfill body itself. In accordance with legal regulations, preventive, organizational, technological, and technical fire protection measures have been taken.

Prediction of hazardous zones due to methane emissions

A landfill fire is a physicochemical process of uncontrolled combustion of flammable municipal waste deposited at the landfill, as well as flammable components of landfill gas resulting from the decomposition of municipal waste. This process occurs at landfills (sanitary, non-sanitary, and illegal dumpsites) over a certain period. The main component of landfill gas is methane, which is flammable and explosive within the flammability range of 5-16%$_{vol}$.

Using the ALOHA v.5.4.4 software package, the hazardous zone and safety zone widths were calculated for four modeled effects at maximum methane emission from the regional sanitary landfill in Pirot. The estimated methane emission value, which was determined using the LandGEM mathematical model, was used as the input parameter. [6].

The EPA model is based on LandGEM (Landfill Gas Emissions Model), which is used to calculate the amount of generated methane in a landfill according to the landfill design capacity, methane generation potential, amount of deposited municipal waste, and landfill age.

$$Q_{CH_4} = \sum_{i=1}^{n} k_{CH_4} L_0 M_i e^{-kt} \quad (1)$$

where:

Q_{CH_4} – methane emission rate [$m^3{}_{CH_4}$/y],

k_{CH_4} – methane generation constant [y^{-1}],

L_0 – methane generation potential [$m^3{}_{CH_4}$/t_{waste}],

M_i – mass of waste in ith section [t], *t* – age of the i^{th} increment or section [y^{-1}].

The prediction for the year 2024 yielded values for the maximum mass emission of methane at $1.689 \cdot 10^3$ tonnes/year, and the maximum volumetric emission of methane at $2.532 \cdot 10^6$ m^3/year. Using the ALOHA software package, a simulation was conducted for the worst-case scenario involving the sudden emission of maximum methane concentrations of 289 m^3/h at the regional sanitary landfill in Pirot, which was used as the main input data. Other data used included the location and characteristics of the regional sanitary landfill in Pirot, meteorological conditions of the city of Pirot, the type of source from which methane is emitted, and the choice of scenario to display the results, [7].

RESULTS AND DISCUSSION

Simulation results were obtained using the scenario for predicting toxic zones during the maximum methane emission from the Pirot landfill (Figure 2). The zone of maximum hazard is represented by the red zone, where the methane concentration values exceed 17,000 ppm, extending downwind from the source in a radius of up to 72 m. The lower-hazard zone is represented by the orange and yellow zones, where the methane concentration values range from 2,900 ppm to 17,000 ppm, extending in a radius of up to 181 m from the source.

Fig. 2. *Prediction of toxic zones due to maximum methane emission*

Based on the fire outbreak zone predictions, the results indicate that the maximum fire hazard zone, the red zone, extends up to 77 meters downwind from the source of hazard, where the methane concentration exceeds 30,000 ppm (60% of the lower explosive limit of methane). The yellow zone, or the lower-fire-hazard zone, extends up to 195 meters from the hazard source. Methane concentrations in this zone range from 30,000 to 5,000 ppm, or 10% of the lower explosive limit of methane. The safe zone is located at distances of over 195 meters, where the occurrence of fire and explosions is not possible.

Fig. 3. *Prediction of fire outbreak zones due to maximum methane emission*

Methane explosions result in the occurrence of explosion pressure. The predictive model shows that the methane explosion pressure zone extends up to 64 meters downwind from the source of hazard. The lower-hazard zone – the yellow zone – has the explosion pressure values between 1 and 3.5 psi.

Fig. 4. *Prediction of explosion pressure zones due to maximum methane emission*

The maximum thermal radiation hazard zone is represented by the red zone, where the intensity of thermal radiation exceeds 10 kW/m², extending circularly within a radius of up to 10 meters from the source of hazard. Due to the intensity of thermal radiation, workers present in the red zone will experience detrimental health effects, with a potentially fatal outcome after 60 seconds.

Fig. 5. *Prediction of thermal radiation zones from fire and explosion due to maximum methane emission*

CONCLUSION

The daily disposal of municipal waste at the landfill poses a potential fire hazard. The emissions of flammable and explosive methane can be one of the causes of surface and underground landfill fires.

The assessment of the maximum and lower fire hazard zones due to methane emissions and its effects on the regional sanitary landfill in Pirot shows that their propagation radii are located on the landfill body, which could lead to the outbreak and spread of landfill fires. There is a clear threat to the life and health of workers on the landfill body, but any potential fire will not pose a threat to workers in the rest of the landfill complex or to the nearby residential area and its population.

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DISTRIBUTION OF PCB CONGENERS IN ENVIRONMENTAL MEDIA

Research paper

Nada Markovic[1], Nebojsa Ralevic[2]
[1]Directorate for Inspection Affairs, Podgorica, Montenegro,
[2]University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

Abstract : Abstract: In this paper, we monitored the behavior of certain congeners of PCBs in the soil near a transformer warehouse. The research was conducted based on samples collected in and around the transformer warehouse of an industrial plant in Montenegro. At this plant, a significant number of transformers were filled with oils containing PCBs. In the 1990s, part of the oil from these transformers leaked into the ground in front of the warehouse where they were located. The behavior of PCB congeners was examined in soil samples taken from a depth of 0 to 20 cm, as well as in samples from a depth of 20 to 40 cm. Additionally, we collected soil samples from three boreholes at depths of up to 20 m, all situated in the immediate vicinity of the transformer warehouse.
The aim of this work is to collect data on the concentration levels of PCBs in the soil from the industrial waste dump. This data will be compared with results from research in other countries and will investigate the behavior of specific congeners in relation to risks to the health of employees and the surrounding population. Additionally, the study will assess the impact of the waste management system on the presence of PCBs, with the goal of improving waste management practices and enhancing environmental protection. This research was conducted for the first time at an industrial waste landfill in Montenegro, utilizing modern methods of sampling and analysis.
Key words: soil, Polychlorinated biphenyls (PCBs),dumps, waste,landfill

INTRODUCTION

The primary goals of waste management are to ensure the safety and health of people, as well as to protect and improve environmental quality. Effective waste management practices are essential for all economic and industrial activities, as well as for human activities, and are crucial for the sustainable development of modern society. Over the past century, significant amounts of organic pollutants have been generated and released into the environment throughout Montenegro due to the operation of industrial plants and improper waste handling. Decades ago, the disposal of industrial waste in landfills was the most common method of waste management in Montenegro. Polychlorinated biphenyls (PCBs) continue to pose a significant environmental challenge. For many years, Montenegro has not given adequate attention to this group of compounds regarding environmental protection, and no protective measures were implemented, resulting in substantial quantities ending up in industrial and municipal landfills, as well as in watercourses.
Experiences from both developed and developing countries have confirmed that waste dumps are significant sources of PCB emissions, contributing to the pollution of groundwater, ambient air, and soil, and negatively impacting human health. Measuring emissions and determining the spread of pollutants from landfills are key components of the research method used to identify the presence of contaminants and assess the environmental state surrounding the landfill. Persistent Organic Pollutants (POPs) are chemical substances that remain unchanged in the environment for extended periods. They can spread over large areas and, through soil, water, and air, enter the food chain, accumulating in the fatty tissues of living organisms, including humans. Their toxicity has been proven to affect both humans and animals.
PCBs are highly toxic chlorinated industrial chemicals classified as Persistent Organic Pollutants (POPs), making them some of the most hazardous substances synthesized by humans. They have garnered significant attention and research interest due to increased soil pollution in industrial areas, the intoxication of aquatic organisms, and their negative impact on both human health and the broader environment, [1,2].

[1]Corresponding author, nadamarkovic71@t-com.me, ORCID: https://orcid.org/0009-0009-8483-5622
[2]nralevic@uns.ac.rs, ORCID: https://orcid.org/0000-0002-3825-9822

CLASIFICATION OF PCB COMPOUNDS

The first molecule of PCB was synthesized in 1881, PCBs are chlorinated aromatic hydrocarbons, which are characterized by the biphenyl structure, connected two phenyl rings (C6H5)2) form a biphenyl molecule. Biphenyl contains 12 carbon atoms (C) and 10 hydrogen atoms (H), chlorine atoms can be attached to any of the ten available places, so in relation to the chemical structure, these organic compounds only differ in the place of attachment and the number of chlorine atoms for the basic the biphenyl molecule. Different representatives of PCB-s are called congeners, there are 209 congeners, of which about 130 have been most often used in technical mixtures so far, and if they have a similar chemical structure, physical and chemical properties as well as toxicity of PCB-s congeners are different, different congeners cause different health effects in the body.
About 10 compounds from this group have toxic properties. According to the IPAC nomenclature, congeners 8,18, 28, 52,101,118,138,153 and 180 are designated as representatives of the homologous series of dichlorobiphenyl, trichlorobiphenyl, tetrachlorobiphenyl, pentachlorobiphenyl, hexachlorobiphenyl and heptachlorobiphenyl, they are very significant due to their toxicity. These extremely toxic congeners have a planar structure and belong to the compounds in terms of toxicity similar to dioxins ("dioxin-like" PCBs), and their toxicity is expressed in relation to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) - the most toxic halogenated aromatic hydrocarbon, [3]. Other PCBs do not have toxicity similar to dioxins ("non-dioxin-like"), but they have a harmful effect on the body, especially harmful effects on the work of the endocrine glands, both in the case of short-term exposure to large concentrations, and in the case of long-term intake and bioaccumulation in the body, [4]. Congeners from the second group ("non-dioxin-like"), which contain from 3 to 7 chlorine atoms in their structure, can be found more often in different parts of the environment compared to other congeners and in larger quantities than the observed presence others [4], which is why they are classified in the group of so-called indicator PCBs, because their contents can indicate the degree of pollution. Indicator PCBs, in addition to 6 congeners ("non-dioxin like"), often include 1 congener similar to dioxin in terms of toxicity ("dioxin-like"), PCB 118.

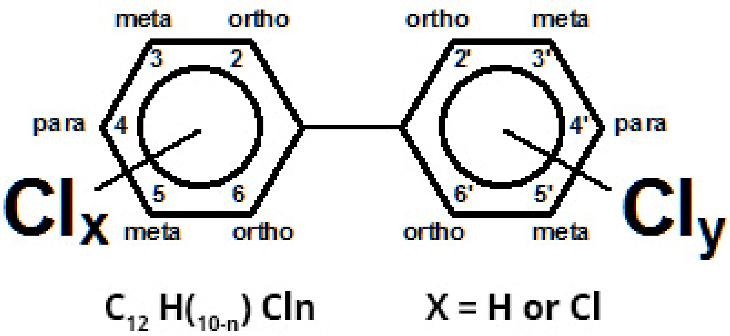

Fig. 1. *General structural formula of polychlorinated biphenyls*

PCBs are exclusively synthetic aromatic compounds, they were never used as individual compounds but always in mixtures of several chloroderivatives under various names (Arochlor, Phenchlor, Chlorphens, Delor and Kanochlor). Of the possible 209 congeners of polychlorinated biphenyls, only about 125 are found in Arochlor technical mixtures. They are very stable and persistent chemical compounds, the physical and chemical properties as well as the toxicity of PCBs congeners depend primarily on their structure, that is, on the position and number of chlorine atoms in their molecules. The greater presence of chlorine in PCB compounds practically leads to insolubility in water and greater chemical stability, they are easily adsorbed on the smallest suspended substances of organic origin.

With an increase in molecular mass, hydrophobicity increases and migration in environmental media decreases, also their washability decreases with an increase in the number of Cl-atoms in the molecule. PCBs are easily absorbed on suspended solid particles (aerosols) and bind to organic components of soil and suspended organic matter in aquatic ecosystems and sediments, the degree of adsorption increases with the number of chlorine atoms, [5].

SOURCES OF PCBS CONTAMINATION

The use of PCBs began in 1929, it is estimated that the quantities produced in the world are around 2.5 million tons. There was no production of PCBs in Montenegro, they were imported for accompanying energy equipment within the power industry, industrial, military and PTT facilities, in which they mainly served as insulating liquids, [6]. They were used in dielectric fluids, they proved to be excellent in places where the risk of fire is high, e.g. when transporting flammable products, where there are sources of heat and flammability, such as in the installations of various plants, also in cooling systems PCBs are the most frequently contaminated various equipment used in industry, in addition to equipment, demolition waste, colored materials, resins for coatings, sealing compounds, oils used in various branches of industry can also be contaminated, [7,8]. High concentration levels of PCBs were identified in the soil near old industrial waste warehouses, which was also shown in this work, then in places of former chemical industries in large industrial centers, [9].
Scientific studies conducted worldwide during the 1960s and 1970s confirmed the remarkable durability of PCBs and their negative effects on human health. As a result, the production of these compounds is prohibited in most industrialized countries, [10]. Today, the use in open systems is prohibited, and the current sources of PCBs in the environment are primarily landfills. Despite the cessation of production in several countries, PCBs remain significant pollutants of global concern. Substantial amounts are still in use, largely due to the long lifespan of equipment such as transformers. Additionally, certain quantities await disposal in storage facilities, [9,10].Material and working methods.

As part of the investigative work at the PCB warehouse, the following types of samples were taken:

Soil samples in the PCB storage area in the surface layer:

- A total of 44 soil samples were taken, of which 28 samples at a depth of 0-20 cm and 16 samples at a depth of 20-40 cm.

- Soil samples in the PCB storage area in boreholes. A total of 67 soil samples were taken 3 wells at a depth of 0-23 m.

Table 1. *Overview of the analyzes performed within the project*

Arial	Number of analyses Analysis
Analysis - land	
PCBs-ground (0-20 cm)	28 samples
PCBs-ground (20-40 cm)	16 samples
PCB-Earth, 3 wells (0-23cm)	67 samples

The analysis of soil samples for this work was conducted using the EPA 8080 A method. Sample preparation consisted of several steps: extraction, purification, and concentration of analytes. After grinding the soil to a granular consistency, extraction was initiated using a solvent mixture of hexane and dichloromethane in a 1:1 ratio. The samples were then purified with sodium sulfate. Following evaporation to a volume of 2-3 ml, the samples were washed with 2 ml of hexane and subsequently evaporated under a nitrogen stream to a final volume of 4 ml, of which 1 ml was reserved for analysis.

Extraction was performed using a solvent mixture of hexane and dichloromethane in a 1:1 ratio. A combined gas chromatograph-mass spectrometer instrument was used for the detection of PCBs in the soil, the mass spectrometer was used as a gas chromatograph detector. The gas chromatograph separates the components in the mixture, while the mass spectrometer enables the individual identification of each component. Based on the intensity of the peaks on the chromatogram, the presence of PCBs in the samples was determined by calculation based on the internal standard. The test results were compared with the maximum allowed concentration of MDK, according to the Rulebook on permitted quantities of hazardous and harmful substances in the soil and methods for their testing (Official Gazette of Montenegro 18/97). This rulebook prescribes the maximum allowed concentration of dangerous and harmful substances that can be found in the soil, for PCB-s congeners 18, 28,31, 44, 52, 101,118, 138,149, 153,180, 194 is 0.004 mg/kg of soil.

Table 2. Maximum concentrations of PCB congeners in the examined samples

	PCB 18 mg/kg	PCB28,31 mg/kg	PCB 52 mg/kg	PCB 44 mg/kg	PCB 101 mg/kg	PCB149 mg/kg	PCB118 mg/kg	PCB153 mg/kg	PCB138 mgkg	PCB180 mg/kg	PCB194 mg/kg
Soil-0-20cm	1,5	7,5	134	72	287	145	222	239	254	109	22
Soil-20-40cm	0,8	9,7	22	12	62	42	44	64	63	49	6,9
Holes 1	0,11	7,1	49	28	129	76	86	118	125	61	13
Holes 2	<0,002	18	193	85	472	302	301	345	411	165	30
Holes 3	0,26	3,1	5,4	3,9	25	24	17	32	36	18	3,6

Based on Table 2, the highest concentration of PCBs was found in PCB 101, which reached 287 mg/kg in the soil sample from 0 to 20 cm. In the soil sample from 20 to 40 cm, the most dominant congener was PCB 153, with a concentration of 64 mg/kg. In wells drilled adjacent to the transformer warehouse, PCB 101 exhibited the highest concentrations of 129 mg/kg, 472 mg/kg, and 25 mg/kg, with peak values occurring at a depth of 1-2 m. The content of dangerous and harmful substances in the soil is regulated by the Rulebook on Permitted Amounts of Hazardous and Harmful Substances in Soil in Montenegro. The maximum acceptable concentration of PCBs in agricultural soil is 0.004 mg/kg for each of the congeners: 28, 52, 101, 118, 138, 153, and 180, while the maximum permissible concentration of PCBs in industrial zones is set at 33 mg/kg.

The results of these analyses revealed that the area in and around the warehouse is highly contaminated and poses unacceptable risks to human health. The findings from this site investigation indicate that measures should be implemented to mitigate the migration of

PCB-containing oil and to address the contaminated land, thereby reducing the potential for human exposure to PCB contamination.

CONCLUSION

The process of joining the European Union and harmonizing domestic legislation with European standards necessitates the improvement of the waste management system and the implementation of continuous pollution monitoring at waste landfills.
In addition to significant systemic issues in waste management and their associated negative impacts on the environment—such as soil, groundwater, and surface water pollution, as well as risks to public health—awareness of the need to reduce waste production and ensure appropriate treatment remains insufficiently developed. The Solid Waste Management Plan, National Waste Management Policy, and the Law on Waste Management aim to address these problems. However, additional measures are necessary to make progress, including the adoption of by-laws, implementation of effective national and local waste management plans, and the construction of sanitary landfills for municipal waste as well as landfills for hazardous waste. Furthermore, establishing a comprehensive waste database and conducting awareness-raising activities about proper waste handling are essential. Stimulating recycling is crucial, especially in the context of joining the European Union, as it necessitates harmonizing domestic legislation with European standards and implementing continuous environmental monitoring.
The use of PCBs in Montenegro is legally permitted only in closed systems, such as dielectrics in transformers and capacitors. The use of PCB-containing equipment is restricted; importing such equipment is prohibited, and existing PCB-containing devices are being gradually replaced in accordance with the Stockholm Convention. In the upcoming period, it is essential to comply with the Stockholm Convention, which mandates the removal of equipment containing PCBs by 2025. Preventive measures should include the implementation of control and supervision during the importation of equipment and devices that may contain PCBs, as well as the development of a timeline for replacing existing operational equipment. This plan should consider the age of the equipment, the economic situation in Montenegro, and the European regulations governing the deadlines for replacing PCB-containing devices.

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ASSESMENT OF WATERBORNE TRANSPORT SECTOR IMPACT ON EUROPE AIR QUALITY WITH SHERPA MODEL

Research paper

Madalina Zot[1], Francisc Popescu[2], Luisa Izabel Dungan[3]
[1,2,3] University Politehnica Timisoara, Timisoara, Romania

Abstract: At European level, the EU's Joint Research Center (JRC) has developed the screening tool SHERPA (Screening for High Emission Reduction Potential on Air) to support decision-makers in assessing the potential to increase air quality through local emission reduction measures. This paper discusses the quantification of emissions and the analysis of the European maritime and road transport sector, evaluating the most polluted areas and the possibility of reducing emissions generated by water and road transport.
Key words: Sherpa, air quality, waterborne transport emissions

INTRODUCTION

In Europe, naval and road transport contribute to environmental pollution through various emissions, such as greenhouse gases, nitrogen oxides, sulfur oxides, particulate matter and other harmful substances. On air quality, human health, but also on the environment, emissions can contribute to a negative impact.

The use of fossil fuels on ships is the main source of emissions from water transport in Europe. Most ships use heavy fuel oil as fuel, having a high sulfur content and tending to emit SOx, NOx and PM. Another source of emissions for water transport can be the release of ballast water, chemicals, anti-fouling paints and accidental oil spills. All the emission sources mentioned have a negative impact on marine ecosystems and biodiversity, but also on human health who live near the coast or the riverbank.

The various policies and regulations desired to reduce emissions from water and road transport were introduced by the European Union, to reduce these problems. The Sulfur Directive (Directive 2012/33/EU) is just one of the regulations brought in, aimed at reducing the sulfur content of the fuels used by ships operating in EU waters and the Framework Directive on marine strategy, which aims to protect and restore the marine environment through various measures, including reducing emissions from ships, [1]. To deal with pollution from inland waterway transport in Europe, the EU has introduced several policies and measures. The most important of these policies is the Inland Waterway Vessel (IWV) certification system, which provides emission standards for NOx and PM emissions from inland waterway vessels. The EU has also developed the Blue Corridors project, which recommends promoting the use of LNG and other alternative fuels in inland waterway transport.

In 2020, the MARPOL Convention members decided under IMO 2020 regulation notes the reduction of the Sulphur content of fuel oil used for ships from 3.5 % to a maximum of 0.5 % by mass, [2]. At the European level, a significant decrease in sulfur oxide emissions from water transport is expected in the coming years. High transport loading capacities make inland waterway vessels considered environmentally friendly means of transport when CO_2 emissions are highlighted. However, as the main enforcements on limiting emissions levels only started in early 1990's, with limits for NOx and PM emissions, most of the marine and inland vessels in operation today are free of emission control. This is mostly due to the high life span of engines designed for marine and inland water transport and is expected that vessel fleet renewal with new diesel engines will not happen before 2040.

Trade and the connection between all the nations of Europe is represented by maritime and inland water transport, being an impactful sector. In the EU for foreign trade in goods, 90% of EU foreign trade is carried out by sea, [3].

[1]Corresponding author, francisc.popescu@upt.ro, ORCID: https://orcid.org/0000-0001-7736-0758

MATERIAL AND METHODS

Usually, to measure the impact of emissions produced by maritime and inland ships, chemical transport models are used that contain in their structure the transport of pollutants, the diffusion of pollutants and the atmospheric reactions of pollutants. Because the models need significant computing power, they are placed in limited and localized areas, from 50 to 500 km in diameter. The tool "Screening for High Emission Reduction Potentials for Air quality" (SHERPA) was created by the Joint Research Center with the aim of preventing these limitations and for the use of common calculation systems, throughout the European continent. The use of the screening tool is done through a chemical transport model, supported by statistical data received from the regulatory institutions of European countries and which provides a shorter waiting period for any dispersion of atmospheric pollutants, [4].
SHERPA uses source-receptor interaction as a basis and was created to analyze possible air quality improvements that can result from the implementation of emission reduction measures, within the stakeholder decision-making process. SHERPA is based on a simplified version of a chemical transport model and provides estimates of the concentrations of precursor pollutants, such as NOx, NMVOC, PPM, SO_2 and NH_3, in a single sector or group of activity sectors, [5]. In its component, SHERPA is made up of 3 independent models, these are source allocation, governance and scenario analysis, each focusing on dealing specifically with air quality issues.
The central formula implemented in SHERPA uses a cell-by-cell approach, with a cell spatial decision of 7x7km^2, with the availability of EU data with reference to source-receiver emission models and emission reduction scenarios. The relationship between the emission *ΔEj,k* and the concentration *ΔCi* is calculated cell by cell:

$$\Delta C_i = \sum_{j}^{Nprec} \sum_{k}^{Ncell} a_{i,j,k}^{1} \Delta E_{j,k} \quad (1)$$

Due to the fact that the coefficients $a_{i,j,k}$ are relatively approximated by a distance function, the main gain is given by its spatial flexibility:

$$a_{i,j,k} = \propto_{i,j} (1 - d_{i,k})^{-\omega^{i,j}} \quad (2)$$

In which *i* represents the grid cell where the concentration is estimated and $d_{i,k}$ represents the distance between cells *i* and *k,* [6].
The definition of areas of interest in SHERPA can be found in the European Nomenclature of Territorial Statistical Units (NUTS) and the Gridded Nomenclature for Reporting (GNFR). For this study we used the entire European territory and focused on GNFR7, Shipping, national shipping, including the inland waterways sector.

RESULTS AND DISCUSSION

The SHERPA approach is based on GWR (Geographically Weighted Regression) and local modelling approaches, methodologies who uses bell-shaped kernel functions to determine weighted regressions of input versus output variables, [7, 8, 9].
In the scenario assumed in this study we focused mainly on NMVOC, SO_2, NOx and PPM emissions generated from marine and inland shipping sector with inclusion of EMEP total emissions per sector (GNFR 7), countries (EU28 and outside) and applying automated SHERPA gridding methodologies, for the year 2022. The results obtained are presented in figures 1 to 4.

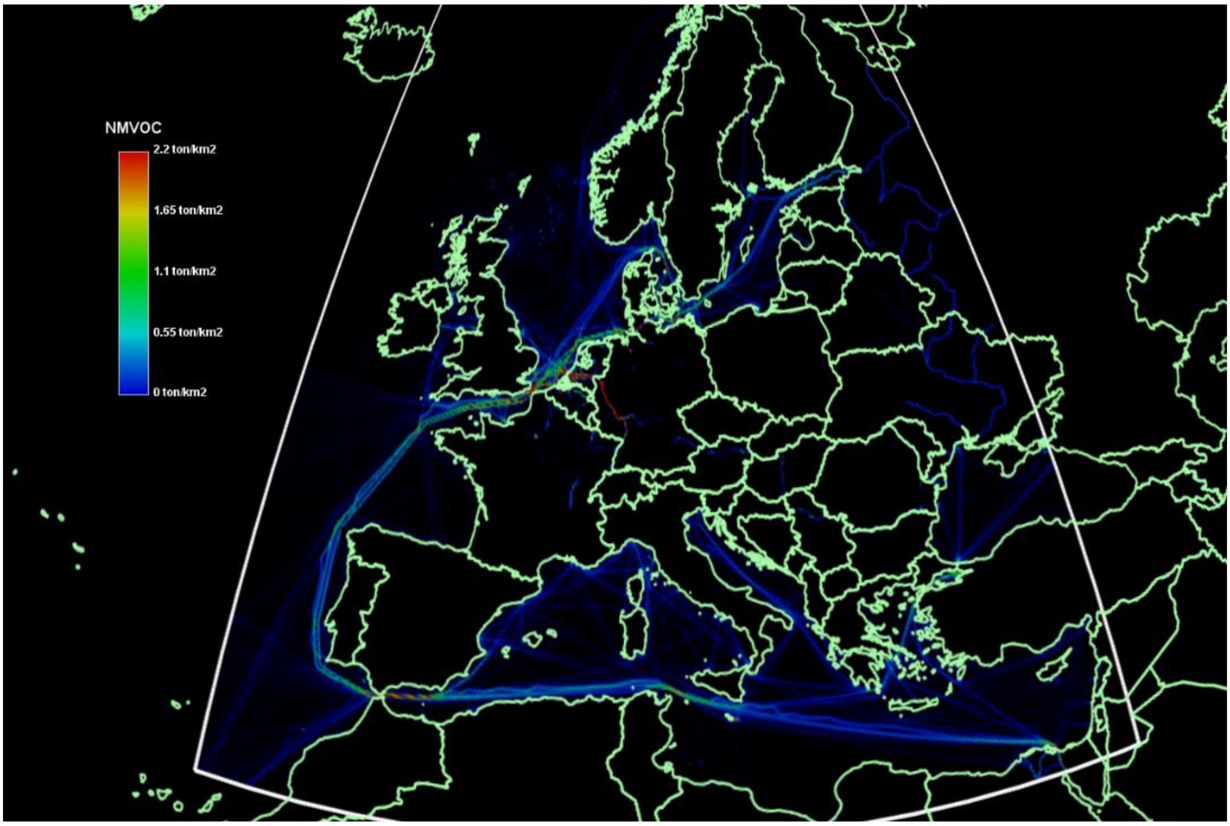

Fig.1. *Europe-region level, NMVOC annual average concentration, exclusively GNFR7 water shipping navigation transport sector*

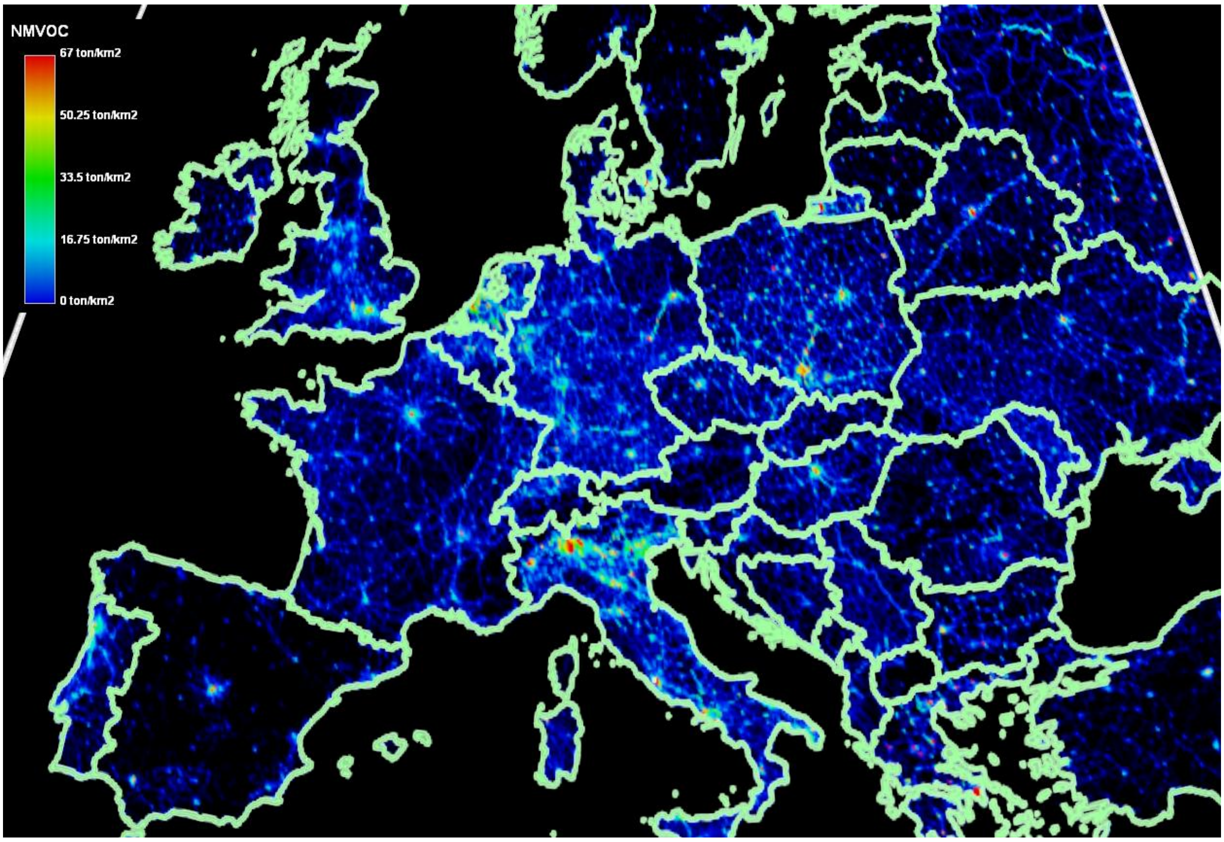

Fig.2. *Europe-region level, NMVOC annual average concentration, exclusively GNFR6 road transport sector*

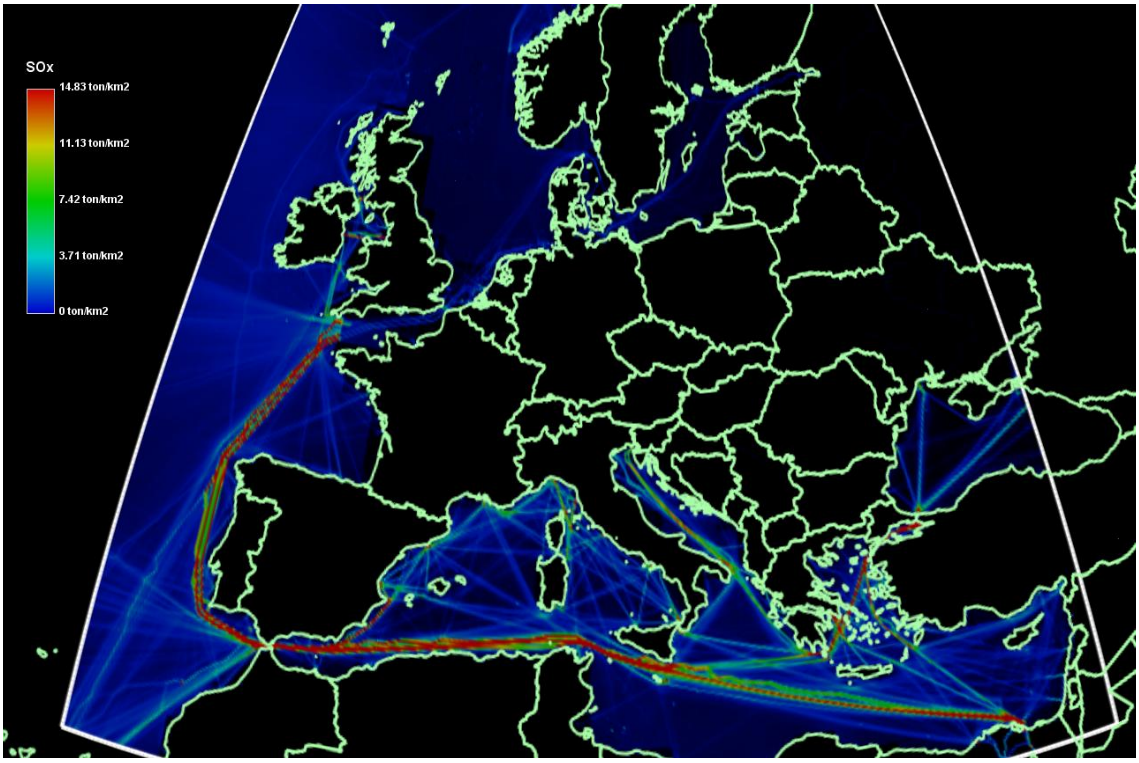

Fig. 3. *Europe-region level, SO_2 annual average concentration, exclusively GNFR7 water shipping navigation transport sector*

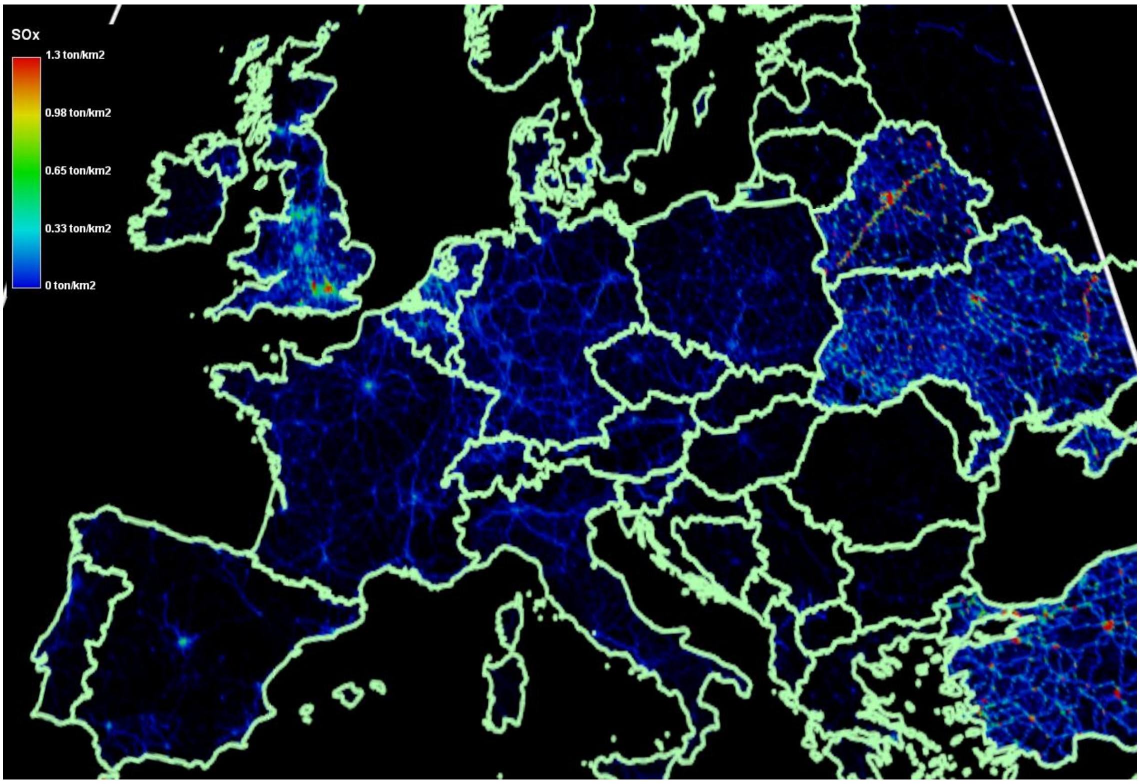

Fig. 4. *Europe-region level, SO_2 annual average concentration, exclusively GNFR6 road transport sector*

The results obtained for Figures 1 and 2 for NMVOC emissions, shows an average of 2.2 ton/km^2 for waterborne transport and up 67 t/km^2 for road transport. In case of SO_2

emissions, an average of 14 ton/km^2 for waterborne transport and 1.3 ton/km^2 for road transport are estimated.

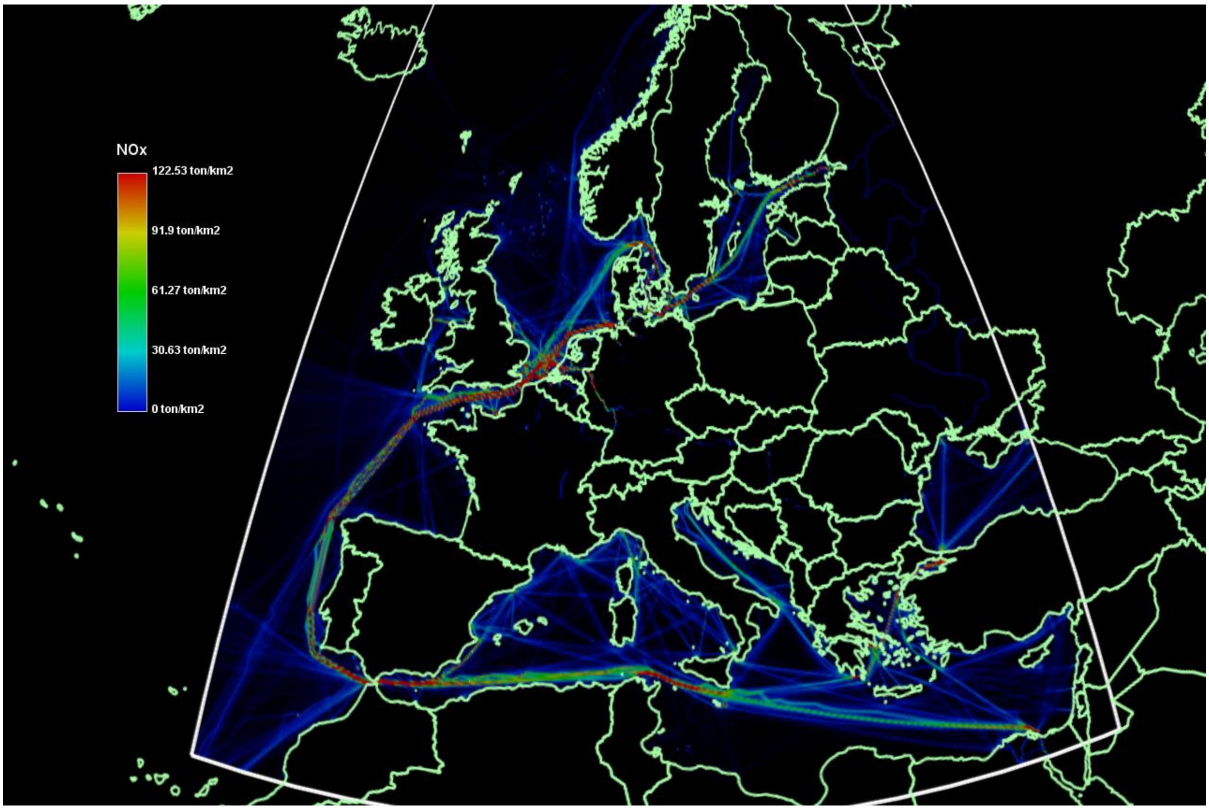

Fig. 5. *Europe-region level, NOx annual average concentration, exclusively GNFR7 water shipping navigation transport sector.*

Figure 5 presents the results obtained for NOx emissions, at maximum of 122 ton/km^2. The maxim emissions are not obtained only high traffic maritime straits (like Gibraltar or Dover straits) but also on inland waters transport, in urban areas on Rhine River in Germany and Netherlands.

CONCLUSION

The International Maritime Organization (IMO) conducted a study in 2018, which shows that the global concentration of water transport in global anthropogenic GHG emissions is around 3% in 2018 [10] by this fact there is a reduced contribution, so we can believe that maritime transport and inland water is an effective method for international transport of goods. Even if the contribution of CO_2 compared to others is low in the maritime transport sector, SO_2 and NOx emissions are relevant, with a 13% share for SO_2 and 15% for global NOx emissions, [10]. The data presented show us that naval transport, especially that on inland waters, forms a problematic source of local pollution, on land, but also in coastal areas.
Another research study that took place in France (2015-2016), [11] with direct emissions determinations on board several types of maritime and inland vessels, shows that a pusher tug emits up to 2 times more emissions. higher NOx, CO and particulate matter than Euro V trucks for 1 ton of goods transported. In this research, similar data were discovered, an example would be by using SHERPA for the GNFR6 sector (Road Transport), we noticed that emissions from road transport in Europe reached a maximum of 44 ton/km^2 compared to 122 ton/km^2 for water transport and SO_2 of 1.3 ton/km^2 compared to 14 ton/km^2 for water transport. And, the NMVOC emissions generated by road transport, 67 ton/km^2, are much higher than the 2.2 ton/km^2 found for water transport.

The European Union has focused on reducing or eliminating GHG emissions from all sectors in recent years, highlighting the energy and transport sectors. The aim of the study is to show that the SHERPA tool can ease the work of researchers and help EU decision-makers to introduce more correct strategies to reduce pollution and GHG in the geographical areas where these problems are encountered most often.

ACKNOWLEDGEMENT

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NAVIGATING TOWARDS ZERO-EMISSION DISTRICT HEATING: THE DANISH GOOD PRACTICE EXAMPLE FROM ESBJERG

Review paper

Borivoj Lj. Stepanov [1*], Zoran M. Čepić [2], Đorđije D. Doder [1]
[1] University of Novi Sad, Faculty of Technical Sciences, Department of Energy and Process Engineering, Novi Sad, Serbia
[2] University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering and Safety at work, Novi Sad, Serbia

Abstract: This document explores the transition to zero-emission district heating in Esbjerg, Denmark, highlighting the innovative practices and technologies implemented in the "Heating for the Future" project. The focus is on the integration of large-scale heat pumps, biomass systems, and advanced energy management solutions to replace traditional fossil fuel sources. With the closure of the Esbjergværket Power Plant, the project aims to achieve a sustainable energy supply by utilizing renewable resources, such as wood chips and seawater heat pumps. This study underscores the importance of transitioning to greener heating solutions while ensuring reliability and efficiency in district heating networks, ultimately contributing to Denmark's ambitious climate goals.
Key words: heat transition, heat pumps

INTRODUCTION

Heat pumps are one of the key ways to support the green transition in heating, as they utilize renewable energy sources and reduce harmful emissions. In their application, the Danes are at the forefront. The classification of large pumps by heat source is shown in Fig. 1, and Fig. 2 presents the growth of installed capacity by year [1]. Here, the focus is on large-scale heat pumps in district heating networks.

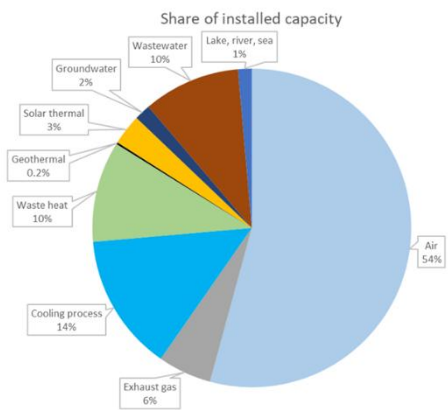


Fig. 1. *Share of heat pump units by (main) heat source.*

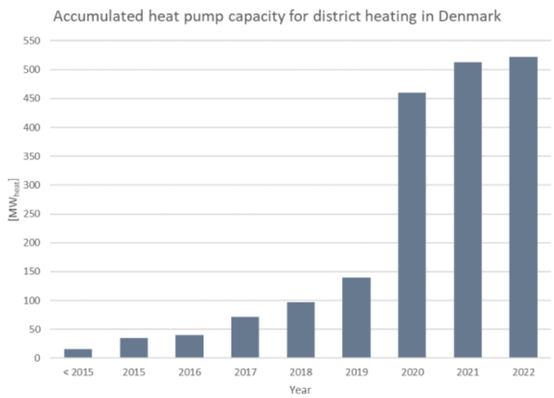


Fig. 2. *Accumulated heat pump capacity (heating) for district heating in Denmark*

The Esbjergværket Power Plant is located in Esbjerg Harbor. It was commissioned in 1943, and the current block 3 was built in 1992. It has used two types of fuel: oil and coal. The plant has produced district heating equivalent to the consumption of 210,000 households and electricity equivalent to the consumption of 100,000 households. Like Ørsted's other combined heat and power plants, it is equipped with flue gas cleaning systems that remove sulfur dioxide (SOx), nitrogen oxides (NOx), and fly ash from the exhaust. Esbjergværket's chimney is 250 meters high, making it the tallest chimney in Denmark.

[1] Corresponding author, bstep@uns.ac.rs, https://orcid.org/0000-0002-0193-8231
[2] zorancepic@uns.ac.rs, ORCID: https://orcid.org/0000-0001-5853-4767
[3] dj.doder@uns.ac.rs, ORCID: https://orcid.org/0000-0002-1489-3183

It was closed on August 31, 2024, following many prior announcements. The closure of Esbjergværket represents the final major step in Ørsted's journey toward achieving a 99 percent green share of energy production by 2025.

Fig. 3. *Ørsted shuts the power plant in Esbjerg, August 31, 2024.*

PROJECT DESCRIPTION [2]

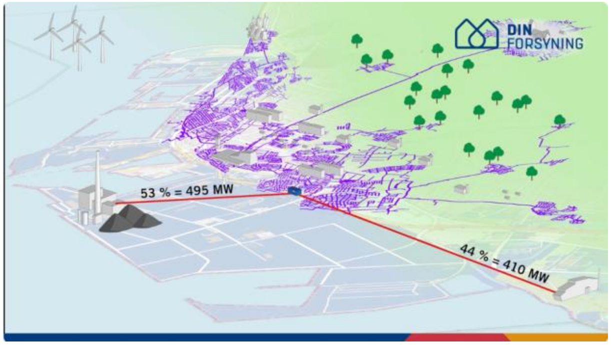


Fig. 4. *Main previous energy sources for district heating*

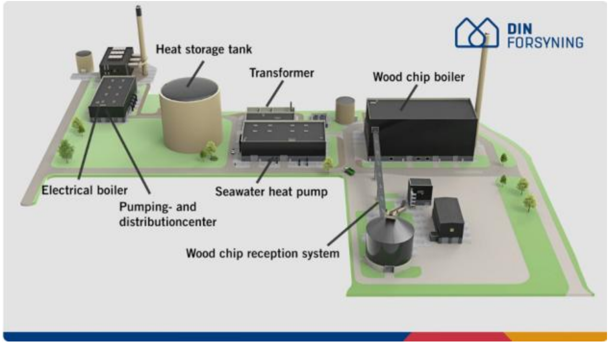


Fig. 5. *Heating for the future*

The "Heating for the Future" project, led by DIN Forsyning, focuses on developing a new heat production facility. Previously, DIN Forsyning sourced heat from two main suppliers (Fig. 4): a waste-to-energy plant and a coal-fired power station. However, the coal plant's owner chose to close it down, prompting DIN Forsyning to investigate alternative solutions. They ultimately opted to construct a new facility that will generate about half of the required heat for consumers, while the waste-to-energy plant will continue supplying the other half.
During the development of this facility, several options were evaluated, resulting in the implementation of a versatile system designed to utilize multiple heat sources. The main components (Fig. 5) include a wood chip boiler with a capacity of about 60 megawatts and a heat pump with a capacity of approximately 50 megawatts, for a combined total of 110 megawatts. An additional electrical boiler with a 40-megawatt capacity increases the overall production capacity to around 150 megawatts. However, this falls short during the coldest days, when demand can peak at 400 megawatts. To address this, peak boilers fueled by natural gas and bio-oil are incorporated as backup.

The facility comprises several essential elements, including a pumping station, an accumulator, a heat pump, a transformer, a wood boiler building, and a wood chip receiving system. Wood chips are delivered by truck, crossing a weighbridge and moving through an open area before being unloaded into the building. Access is regulated by traffic lights, and ventilation systems are in place to manage dust and odors. The wood chips undergo quality control, where foreign materials and oversized pieces are removed. Once screened, the wood chips are stored in a silo with a capacity of around 8,000 cubic meters, enough to sustain about four days of boiler operation. This setup allows for extended breaks, such as over Christmas or long weekends. The facility is designed to run without continuous staffing, with operational and maintenance personnel only present during regular business hours. The automated system requires the large storage capacity to ensure uninterrupted operation.

Wood chips are moved via a conveyor system to the boiler hall and allocated to the day silos. The wood chip boiler generates a total output of 60 megawatts, with 45 megawatts coming from the main part and an additional 15 megawatts derived from flue gas condensation. The flue gases are filtered through a fabric filter and treated with a Selective Catalytic Reduction (SCR) system to eliminate dust and nitrogen oxides. After this, the gases are cooled by an economizer and quenched with water, resulting in clean water for the district heating system and reducing reliance on other water sources.

The heat pump, one of the two primary heat-generating units, utilizes heat from the seawater drawn from the harbor in the evaporator. It comprises two identical units, each with a heat capacity of approximately 25 megawatts, and operates using CO_2 as a refrigerant. This selection was made due to its environmental advantages, as CO_2 is non-toxic in case of leaks and offers exceptional thermodynamic efficiency.

The plant receives electrical energy via two 25 MVA transformers that reduce the voltage from 60 kilovolts to 10 kilovolts. Additionally, it is equipped with harmonic filters to control grid harmonics, along with an emergency generator that can supply 2.5 megawatts during power outages. This generator guarantees the continued operation of the pumping station and backup boilers, ensuring reliability and redundancy.

A 40-meter-high tank supplies static pressure to the district heating network and holds about 40,000 cubic meters of water, which is roughly 2,500 megawatt-hours. This tank facilitates a separation between heat production and consumption, enabling optimization according to electricity prices. Its capacity is tailored to match the original coal-fired power plant's output of 400 megawatts.

At the center of the district heating facility, the pumping house oversees the distribution pumps for the four separate networks, regulating temperature and pressure to reduce network losses. The electrical boiler, which has a capacity of 40 megawatts, is mainly utilized when electricity prices are low, functioning as a backup and emergency source at other times.

Overall, this facility integrates various heat production methods and technologies to ensure a reliable and efficient supply of heat for the future.

Various scenarios

The Tab. 1 [3] outlines the energy production estimates for various proposed configurations of heat generation for Esbjerg district heating. It includes:

- S1. ESV3: Conversion of the existing Block 3 of the power plant Esbjergværket to wood pellets.
- S2. ESV4: New Block 4 of the power plant Esbjergværket with 160 MW wood chip cogeneration.
- S3. Shutting down of the power plant Esbjergværket with heat pump centered scenario: 110 MW sea water heat pump and 80 MW air to water heat pump.
- S4. Shutting down of the power plant Esbjergværket with Biomass scenario: 110 MW from wood chips, with additional configurations.

- S5. Shutting down of the power plant Esbjergværket with Heat pump + Biomass scenario - Chosen scenario: 60 MW wood chips + 50 MW hp + 20 MW wood chips + 40 MW air to water heat pump

The total energy production across all configurations sums to approximately 1,208,586 MWh. A significant share comes from heat generated by the waste incineration plant (Energnist L1). At the time of these calculations, CO_2 heat pumps were not the focus; instead, the emphasis was on heat pumps based on hydrofluoroolefin R1234ze and ammonia R717.

Table 1. *Various scenarios heat production*

		S1	S2	S3	S4	S5
Energnist L1	MWh	520.917	517.730	548.036	555.152	546.469
Esbjergværket Blok 3	MWh	686.418	0	0	0	0
Esbjergværket Blok 4	MWh	0	654.027	0	0	0
Electric boiler	MWh	480	480	480	511	480
Woodchips boiler with condensation in flue gasses	MWh	0	0	0	533.877	301.968
Woodchips boiler without condensation in flue gasses	MWh	0	0	0	77.718	41.386
Seawater heat pump (R1234ze)	MWh	0	0	134.949	0	0
Seawater heat pump (R717)	MWh	0	0	287.341	0	217.200
Air water heat pump (R717)	MWh	0	0	202.517	0	62.465
Gas boiler	MWh	914	36.312	35.323	40.990	38.618
Sum production	MWh	1.208.729	1.208.549	1.208.647	1.208.248	1.208.586

Economics

This table, Tab. 2 [3] presents a financial analysis of different heat production scenarios. The total net present value across scenarios ranges from 3,517 to 5,981 million DKK. Savings range from 1,814 to 2,464 million DKK, indicating potential benefits to the community economy, with the base scenario based on the conversion of Block 3 from coal to biomass.

Table 2. *DinForsyning - Community economy*

		S1	S2	S3	S4	S5
	Unit	NPV	NPV	NPV	NPV	NPV
Fuel costs	mill. DKK	5.119	2.782	1.920	2.113	1.956
Electricity sale/Electricity purchase	mill. DKK	-3.892	-2.266	-923	-946	-966
Operation and maintenance	mill. DKK	2.348	1.447	649	839	750
Capital costs	mill. DKK	1.791	1.588	1.483	1.086	1.175
Environmental costs	mill. DKK	132	109	59	117	90
CO_{2eq} costs	mill. DKK	558	588	624	615	618
Tax effects	mill. DKK	-75	-81	-127	-92	-106
In total	mill. DKK	5.981	4.167	3.684	3.732	3.517
Socio-economic savings	mill. DKK		1.814	2.296	2.248	2.464

The Fig. 6 depicts the district heat production and storage over the course of a year, from January to December, 2040. It illustrates various heat production sources, represented by different colored areas. Additionally, the graph features an interrupted yellow line representing Stored DH (District Heat), while the interrupted black line shows the Delivered DH (District Heat). The graph shows seasonal variations in heat production, with peaks and troughs correlating with demand, highlighting the reliance on different heat sources throughout the year.

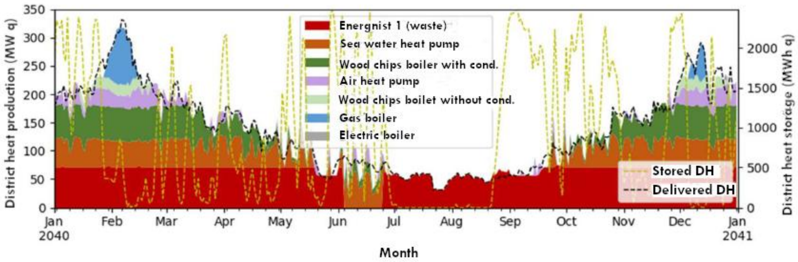


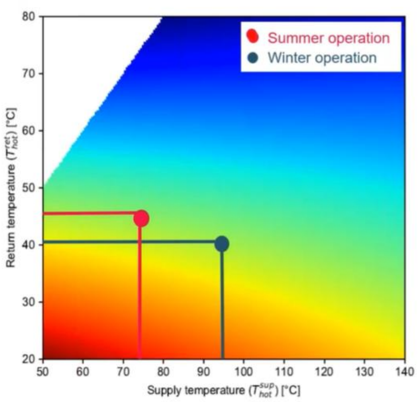
Fig. 6. *Example of annual production simulation*

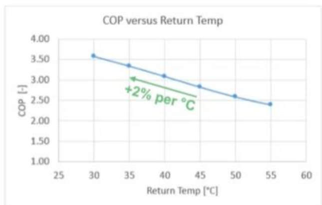
LESSONS LEARNED

Heat pumps COP

The Fig. 7 shows the relationship between the return temperature and the Coefficient of Performance (COP) of a heat pump [4]. The key information we can gather from the image is:

1. The line graph shows that as the return temperature decreases, the COP of the heat pump also increases, meaning that the heat pump operates more efficiently at lower return temperatures.
2. The blue and red dots represent the heat pump's operation mode in winter and summer conditions, respectively. Shown is a contour plot diagram that displays COP as a function of two temperatures, supply and return. Even though the supply temperature is higher in winter compared to summer, the lower return temperature during winter enables the heat pump to achieve a similar COP to that of the summer.
3. The tabular data provides the specific numerical values for COP, heat input, power consumption, and energy output at different return temperatures. Based on these data, we can see that a 10°C increase in return temperature leads to an approximately 2% increase in COP.
4. The main message of the image is that heat pumps operate more efficiently at lower return temperatures, which highlights the importance of optimizing the heating system to achieve greater energy efficiency.





*) assuming 5000 h/year
**) assuming 0.2 EUR / kWh
= average price in EU in 2022
acc. to Eurostat

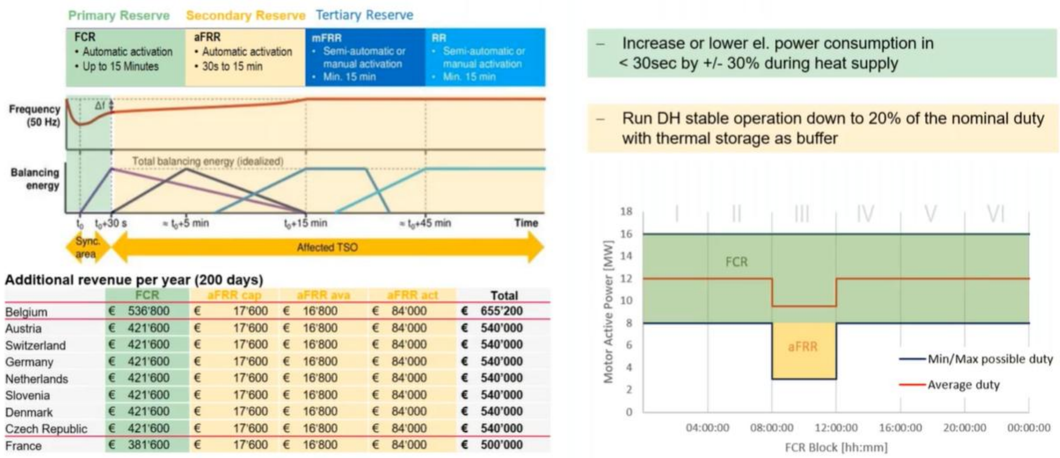
Heat duty [MW]	50	50	50	50	50	50
Supply Temp [°C]	90	90	90	90	90	90
Return Temp [°C]	**55**	**50**	**45**	**40**	**35**	**30**
COP [-]	**2.39**	**2.59**	**2.83**	**3.09**	**3.34**	**3.58**
COP Increase [%]	-	8.1%	18.1%	29.1%	39.7%	49.6%
El. Power [MWe]	20.9	19.3	17.7	16.2	15.0	14.0
El. Consumption saving per year [MWh] *	-	7'838	16'046	23'554	29'694	34'627

Fig. 7 *The impact of return temperature on heat pump efficiency*

Heat-pumps helping balancing the grid

This image, Fig. 8 provides an overview of how MAN heat pumps can help balance the electricity grid by providing fast grid balancing capabilities in under 30 seconds [4].
The key points are:

1. The image outlines the different reserve types (Primary, Secondary, Tertiary) that heat pumps can provide to help balance the grid. This includes fast frequency control reserve (FCR) that can respond in under 30 seconds, as well as automatic or manual secondary and tertiary reserves.
2. The frequency and balancing energy graphs show how heat pumps can rapidly increase or decrease their power consumption to help stabilize grid frequency fluctuations within a 30-minute window.
3. The table provides estimated additional revenue per year that heat pump owners could earn in various European countries by providing these grid balancing services, ranging from €381,600 in France to €655,200 in Belgium, where FCR generates the highest revenue.
4. The lower graphs show the power consumption profile of the different heat pump reserve types, with the FCR reserve providing the most rapid response by increasing/decreasing power by up to 30% of the nominal duty.



	FCR	aFRR cap	aFRR ava	aFRR act	Total
Belgium	€ 536'800	€ 17'600	€ 16'800	€ 84'000	€ 655'200
Austria	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Switzerland	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Germany	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Netherlands	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Slovenia	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Denmark	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
Czech Republic	€ 421'600	€ 17'600	€ 16'800	€ 84'000	€ 540'000
France	€ 381'600	€ 17'600	€ 16'800	€ 84'000	€ 500'000

Fig. 8. *MAN heat-pumps helping balancing the grid*

Biomass

There are a few key controversies surrounding the use of biomass as an energy source in Denmark:

1. Carbon neutrality concerns: There is debate around whether biomass can be truly considered carbon neutral, as the combustion of biomass still releases CO_2 into the atmosphere. Critics argue that the regrowth of biomass to reabsorb this CO_2 can take decades, making it problematic as a near-term climate solution.
2. Environmental impacts: The large-scale harvesting of biomass, such as wood pellets, has raised concerns about the sustainability of forestry practices and potential deforestation impacts, both locally and globally.
3. Efficiency and cost: Burning biomass is less efficient than other renewable energy sources like wind and solar. The costs of biomass energy can also be higher, leading to questions about its economic viability compared to other green alternatives.
4. Competing land use: Using agricultural land or forests to grow biomass feedstocks has sparked debates about tradeoffs with food production, biodiversity, and other important land uses.

5. Particulate emissions: The combustion of biomass, especially wood, can produce higher levels of particulate matter and other air pollutants compared to cleaner energy sources, raising air quality concerns.
1. These controversies have led to calls for more rigorous sustainability criteria, lifecycle assessments, and a reexamination of biomass' role within Denmark's broader renewable energy and climate strategies. The debate continues as Denmark tries to balance its renewable energy goals with environmental and economic considerations.

CONCLUSION

The Danes have long been at the forefront of heating efficiency, with a significant share of their heating coming from cogeneration, where heat is always produced alongside electricity. They have opted for the decommissioning of coal power plants, and their path to CO_2-neutral electricity production is largely based on wind turbines.
Their power plants are equipped with comprehensive environmental protection technologies, such as desulfurization systems and electrostatic filters. However, the main challenge remains CO_2 emissions, as they have not adopted carbon capture and storage (CCS) technology.
Given their green electricity from wind power, the choice of heat pumps as a heating technology is unsurprising. In terms of applying heat pumps of this capacity, Denmark is among the pioneers, approaching the technology with caution and dedication to achieve maximum efficiency once again, aiming to serve as an example of best practices.
On this path, they had to secure approval to separate electricity production from heating. They also accounted for potential volatility in the electricity market, with diversification strategies in place. In addition to these seawater heat pumps, biomass boilers, bio-oil, gas, and electric boilers have been introduced. Plans for air-source heat pumps are underway, and a thermal accumulator is already in use for energy storage.
However, the transition to 100% heat supply from heat pumps has not been fully adopted. Although biomass remains financially competitive, it does not hold a central position, yet it still forms part of the energy mix. In Denmark, there is ongoing serious debate about whether the transition should partially include biomass. To be burned, biomass must be certified and sourced from waste biomass.
Heat pump technology can be a valuable asset for grid operators, enabling fast frequency regulation and load balancing to maintain grid stability, while also providing a lucrative additional revenue stream for heat pump owners.

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IMPACT OF FUEL CONSUMPTION ON CO_2 EMISSIONS IN ROAD TRANSPORT IN EUROPEAN COUNTRIES

Research paper

Ermina Ćosović[1*], Ivan Mihajlović[2], Vesna Spasojević Brkić[3]
[1,2,3]University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia

Abstract: Given the increasing challenges posed by climate change, reducing carbon - dioxide (CO_2) emissions has become one of the key goals of the global community. Carbon – dioxide emissions are directly linked to the consumption of fossil fuels, which are used in various sectors, including transportation, industry, and energy. This research is based on conducted detailed analysis of fuel consumption in several European countries, in the period from 2011 to 2022. The results are presented through diagrams that clearly illustrate CO_2 emissions per capita, broken down by different types of fuel, allowing for better insight into their contribution to total emissions.
Key words: fuel consumption, CO_2 emissions, transportation sector

INTRODUCTION

Air pollution remains one of the key factors affecting the quality of life in urban areas, increasing the risk of health problems and negatively impacting ecosystems. To develop effective air quality management plans, it is essential to first gather accurate and comprehensive data on the level of environmental pollution.

In this context, the emission of carbon dioxide is actively playing its role in the global warming and the increase of greenhouse gas emissions. Greenhouse gas emissions are composed of almost 72% carbon dioxide, 18% methane, 9% nitrogen oxide and 1% other gases. The thorough study of carbon dioxide in the atmosphere layer shows that after the first Industrial Revolution in the year 1700, the level of carbon dioxide emission has increased by almost 30% globally. [1]

As emissions of Greenhouse Gases started rising, more attention has been given to their impact on the environment and human life which consequently increased concern about eventual natural threats which may happen in the future such as long droughts, global warming, devastating floods, and so on. These threats are caused due to the combustion of fossil fuels. With the worldwide high awareness and concern about global warming, unfortunately, the world demand for fossil fuels and the level of world GHGs emissions significantly increased over time. [2]

Carbon - dioxide emissions of recent years have grown at the highest rates ever recorded, an observed trend incompatible with stabilizing atmospheric concentrations of greenhouse gases and avoiding long-term climate change. Within this aggregate upward trend, a comparison of emissions sources proves dynamic: while industrialized countries have so far dominated historical emissions, rapid growth in energy demand of developing economies, led by China, may soon spur their absolute emissions beyond those of industrialized countries. [3]

The incentive to use public transport to higher extend is a measure focusing on the transition to a green economy as it leads to a reduction in fossil fuel spending and to a lower GHG emissions. However, in addition to the techniques and/or mechanical characteristics implemented in today's vehicles, the driver behavior is also one of the factors that affects fuel consumption and which in turn leads to increased carbon emissions in the transport sector. [4]

The choice of vehicle also influences fuel consumption, which in turn dictates the amount of CO_2 emissions.

The choice between a gasoline versus a diesel car is a key factor in a consumer's decision when purchasing a new car. Nowadays, when comparing certain important vehicle attributes, such as speed, safety, size, design or horsepower, there are hardly any substantial

[1] Corresponding author, ORCID: https://orcid.org/0009-0002-7285-2977
[2] ORCID: https://orcid.org/0000-0002-9489-8207
[3] ORCID: https://orcid.org/0000-0003-4642-3482

differences between the two types of vehicles. But in terms of fuel efficiency, diesel cars consume, on average, about 17% less fuel per kilometer than gasoline cars. [5]

METHODOLOGY

The combustion of fuel in motor vehicles leads to significant environmental pollution due to the emission of various exhaust gases. Among the most significant pollutants, in terms of the amount emitted, is carbon - dioxide (CO_2). Calculating CO_2 emissions is crucial, as the starting step, in the fight against climate change as it enables the identification of major sources of pollution, which is important for developing emission reduction strategies. Additionally, this process raises citizens' awareness of the impact of their daily activities on the environment, which can encourage behavioral changes, such as reducing the use of motor vehicles. Ultimately, precise measurement of CO_2 emissions aids in effective traffic planning, allowing authorities to develop sustainable traffic policies that reduce congestion and air pollution, thereby improving the overall quality of life in urban areas. In this study, CO_2 emissions were calculated using the equation that was modified in relation to the equation used in the paper [6]:

$$E(CO_2) = \frac{E_f(CO_2)}{\rho_g} \cdot C_g \quad (1)$$

where: $E(CO_2)$ – total annual CO_2 emissions; $E_f(CO_2)$ – CO_2 emission factor; C_g – quantity of fuel consumed; ρ_g – density of fuel.
Emission factors found in the literature are expressed in grams of pollutant per liter of fuel consumed, while the consumption of motor fuels is given in tons. The initial data presenting the fule consumption,for this study, was obtained from the website of the Statistical Office of the European Communities (EUROSTAT).

RESULTS AND DISCUSSION

Gasoline-powered vehicles

The U.S. Environmental Protection Agency reports that the average CO_2 emission per liter of gasoline consumed across the U.S. is 2,348 g. [7] While, in China, a study conducted in the city of Hangzhou produced an average value of $E_f(CO_2)$ of 2,184 g/l. [8] This value represents the projected average for the period from 2004 to 2030. The value of $E_f(CO_2)$ for gasoline in this study is calculated as the average of the above-mentioned values, amounting to 2,266 g/l. Fig. 1. shows gasoline consumption per capita in several European countries.

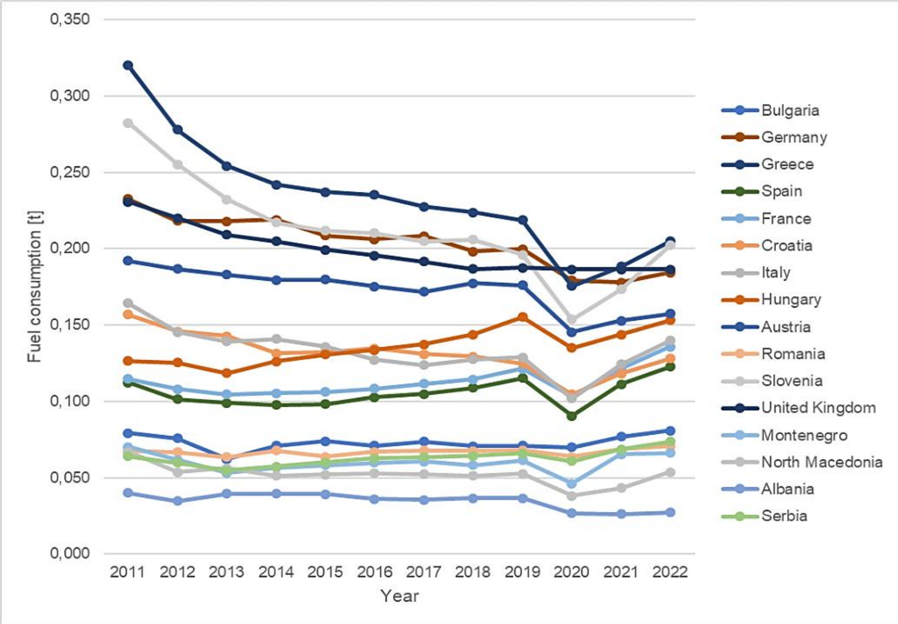

Fig. 1. *Gasoline consumption per capita*

The diagram of gasoline consumption per capita reveals interesting patterns in fuel consumption among different countries. Greece stands out as a leader, which may result from several factors. As a tourist destination, Greece has high demand for gasoline, not only from the local population but also from hundreds of thousands of tourists renting vehicles.
The following countries, such as Slovenia, Germany, and Austria, also show significant per capita consumption, which can be linked to developed infrastructure, a higher number of motor vehicles, and high mobility of the population. In these countries, economic standards and lifestyle contribute to increased gasoline consumption. Fig. 2. shows CO_2 emissions per capita for 17 European countries, resulting from gasoline consumption.

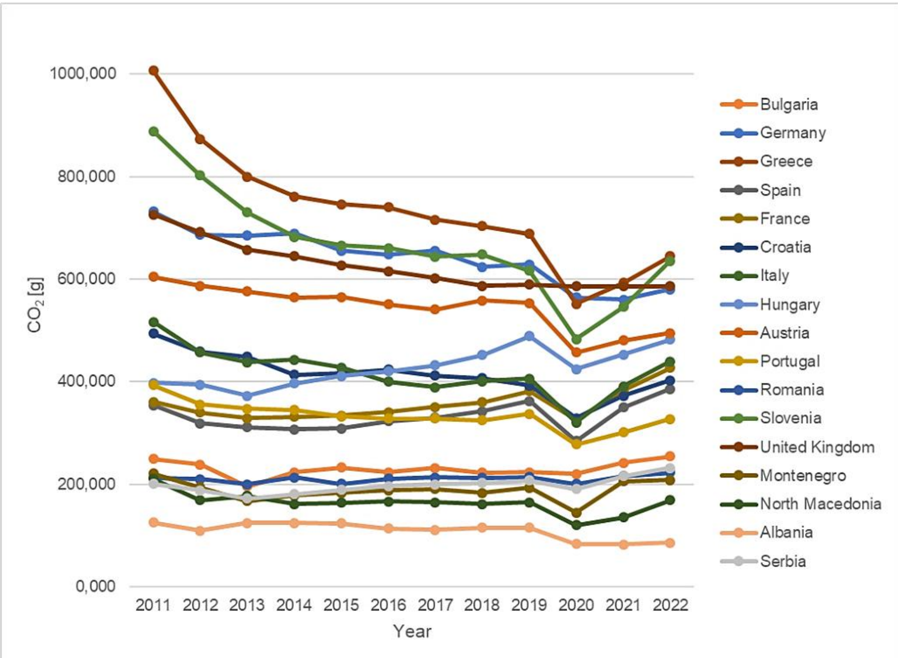

Fig. 2. *CO_2 emission from gasoline per capita*

On the other hand, Albania has the lowest gasoline consumption, and accordingly the CO_2 emissions per capita. This situation may be a result of lower economic development, less purchasing power, and a smaller number of vehicles relative to the population. Additionally, the transportation infrastructure may be less developed, which affects the overall CO_2 emissions.

Diesel-powered vehicles

Generally speaking, carbon dioxide emissions from diesel-powered vehicles are somewhat higher than those from gasoline-powered vehicles. The U.S. EPA has reported that the average CO_2 emission per liter of diesel fuel consumed is 2,690 g. [7] Emission factors obtained from analyzing freight vehicles in the U.S. range from 2,421 g/l to 3,117 g/l.
Values presented in the paper it deals with by forecasting emission factors until 2030 in Hangzhou range from 2,405 g/l to 2,518 g/l, depending from the class of analyzed vehicles, where the mean value of Ef(CO2) for the entire vehicle fleet is 2,472 g/l. [8]
The value of $E_f(CO_2)$ for diesel fuel is calculated as the average of the mean values obtained in the U.S. and China, amounting to 2,581 g/l.
Fig. 3. shows diesel consumption per capita, clearly indicating that Bulgaria was the leading country in per capita consumption of this type of fuel, but with a declining trend.
Slovenia recorded the largest decrease in diesel consumption compared to other countries. In 2019, diesel consumption was 0.66545 tons, while in 2020 it dropped to 0.54248 tons, representing a decrease of about 18.4%. This decline can be linked to the impact of the COVID-19 pandemic and reduced mobility of citizens. Although consumption in 2022 increased to 0.67678 tons, it has not reached the level of 2018.

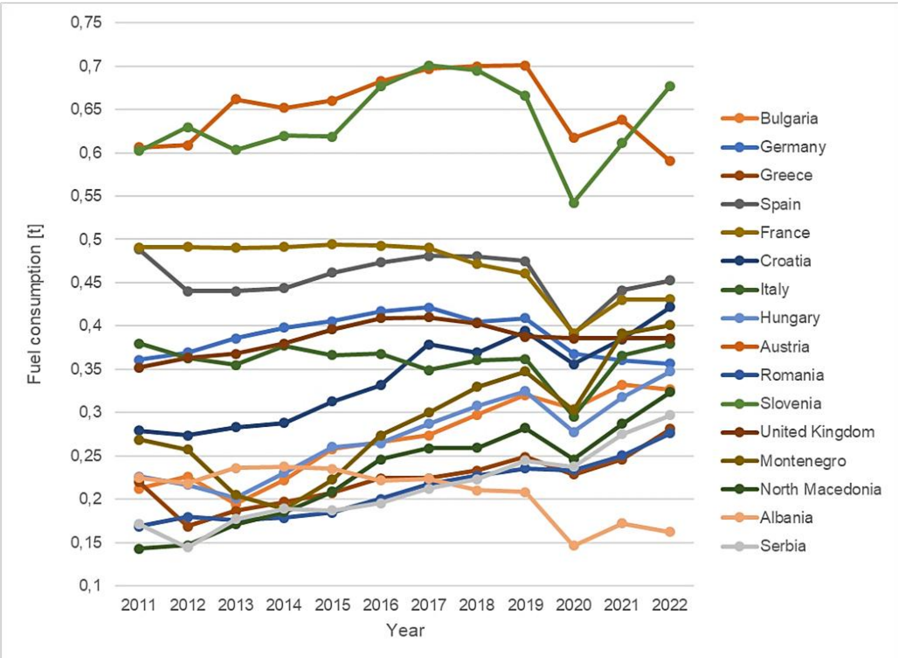

Fig. 3. *Diesel consumption per capita*

Fig. 4. shows CO_2 emissions per capita, resulting from diesel consumption, where it is clear that the emission of this gas changes minimally in France, which may indicate a stable structure in the transportation sector. In this country, in the period between 2011 and 2018, CO_2 emissions per capita fell from 1508.29 g to 1449.12 g, representing a decrease of approximately 3.9%.

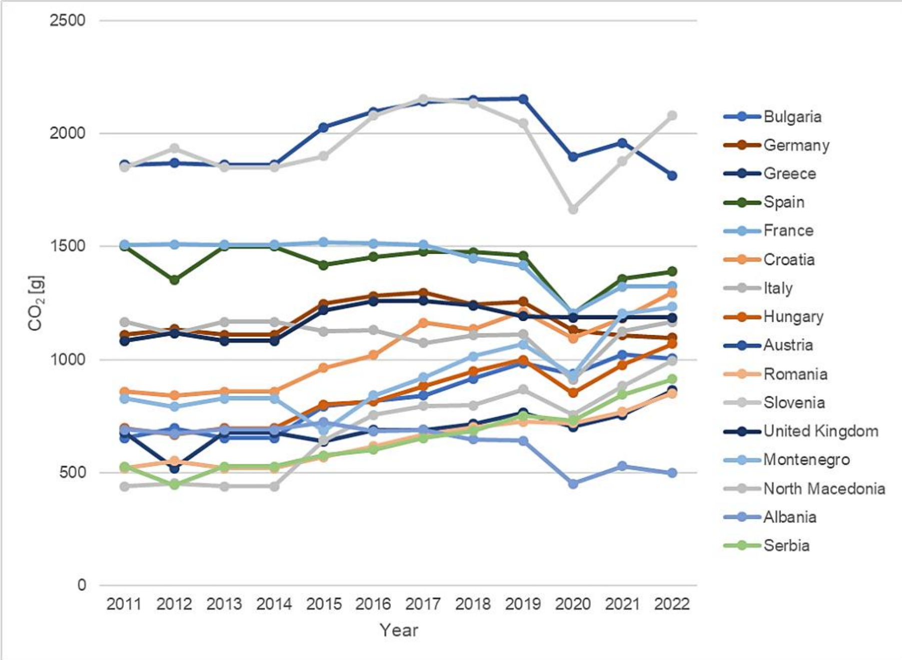

Fig. 4. *CO_2 emission from diesel per capita*

LPG-powered vehicles

As with the previous fuels, the values of the emission factor for CO_2 from LPG fuel were given by the U.S. EPA. U. S. Environmental Protection Agency provides information on the individual emission factor for butane at 1,716 g/l and propane at 1,500 g/l. [7]
The value adopted in this study is 1,600 g/l.
Fig. 5. shows LPG consumption per capita.

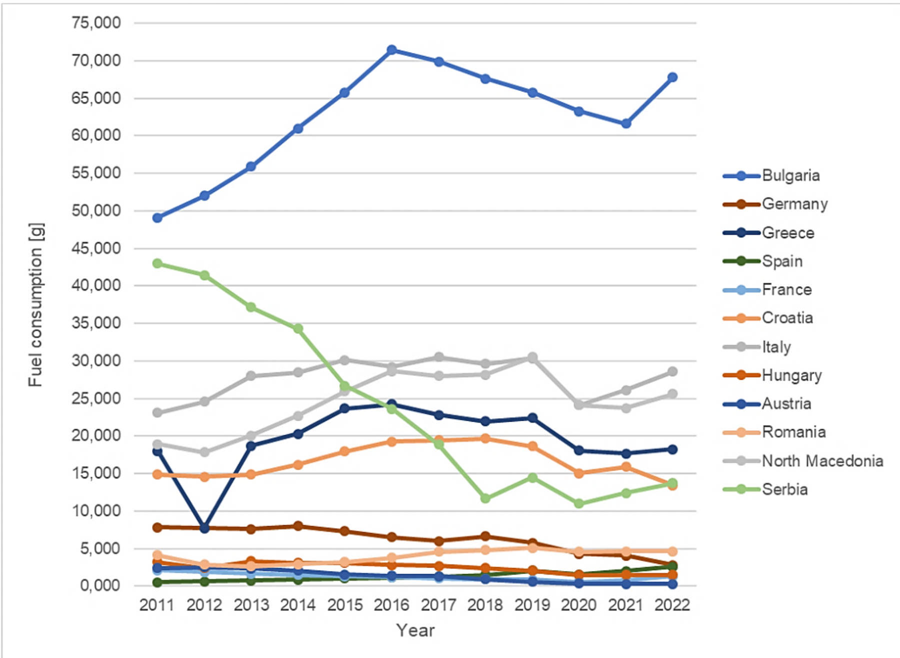

Fig. 5. *LPG consumption per capita*

This type of fuel consumption revealed the most interesting trend fror some of the countries. For example, in Serbia, there was an increase in LPG fuel consumption in 2011, which can be attributed to its more favorable price compared to gasoline and diesel, at that time. A key factor in this trend was the conversion of vehicles, which became increasingly accessible, allowing drivers to easily switch to LPG. The rise in the number of vehicles converted for LPG use contributed to the growth of the vehicle fleet, making Serbia, alongside Bulgaria, one of the leading countries in the consumption of this type of fuel.

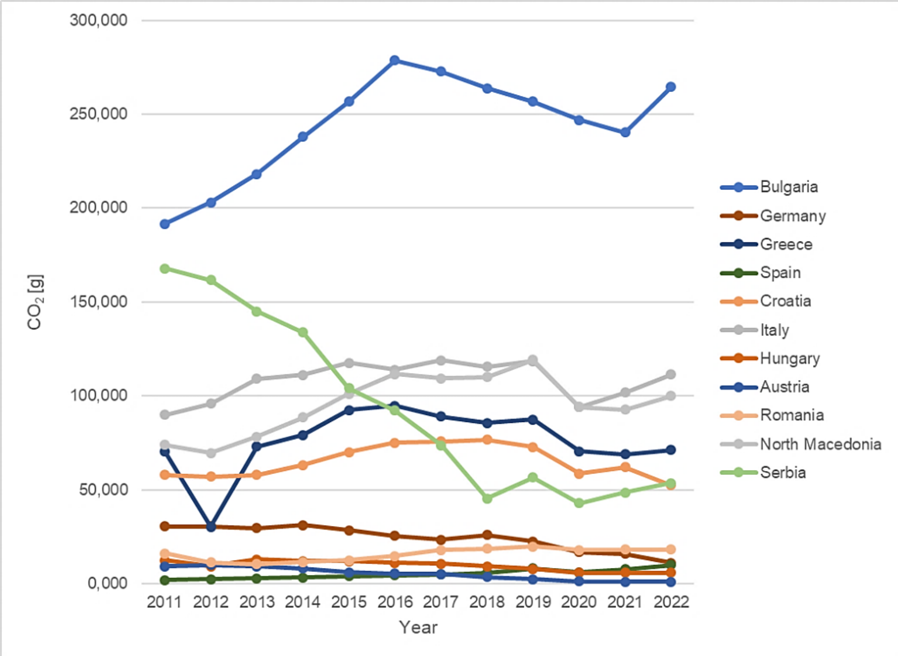

Fig. 6. *CO_2 emission from LPG per capita*

In Fig. 6., which shows CO_2 emissions per capita, resulting from LPG consumption, it is evident that in Bulgaria, CO_2 emissions per capita increased from 191.564 g in 2011 to 278.681 g in 2028, representing an increase of approximately 45.5%. On the other hand, Austria reduced its emissions from 9.335 g in 2011 to 5.468 g in 2016, reflecting a decrease of about 41.4%. These data indicate opposing trends: while Bulgaria recorded a significant increase in emissions, Austria achieved a notable reduction during the same period.

Fig. 7. shows CO_2 emissions per capita, resulting from consumption of different types of fuel in Serbia.

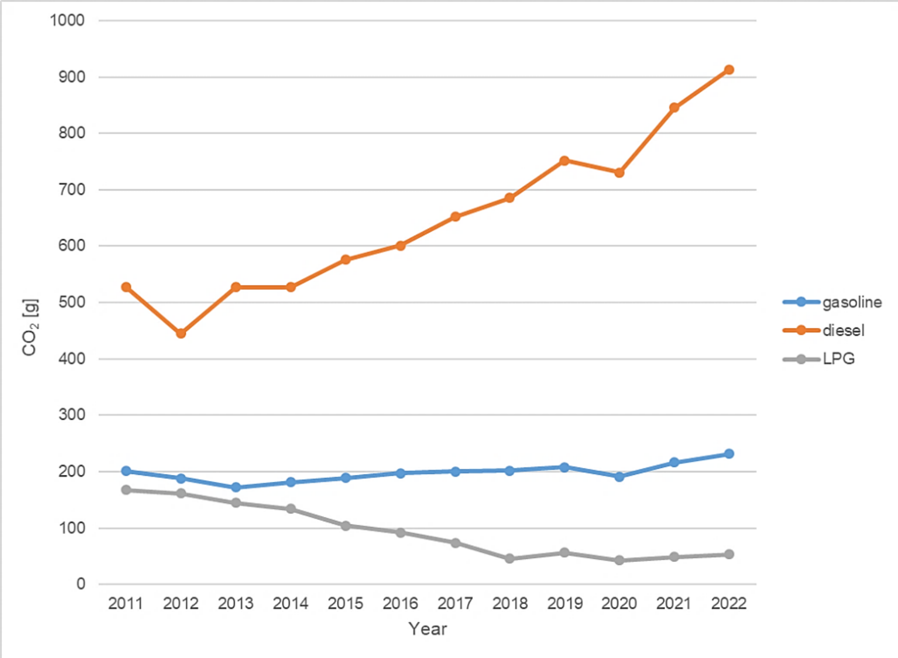

Fig. 7. *CO_2 emission per capita in Serbia*

According to the results presented in Fig. 7., it can be noticed that from 2011 to 2022, the consumption of diesel, gasoline, and LPG in Serbia underwent significant changes, influenced by various factors such as economic conditions, regulations, and fuel prices. Diesel consumption continuously increased, partly due to the rising number of diesel vehicles, which were considered a more economical choice. Additionally, diesel vehicles were often more appealing due to their lower CO_2 emissions, although they later proved problematic regarding NOx and particulate emissions, leading to stricter environmental regulations.

On the other hand, gasoline consumption remained relatively stable, with a slight declining trend compared to diesel. Economic conditions, inflation, and changes in fuel prices directly impacted consumption. During crisis years, such as 2014 and 2020, consumption decreased due to economic uncertainty. The COVID-19 pandemic particularly had a significant impact on traffic activities, resulting in a decline in the consumption of all fuel types.

Looking ahead, trends toward the use of electric vehicles and other alternative energy sources are expected to become more pronounced. Increasing regulations for emission reduction and the promotion of more environmentally friendly options will likely further shape fuel consumption patterns in Serbia. This will be the subject of our future research.

Regarding CO_2 emissions, the transportation sector in Serbia significantly contributes to total emissions of this pollutant. Although diesel vehicles emit less CO_2 per kilometer traveled, total emissions from all vehicles remain high, especially due to the growing number of cars on the roads. Gasoline vehicles, while stable in consumption, also contribute to this issue. Increased awareness of environmental concerns and pressure to reduce emissions have led to initiatives for switching to alternative fuels, which could help decrease overall CO_2 emissions in Serbia. In this context, changes in fuel consumption and the transition to cleaner technologies will be crucial for achieving emission reduction goals and protecting the environment.

CONCLUSION

The amounts of CO_2 emissions presented in this study, which are generated by consumption of various fuels, indicate an urgent need for countries to reduce their gas emissions in order to save the environment. Private vehicles, especially those with gasoline and diesel engines, significantly contribute to air pollution, which has serious consequences for human health and the environment.

To protect the environment, it is crucial to improve public transport and encourage citizens to switch to more sustainable transportation options. Key factors influencing individuals' decisions to transition to public transport include traffic congestion, costs, convenience, and the availability of stops. Given the current road capacities, it is expected that congestion levels will reach a critical point in the near future, forcing drivers to consider alternative options.

Reducing CO_2 will not only contribute to better air quality but also will be the aid in the struggle against the climate change. Implementing measures such as lower public transport fares, better accessibility, and more efficient infrastructure can create conditions for a significant shift from private vehicles to public transport. These changes are essential to ensure a sustainable future for upcoming generations and to preserve our planet. Reducing CO_2 emissions has become imperative, and our collective efforts can significantly contribute to achieving this goal.

ACKNOWLEDGEMENT

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APPLICATION OF THE MACHINE LEARNING IN SURFACE WATER QUALITY ASSESSMENT

Review paper

Jelena Antović[1], Katarina Batalović[2], Ivana Mihajlović[3*]
[1]University of Priština, Faculty of Technical Sciences, Knjaza Milosa 7, Kosovska Mitrovica 38220
[2]VINČA Institute of Nuclear Sciences—National Institute of the Republic of Serbia, University of Belgrade, Mike Petrovica Alasa 12–14, Belgrade11000, Serbia
[3]University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering and Occupational Safety and Health, Trg Dositeja Obradovića 6, Novi Sad 21000, Serbia

Abstract: This paper provides a comprehensive review of the existing literature on the application of machine learning (ML) in surface water quality assessment. The focus is on analyzing contemporary research that explores how ML models enable a deeper understanding of complex relationships between biological, physical, and chemical parameters through the processing of large datasets. The review covers key challenges, advantages, and limitations of ML techniques in comparison to traditional methods, with particular emphasis on the accuracy of pollutant identification and the prediction of changes in water quality. The paper offers a critical overview of current studies and provides guidance for future research and applications of machine learning in this field.

Key words: machine learning, surface water monitoring, machine learning algorithms, artificial intelligence.

INTRODUCTION

Water quality is a crucial factor in maintaining ecological integrity, protecting public health, and sustainable water resource management. Traditional methods of monitoring and assessing water quality, which rely on conventional measurements of physicochemical parameters, are often time-consuming and financially burdensome, with limited capacity to predict dynamic changes within aquatic ecosystems [1]. In recent decades, rapid advancements in technological innovations and increased availability of complex data have laid the foundation for the development of advanced methodologies that significantly enhance the efficiency and accuracy of water quality assessment. These approaches leverage artificial intelligence and sophisticated data processing models, enabling the analysis of large datasets and accurate prediction of future ecosystem states [2]. Assessing and predicting surface water quality pose challenges due to their inherent variability and specificity across different ecosystems. In this context, machine learning (ML) offers advanced tools for analyzing and modeling complex relationships between various water quality parameters. This technology enables the development of precise and reliable models that effectively monitor and predict surface water quality, thereby improving water resource management [3]. Machine learning techniques, such as regression, classification, and clustering, are used to analyze data and identify patterns within complex ecological systems. These methods can encompass various water quality parameters, including chemical, physical, and biological aspects, as well as their interactions. For example, machine learning models can process data on pollutant concentrations, such as xenobiotics, heavy metals, and organic matter, and assess their impact on the ecological status of water bodies [4]. A key advantage of ML in this field is its ability to identify complex relationships and patterns that are not apparent in traditional analyses. For instance, ML algorithms can assist in recognizing the impact of changes in physicochemical parameters on biological water quality and their reflection on biodiversity and ecosystems. Furthermore, these models facilitate the analysis of the effects of anthropogenic activities and natural phenomena on water quality,

[1] jelena.antovic@pr.ac.rs, ORCID: https://orcid.org/0009-0000-4530-9421
[2] kciric@vin.bg.ac.rs, ORCID: https://orcid.org/0000-0003-2027-5733
[3]Corresponding author, ivanamihajlovic@uns.ac.rs, ORCID: https://orcid.org/0000-0002-3908-8690

providing more accurate forecasts and enhancing water resource management [5]. The implementation of machine learning can significantly improve the efficiency of detecting and responding to changes in surface water quality, offering valuable insights for decision-making in water resource protection and management [6].

MATERIAL AND METHODS

Analysis of current research on the application of machine learning in surface water monitoring

The development of ML applications in water quality monitoring began in the late 20th century, when initial algorithms were employed to analyze complex ecological data. Early research focused on predicting parameters such as pH, nitrate concentration, and dissolved oxygen, utilizing several key input features. Temperature plays a significant role in influencing chemical reactions and biological activity within aquatic ecosystems. Turbidity measures the presence of suspended particles in water, which can affect other quality parameters. Conductivity indicates the concentration of ions, directly impacting nutrient levels, while total dissolved solids (TDS) reflect the overall content of inorganic and organic substances in the water. Biochemical oxygen demand (BOD) serves as an indicator of organic matter presence, highlighting potential pollution. Chemical oxygen demand (COD) quantifies the total amount of chemicals in water that can be oxidized, offering insights into pollution levels. Alkalinity denotes the water's capacity to neutralize acids, which is crucial for pH stability. Additionally, nutrient levels, including phosphorus and nitrogen compounds, significantly influence eutrophication and algal growth Fig. 1.

These characteristics were typically derived from field measurements and laboratory analyses, serving as inputs for statistical models and early neural networks aimed at predicting water quality. This analytical approach facilitated the assessment and monitoring of changes in water quality, essential for effective management of water resources and ecosystem protection. With advancements in computing power and the increasing availability of large datasets, machine learning models have evolved to become significantly more sophisticated, enabling a detailed analysis of the interdependencies among physical, chemical, and biological factors [7]. In recent years, the application of ML methods to water quality assessment has become a significant focus of research. Various ML techniques have demonstrated exceptional results in improving the accuracy and efficiency of water quality evaluations. Numerous studies have explored a range of ML models to address the complex, non-stationary, and nonlinear characteristics of hydrological and ecological processes [4].

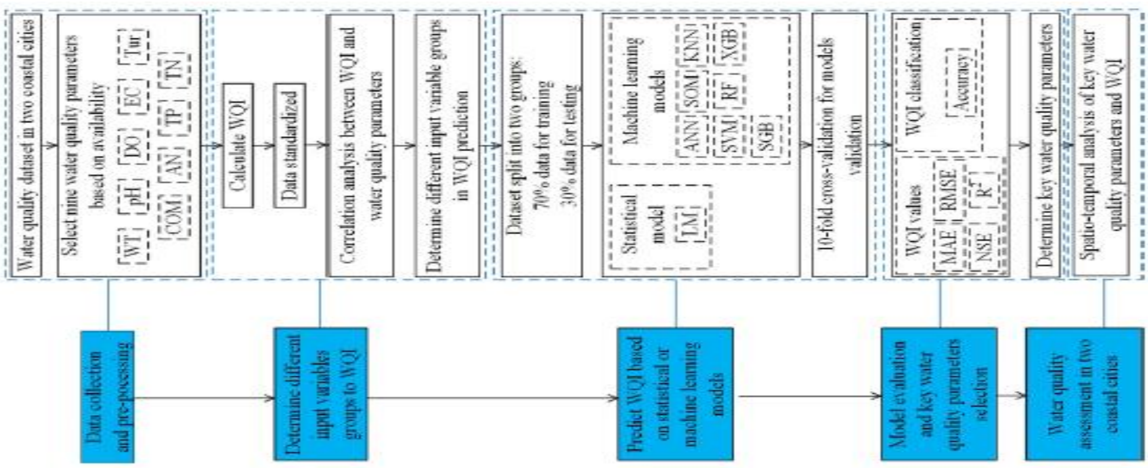

***Fig 1**. The metodological framework for prediction water quality and key water quality parameters selection*

RESULTS AND DISCUSSION

Review of machine learning applications in water quality prediction

Machine learning is widely applied in the field of environmental protection and engineering due to its high precision, flexibility, and ability to effectively solve complex data patterns [8]. The significance of ML applications in river research is evident from the increasing number of publications, which rose from 310 in 2000 to 3,444 in 2020. While supervised learning was dominant until the 2000s, it has since become more balanced with unsupervised learning. Trend analysis also shows that both supervised and unsupervised learning have been prevalent in river research (1990–2020), with neural networks and deep learning gaining increasing attention in recent decades, accounting for 15–21% of the total number of publications [8]. Frequently used ML models for water quality classification, assessment, prediction, and anomaly detection include tree-structured algorithms, DT and random forests (RF), support vector machines (SVM), artificial neural networks (ANN) and LSTM networks as a type of ANN. Regression models are effective for predicting continuous values, such as the concentrations of specific pollutants, allowing precise forecasting of contaminant levels based on input parameters [9]. Artificial Neural Networks, with their ability to model complex nonlinear relationships, are valuable for intricate ecosystem analyses where variable relationships are complex and nonlinear [2]. The Random Forest method utilizes an ensemble of decision trees to enhance prediction accuracy and reduce the risk of overfitting by combining the results from a large number of decision trees. Clustering analysis, on the other hand, groups data based on similarity, enabling the identification of patterns in large datasets and facilitating the analysis and interpretation of complex ecological information [9].

Recent research, focused on the prediction of water quality, has increasingly analyzed various ML models to enhance the accuracy and precision of forecasts. These models include Stacked Autoencoders (SAE) combined with Long Short-Term Memory (LSTM) networks, as well as deep learning approaches, hybrid models, and Extreme Learning Machines (ELM). Short-term predictions concentrate on time frames ranging from a few hours to several days, facilitating real-time decision-making. In contrast, long-term predictions cover periods extending from several weeks to a year, employing advanced techniques such as Deep Recurrent Neural Networks (DRNN), Artificial Neural Networks (ANN), Multilayer Perceptrons (MLP), and Convolutional Neural Networks (CNN) [3]. Techniques related to prediction and anomaly detection predominantly rely on supervised learning, which can be implemented through regression or classification, while unsupervised learning, such as clustering, is used to a lesser extent. Methods for identifying feature importance and material discovery can be executed through supervised learning, utilizing techniques like Linear Discriminant Analysis (LDA) for feature importance identification. Supervised learning is primarily applied in areas such as particulate matter (PM2.5) pollution prediction, water resource availability, and biochemical system modeling for wastewater treatment [10]. Fig. 2. In recent decades, modern research on surface water quality assessment has increasingly relied on machine learning for accurate analysis of key parameters. For example, Wang et al. developed a ML technique utilizing vector calibration and fractional derivative methods to determine spectral indices in remote sensing. Their study implemented a Support Vector Regression (SVR) model to assess the prediction accuracy of this approach [11]. Lamare and Singh employed six different machine learning models to predict irrigation water quality. Research demonstrates how artificial intelligence models can provide precise analysis of water systems. Automated sensor technology, combined with K-Nearest Neighbors (K-NN) and Support Vector Regression (SVR) algorithms, achieves high accuracy in regulating irrigation water quality [12]. To determine the quality of surface waters in limestone extraction areas, ten different physicochemical parameters (pH value, DO, turbidity, conductivity, COD, BOD, temperature, nitrates and nitrites, phosphates, turbidity) were seasonally analyzed at five different sampling locations. Shakhari and Banerjee applied a multi-class classification system to continuous datasets for water quality regulation, utilizing a decision tree classification model to predict the quality of bottled, piped, and pond water, while comparing the performance of classification and regression methods. Their study incorporated a pH sensor and a TDS (Total Dissolved Solids) sensor to gather essential data for analysis [13].

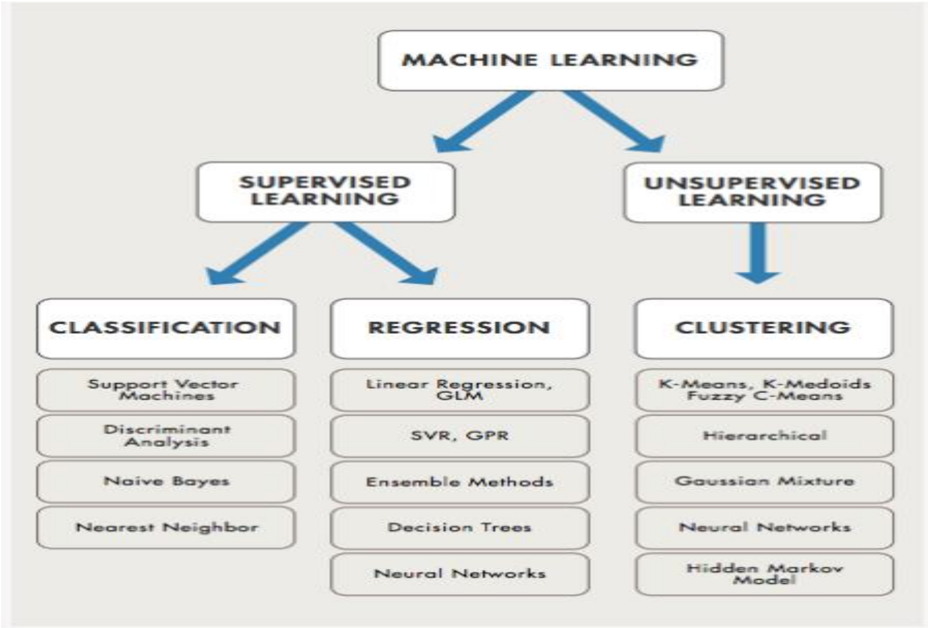

Fig 2. *Overview of some supervised and unsupervised ML algorithms*

Liu et al. conducted research on smart water quality analysis and prediction using Long Short-Term Memory (LSTM) time series neural networks in an IoT environment. The results showed a high correlation between expected and actual model values, employing multidimensional input datasets [14].

The input features in these studies encompass several key physicochemical parameters: pH, which measures the acidity or alkalinity of water; dissolved oxygen, indicating the amount of oxygen available for aquatic life; conductivity, reflecting the levels of dissolved salts and chemicals; turbidity, which denotes water clarity and the presence of solid particles; chemical oxygen demand (CODMn), serving as an indicator of pollution levels and organic matter; and ammonia (NH_3–N), indicating potential contamination. These parameters are crucial for developing water quality prediction models and improving forecast accuracy. Sharma et al. employed supervised machine learning algorithms to predict water quality. By analyzing four parameters: turbidity, temperature, pH value, and Total Dissolved Solids (TDS), they found that second-degree polynomial regression, with an auxiliary angle and a learning rate of 0.1, outperformed other methods in predicting Water Quality Index (WQI) [5]. Chen et al. conducted a comparative analysis of water quality prediction using various ML models. The study encompassed ten models, analyzing parameters such as pH, Dissolved Organic Carbon (DOC), CODMn, and NH_3. The best models were identified based on improved prediction efficiency for surface water quality, including Decision Tree (DT), Random Forest (RF), and Deep Cascade Forest (DCF) models [8]. Aldhyani et al. explored water quality prediction using AI algorithms, including Nonlinear Autoregressive Neural Network (NARNet) and LSTM deep learning algorithms [15]. Uddin et al. analyzed WQI and Water Quality Classification (WQC) using machine learning techniques, demonstrating that the GARNET model rovided better forecasting compared to LSTM algorithms. GARNET (Graph Attention Networks for Time Series) is a ML model that utilizes graphs and attention mechanisms for time series analysis. It effectively identifies interdependencies between variables, focusing on relevant information to enhance prediction accuracy. This model is particularly useful for analyzing seasonal patterns and can be applied in various fields, including ecological research [16]. Additionally, it is robust against noise and data errors, making it a reliable tool for analyzing complex time series Dohare et al. developed a hybrid data mining algorithm for WQI prediction, with standalone and hybrid models showing varying performance regarding errors and deviations in sub-indices. The hybrid package of algorithms, including Bayesian Adaptive Regression Trees (BART) and Random Tree (RT), outperformed other models using R^2, RMSE, MAE, and NSE as accuracy metrics indicators that enable researchers to evaluate and compare the performance of various machine learning models in prediction, offering insights into the accuracy and reliability of the forecasts [17]. Parsouj et al. evaluated the performance of three ML algorithms: Support Vector Regression (SVR), Backpropagation Artificial Neural Network (ANN-BP), and Extreme Learning Machine (ELM) for monthly and daily water quality assessment in U.S. rivers. The SVR model proved to be the most accurate, though its accuracy declined on daily time scales, particularly in catchments with seasonal variability. Lin et al. proposed a hybrid model (DIFF–FFNN–LSTM) combining first-order differencing (DIFF), Feedforward The study explores the application of Artificial Neural Networks, specifically Feedforward Neural Networks (FFNN) and (LSTM) networks, for hourly water quality assessment in the Andun River basin in China. This model demonstrated superior performance compared to other methods, underscoring its potential for hydrological and ecological predictions [18] Venkatachalam and Ray emphasize the necessity of training algorithms to enhance prediction accuracy [19]. Ahmed et al. conducted an analysis using supervised algorithms, revealing that the Gradient Boosting algorithm outperformed other regression techniques in assessing Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R^2, while polynomial regression yielded better results compared to other models [11].

Pasika and Gandla highlight the critical role of data analytics in monitoring pollutant concentrations in water, enabling early detection of potential issues and preventive measures. Furthermore, data analytics can assist in predicting the impacts of climate change on water quality standards and in analyzing spatial distribution and geographic characteristics [20]. In the proposed system for water quality monitoring, input parameters include pH value, turbidity, water voltage, water level in the tank, temperature, and humidity of the surrounding environment. The output parameters consist of updated values for pH, turbidity, water level, temperature, and humidity, which are displayed on the ThingSpeak server and a mobile application for monitoring. Thus, input parameters represent the measurements collected, while output parameters reflect the results that are updated and made available to users. Krtolica et al. presented an (ANN) model for assessing the ecological status of the Danube Basin. In this model, data on macrophyte presence and concentrations of dissolved oxygen, orthophosphates, nitrates, and nitrites are used as input variables to analyze and predict various ecological aspects, including water quality. The developed ANN models demonstrated high predictive performance, with a significant percentage of accuracy in classifying ecological status based on selected chemical parameters and visible plants [2]. Kalini underscores the importance of data analytics for developing water quality conservation measures under climate change conditions [21]. Yan et al. focus on the application of ML methods in water quality prediction, providing an in-depth analysis of over 170 studies from the past five years. The study highlights various approaches for water quality assessment, including methods based on individual indicators and more complex combinations of multiple indicators [22]. Akbulut et al. utilized various ML algorithms, including (RF) and Extra Trees (ETR), combined with wavelet transform. The research showed that models using wavelet transform achieved significant improvements in prediction accuracy, with increased correlation coefficients and reduced error. This study demonstrates that integrating wavelet transform with ML enhances river flow prediction, especially in complex time series and irregular data [23]. According to Zhong et al., from 1990 to 2020, a total of 5,855 publications were generated regarding the application of ML, distributed across water (47.63%), air (27.32%), soil (21.02%), and sediments (4.02%) [3]. Zhu et al. identify four main applications of ML: prediction, feature importance identification, anomaly detection, and discovery of new materials or chemicals [4]. Hassan et al. developed a software application utilizing ML algorithms for real-time water quality prediction in India. The application employs Multiple Linear Regression (MLR) to classify water into three categories: good, poor, and unsuitable for drinking, while the RF model is used to address missing data [24]. The performance of various models was high, with accuracy rates of 99.83% for MLR, 98.99% for RF, 98.99% for Bayesian trees (BT), 98.65% for ANN and 96.98% for SVM. In the ANN model, the most significant input paramters included NO_3, pH, EC, DO, TC, and BOD, all exhibiting high importance values. These variables were essential for accurately predicting the ecological outcomes under investigation [8]. A similar approach was taken by Shamsuddin et al., who used ANN, DT, and SVM for the classification of water quality in the Langat River. Although ANN and SVM yielded different results, SVM demonstrated superiority with small datasets due to its kernel function. Most samples fell into classes III and II, indicating water suitable for supply and fishing. The advantages of ANN, DT, and SVM include the ability to model complex nonlinear relationships, ease of application, and wide usage. All models achieved high levels of accuracy, with macro-precisions of 96.35% for SVM, 95.62% for ANN, and 94.71% for DT [25]. Sillberg et al. applied the AR-SVM model for the classification of water quality in the Chao River using 11 water quality parameters. Linear regression proved to be the most effective, with an accuracy of 94% and precision of 84%. Class III, indicating poor water quality, was the most prevalent [6].

This review provides insights into current use of ML in quality assessment of surface wáter, focusing on the used algorithms and main input features found in recent literature and laying grounds for future enhancement in applying ML in Serbia and region.

CONCLUSION

The concluding analysis demonstrates that integrating artificial intelligence into the processes of analyzing and predicting water quality offers numerous advantages over traditional methods. The use of machine learning models enables not only faster and more precise predictions of key parameters but also a deeper understanding of the complex interactions among various factors affecting water quality. These models have the capability to handle large dataset, including those from different geographic regions and time periods, thereby improving prediction accuracy and reliability. Furthermore, the application of artificial intelligence in this domain facilitates the development of adaptive monitoring systems that can swiftly respond to changes in water quality and enable timely decision-making for the protection and sustainable management of water resources. Despite challenges such as limited data availability and the need for better result interpretation, the potential for enhancing ecological monitoring and management through the integration of artificial intelligence is significant. With further research and advancements, these models could become indispensable tools in global efforts to preserve the quality and safety of water resources.

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COMPARATIVE STUDY OF SODA LAKES AND PANS CHEMICAL PROPERTIES IN SERBIA AND HUNGARY

Review paper

Nevena Živančev[1], Srđan Kovačević[2], Ivana Mihajlović[3*]
[1,2,3]University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

Abstract: Soda lakes and pans are unique saline ecosystems characterized by high alkalinity (pH > 9) and a specific ionic composition dominated by sodium carbonate. These ecosystems play a critical role in biodiversity conservation, hosting distinct biological communities and supporting migratory birds. However, soda lakes and pans are increasingly vulnerable to climate change, with rising temperatures, altered precipitation patterns, and increased evaporation rates leading to reduced water levels and habitat alterations. This paper focuses on the chemical properties and ionic composition of soda lakes and pans in Serbia and Hungary, examining the concentrations of major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) and categorizing the lakes based on their ionic. By comparing these ecosystems across both countries, this study enhances understanding of their biogeochemical processes and highlights the need for effective conservation and management strategies considering ongoing environmental changes.
Key words: *soda pans, soda lakes, ionic composition*

INTRODUCTION

Soda lakes and pans are rare ecosystems compared to other saline water bodies. These waters are characterized by high concentrations of sodium carbonate and high alkalinity (pH > 9) [1]. As a result, soda lakes and pans support distinct biogeochemical cycles and biological communities [2]. Their typically lower salinity fosters greater biodiversity compared to other inland saline waters [3].

Most soda lakes are shallow, making them especially vulnerable to rising temperatures, shifting precipitation patterns, and increased evaporation rates. These factors have led to declining water levels and, in some cases, significant drying [3,4], which alters habitats. Due to their susceptibility to climate change, soda lakes and pans in the European Union are prioritized for protection under the Natura 2000 network, particularly within habitats like the "Pannonic Salt Steppes and Salt Marshes" [5,6]. Some are also recognized as Ramsar sites for their importance to migratory birds, with many located in national parks [7].

The largest concentrations of soda lakes and pans are found in the Carpathian Basin, with approximately 80 such ecosystems in Austria, Hungary, and Serbia [1]. In Hungary, these areas receive legal protection, and some are similarly protected in Serbia.

The chemical composition of soda lakes is influenced by geological, hydrological, and climatic factors, resulting in specific ionic concentrations that shape the biological communities they support. The major ions found in soda lakes and pans include sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}). These ions are present in correlated concentrations, limiting the number of distinct chemical types. Boros and Kolpakova [8] classify these systems into two main types: "Soda" and "Soda-Saline." The "Soda type" is dominated by Na^+ and HCO_3^- + CO_3^{2-} ions, both exceeding 25%. In contrast, the "Soda-Saline" type features Na^+ as the dominant cation, while HCO_3^- and CO_3^{2-} exceed 25%, though they are not the dominant anions.

This review focuses on the chemical properties and ionic composition of soda lakes and pans in Serbia and Hungary. Eight ion concentrations (four cations and four anions) were used to classify and assess the types of soda lakes and pans in these regions. By comparing the similarities and differences between the lakes in Serbia and Hungary, this study aims to improve understanding of the biogeochemical processes sustaining these unique

[1]nevenazivancev@uns.ac.rs, ORCID: https://orcid.org/0000-0002-5434-5210
[2]srdjankovacevic@uns.ac.rs, ORCID: https://orcid.org/0000-0002-5440-8752
[3]Corresponding author, ivanamihajlovic@uns.ac.rs, ORCID: https://orcid.org/0000-0002-3908-8690

ecosystems and provide insights into their conservation and management in the context of climate change.

CATEGORIZATION OF SODA PANS AND LAKES IN HUNGARY AND SERBIA

Sodic waters in the Pannonian Biogeographic Region are inland alkaline saline waters, with an ionic composition primarily dominated by sodium (Na^+) and carbonates (CO_3^{2-} and HCO_3^-) [9]. These waters are naturally saline in this region, where their presence is influenced by both climatic and geological factors. Their salinity can vary significantly across different locations and over time. Soda pans dry out each year, leading to a wide range of salinity levels, from freshwater conditions in early spring to, in extreme cases, hypersalinity (over 50 g/L) by the end of the growing season.
Categorization of soda pans and lakes in Hungary and Serbia was conducted using literature data [5,6,10,11], with the 1.0 g L^{-1} salinity threshold selected as it was experimentally found to be characteristic boundary of soda ecosystems [8].
Equivalent ionic composition of soda lakes and pans in Hungary and Serbia according to the literature data [5,6,10,11] is presented in Table 1, and it is used for determination of the type of soda lakes and pans by Boros et al. [8] into "Soda", "Soda-saline" and "Saline" lakes and pans.
Equation used for calculating equivalent percentage of each cation is equation(1) and for each anion is equation(2):

$$e\%^{(i)}\mathrm{cat} = \frac{\frac{C_i}{M_m/F_e}}{\sum_4 \mathrm{cat}\left(\frac{C_i}{M_m/F_e}\right)} \times 100 \quad (1)$$

$$e\%^{(i)}\mathrm{ani} = \frac{\frac{C_i}{M_m/F_e}}{\sum_4 \mathrm{ani}\left(\frac{C_i}{M_m/F_e}\right)} \times 100 \quad (2)$$

where $e\%^{(i)}_{cat}$ is equivalent percentage of one (i) cation, $e\%^{(i)}_{ani}$ is equivalent percentage of one (i) anion, C_i is ion concentration (mg L^{-1}), M_m is molar mass (g mol^{-1}) and F_e is equivalence factor (if ion charge is ±1, the value is 1; if ion charge is ±2, the value is 2).

Table 1. *Locations in Hungary (HU) and Serbia (S) with detailed chemical characteristics of soda pans [5,6,10,11]*

Country	Name	Salinity (g L^{-1})	pH	Na^+ (e%)	K^+ (e%)	Ca^{2+} (e%)	Mg^{2+} (e%)	Cl^- (e%)	SO_4^{2-} (e%)	HCO_3^- (e%)	CO_3^{2-} (e%)	Ref
HU	Tóalj (Bíbic-tó)	1.41	8.33	44.75	6.13	13.71	35.42	11.18	20.90	67.92	0.00	[5]
HU	Sóstó	3.94	9.25	54.31	5.21	6.10	34.38	23.39	30.47	39.69	6.46	[5]
HU	Sóstó	3.79	9.11	68.92	5.96	0.33	24.80	30.99	40.74	24.42	3.85	[5]
HU	Fehér-tó	1.31	8.23	69.28	1.39	11.30	18.03	19.09	11.30	69.61	0.00	[5]
HU	Kerek-tó	1.04	8.47	70.53	8.02	8.47	12.97	16.38	12.66	70.97	0.00	[5]
HU	Vesszős-szék	1.54	9.15	72.09	1.49	7.07	19.35	14.03	13.83	72.05	0.09	[5]
HU	Pallagi-szék	2.91	8.30	82.04	3.22	3.86	10.87	25.12	10.10	64.78	0.00	[5]
HU	Meggyes-lapos	1.37	9.37	83.81	2.66	5.60	7.93	30.44	8.19	61.23	0.14	[5]
HU	Kis-sóstó	1.06	8.65	83.91	1.63	6.13	8.32	16.82	17.56	65.62	0.00	[5]
HU	Dong-ér	3.27	10.00	85.25	0.47	0.67	13.62	25.17	45.65	27.72	1.46	[5]
HU	Fényes-tó	1.96	7.72	88.57	1.13	1.42	8.88	29.12	21.96	48.92	0.00	[5]
HU	Petrovics-lapos	2.27	9.41	88.77	0.45	2.91	7.87	3.82	9.81	86.31	0.07	[5]
HU	Sóstó	3.51	9.44	88.93	5.99	0.66	4.41	6.91	23.14	61.61	8.34	[5]
HU	Fehér-tó	2.51	10.07	88.98	0.30	3.24	7.48	17.99	9.72	72.21	0.08	[5]
HU	Sárkány-tó	19.90	10.15	89.10	1.02	1.05	8.84	57.88	22.41	15.90	3.81	[5]
HU	Göbölyös-szik	1.14	7.76	91.05	1.45	4.13	3.36	5.56	12.20	79.98	2.27	[5]

Country	Name	Salinity (g L^{-1})	pH	Na^+ (e%)	K^+ (e%)	Ca^{2+} (e%)	Mg^{2+} (e%)	Cl^- (e%)	SO_4^{2-} (e%)	HCO_3^- (e%)	CO_3^{2-} (e%)	Ref
HU	Sósér	4.00	9.00	91.16	0.73	2.70	5.41	26.68	18.74	54.55	0.03	[5]
HU	Kis-sóstó	1.06	9.68	92.75	0.68	5.50	1.08	14.93	1.19	83.88	0.00	[5]
HU	Alsó-Szúnyog	2.06	9.80	93.44	0.59	3.39	2.57	14.00	12.67	73.25	0.08	[5]
HU	Nagy-Vadas-tó	2.82	9.92	93.63	0.37	0.43	5.57	7.40	11.22	81.31	0.07	[5]
HU	Fehér-tó	11.91	9.40	94.06	0.45	1.49	4.00	22.31	9.85	65.55	2.29	[5]
HU	Pipás-szék	4.40	9.53	94.38	0.66	2.94	2.02	22.88	11.37	64.20	1.56	[5]
HU	Csikóspusztai-tó	2.08	9.30	94.70	0.57	2.62	2.11	6.74	24.41	68.77	0.07	[5]
HU	Fűzfa-szék	3.90	9.30	94.98	0.25	2.93	1.83	23.86	21.62	54.49	0.03	[5]
HU	Fehér-szék	2.74	9.43	95.06	0.36	1.07	3.50	32.90	9.53	55.37	2.21	[5]
HU	Kelemen-szék	6.55	9.37	95.59	0.59	1.42	2.40	35.53	7.06	39.13	18.27	[5]
HU	Bocskoros-szik	3.38	9.55	95.73	0.39	0.95	2.93	9.71	16.67	73.58	0.04	[5]
HU	Bába-szék	4.18	9.51	96.32	0.36	1.48	1.85	51.39	1.21	47.40	0.00	[5]
HU	Böddi-szék	8.67	9.20	96.56	0.33	1.03	2.08	46.54	8.74	32.26	12.45	[5]
HU	Fehér-szik	3.66	9.23	96.92	0.63	0.83	1.62	23.60	13.92	62.44	0.04	[5]
HU	Büdös-szék	4.45	9.52	96.95	0.50	0.93	1.62	20.79	5.53	58.29	15.39	[5]
HU	Zab-szék	5.36	9.53	96.96	0.44	0.97	1.63	26.27	6.88	48.45	18.40	[5]
HU	Bogárzó	6.46	9.50	97.08	0.38	0.98	1.56	25.56	4.04	55.48	14.91	[5]
HU	Kerek-Szik-tó	2.01	10.31	97.23	0.29	0.60	1.87	6.10	10.69	72.70	10.51	[5]
HU	Csukáséri-tavak	13.99	9.69	98.84	0.85	0.03	0.28	23.13	21.68	42.59	12.60	[5]
S	Medura	4.93 7.12	9.30 9.21	85.70 91.97	0.76 1.17	0.36 1.08	13.18 5.78	18.19 19.06	11.81 21.60	63.81 26.48	6.18 32.87	[5] [10]
S	Slano Kopovo	2.60 2.16	8.77 8.81	94.57 88.52	0.54 0.61	2.42 4.58	2.47 6.29	48.43 52.96	21.05 14.61	30.52 24.15	0.00 8.28	[5] [10]
S	Velika Rusanda	18.19 16.40 11.66 13.90 30.24 11.44 10.82	9.20 9.67 9.70 9.64 9.61 9.60 9.62	94.57 97.21 96.03 98.28 98.59 96.49 97.43	1.86 1.11 2.89 1.33 1.22 2.75 1.48	1.24 0.15 0.32 0.08 0.03 0.24 0.21	2.33 1.53 0.76 0.31 0.17 0.52 0.88	29.42 30.81 37.00 40.55 29.97 39.18 37.50	32.72 26.45 29.68 35.34 29.29 32.15 22.84	34.75 20.50 7.32 4.25 4.66 0.50 17.34	3.11 22.25 25.99 19.86 36.08 28.17 22.32	[5] [11] [11] [11] [11] [10] [6]
S	Mala Rusanda	3.23 4.11	9.05 8.91	92.35 86.21	4.28 3.46	0.92 2.48	2.45 7.85	31.06 39.43	32.60 47.38	25.15 8.76	11.20 4.42	[10] [6]
S	Velika Slatina	3.61 4.46	7.63 8.00	53.25 60.68	0.26 0.02	20.55 16.31	25.93 22.99	73.01 71.88	0.52 0.82	24.03 27.24	2.44 0.06	[10] [6]
S	Pečena Slatina	6.67	9.32	85.65	0.18	0.53	13.64	55.98	0.71	30.40	12.91	[6]
S	Okanj bara	1.28	8.39	82.99	1.36	4.48	11.17	15.47	8.84	57.45	18.24	[6]

According to calculations presented in Table 2, soda pans and lakes in Hungary are categorized as "Soda" (85.29%), "Soda-Saline" (11.76%) and "Saline" (2.94%). Salinity varies from 1.04 to 19.90 g L^{-1}, while pH varies from 7.72 to 10.31.

In Serbia, soda pans and lakes are categorized using major ion types and subtypes identified based on the dominant ion method [8]. According to the data, out of 7 soda pans and lakes in Serbia, 3 are categorized as "Soda" (Medura, Pečena Slatina and Okanj bara), one is categorized as "Soda-Saline" (Slano Kopovo), while the other three pans and lakes are categorized as "Soda-Saline", "Soda" and "Saline", depending on the period of sampling. The most deferring results are for lake Velika Rusanda, where both major type and subtypes vary depending on the season. It classifies from "Saline" type in summer period, with Cl^- ion as dominant anion, followed by SO_4^{2-}, with HCO_3^- and CO_3^{2-} content less than 25e%, to "Soda" type in autumn and early spring, when major type ions are HCO_3^- and CO_3^{2-}, followed by Cl^- and SO_4^{2-}. In late spring sampling campaigns, Velika Rusanda can also be categorized as "Soda-Saline", with dominant Cl^-, followed by HCO_3^- and CO_3^{2-} and SO_4^{2-}. This largely depends on the amount of water present in the pan.

Soda pans primarily rely on precipitation to meet their ecological water needs, which supplies sufficient water for the plants and animals living there. This helps sustain the ecosystem services wetlands provide, including climate regulation and biodiversity support [12].
Soda pan restoration and reconstruction projects, especially in Hungary, often focus on reviving alkaline wetland ecosystems, which are rare and important habitats for biodiversity. These projects aim to restore the unique hydrology and saline conditions of the soda pans, which are critical for specific plant and animal species, including migratory birds.
Literature studies from Hungary [13-14] suggest that the restoration and reconstruction of soda pans are achievable, but they emphasize the importance of carefully managing several key factors. Specifically, attention must be given to the physical and chemical properties of the water, such as salinity, conductivity, and nutrient levels, to ensure they align with natural soda pan conditions. Additionally, it is crucial to monitor and support the local flora and fauna, ensuring the re-establishment of species that thrive in soda pan environments. The water inputs that feed the soda pan also require close management, as they play a critical role in maintaining the hydrological balance necessary for a healthy ecosystem. Properly addressing these elements can improve the chances of successful restoration efforts.

CONCLUSIONS AND FUTURE CONSIDERATIONS

The categorization of soda pans and lakes in Hungary and Serbia highlights the variability in their chemical properties and the influence of environmental conditions on their classification. In Hungary, the majority of these ecosystems are categorized as "Soda" (85.29%), with smaller percentages falling into the "Soda-Saline" (11.76%) and "Saline" (2.94%) categories. The salinity and pH levels of these waters vary significantly, reflecting the diverse ecological conditions across different sites. Similarly, soda pans and lakes in Serbia demonstrate dynamic shifts in their chemical properties, particularly in the case of Velika Rusanda, where the type of lake varies between "Soda," "Soda-Saline," and "Saline" depending on the season and water levels.
The results indicate that soda pans are highly sensitive to seasonal and environmental changes, with precipitation playing a critical role in maintaining the ecological balance of these unique ecosystems. This sensitivity also underscores the importance of ongoing conservation and restoration efforts, particularly in the face of climate change and hydrological alterations.
Restoration and reconstruction projects in Hungary provide valuable insights into the potential for rehabilitating these rare alkaline wetland ecosystems. Successful restoration depends on managing the chemical and physical properties of the water, such as salinity and nutrient levels, while ensuring the re-establishment of species adapted to soda pan conditions. Careful control of water inputs is crucial for maintaining the hydrological balance necessary to support the biodiversity and ecosystem services provided by these habitats.
Given the vulnerability of soda pans and lakes to environmental fluctuations, particularly in Serbia, further research and conservation actions are essential. These efforts will help sustain the ecological functions and biodiversity of these rare ecosystems, ensuring their resilience in the face of ongoing climate change.
In the case of Velika Rusanda salt pan in the Republic of Serbia, a potential future measure to supply additional water during dry periods, when the lake is dry, includes the use of treated spa wastewater. There is a possibility that, after treatment, this water could be directed into the lake, mitigating the negative effects of external water inputs and preventing damage to natural habitats. The quality of the treated spa water would need to be carefully monitored, along with continuous observation of the water's physical and chemical properties, as well as the flora and fauna, to ensure the health of the ecosystem.

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THE NECESSITY OF ROOFTOP GREENHOUSES FOR IMPROVING URBAN AIR QUALITY AND TEMPERATURE REGULATION

Research paper

Mihaela POPA[2], Valentina-Emilia BĂLAȘ[1,2,3]
[1]Petroleum-Gas University of Ploiesti, Romania
[2]Aurel Vlaicu University of Arad, Romania
[3]Academy of Romanian Scientists

Abstract: Rooftop greenhouses (RGHs) offer a compelling solution to two of the most pressing environmental challenges in urban areas: poor air quality and the rising temperatures associated with the urban heat island (UHI) effect. This paper presents a detailed analysis of the role of RGHs in mitigating these problems, using data on global temperature and air quality. By examining trends in urban temperatures and pollutant concentrations, the paper demonstrates how RGHs can be integrated into urban planning to create sustainable, resilient cities.
Keywords: PV, grid, green deal, residential photovoltaic panel

INTRODUCTION

As cities grow, the environmental burden on urban areas increases, with challenges such as rising temperatures and worsening air quality becoming critical issues. These trends are particularly prevalent in densely populated areas where the urban heat island (UHI) effect and high concentrations of pollutants directly impact public health and urban livability. Rooftop greenhouses (RGHs) have emerged as a potential solution, offering multiple benefits, including reducing heat, filtering pollutants, and contributing to local food security. This paper examines the need for integrating RGHs into urban landscapes by analyzing temperature and air quality data from various cities.

Rising Urban Temperatures and the UHI Effect

Urban areas, due to their extensive concrete, asphalt, and high-density structures, experience higher temperatures than rural areas, known as the **urban heat island effect**. The dataset from **GlobalLandTemperaturesByCity.csv** reveals a consistent rise in temperatures across major global cities over the past century. On average, temperatures in cities have increased by 1.5°C, with more significant spikes during heatwaves, which stress energy systems and increase the use of air conditioning, contributing to further emissions.

Fig. 1. *Arbor House, New York, building with a greenhouse on the roof from the 1930s*

[1]Corresponding author, mihaela.popa@uav.ro, 0009-0008-2208-8492
[2]balas@drbalas.ro, 0000-0003-0885-1283

Although not so acute, the problem has been raised since the last century, with attempts to solve it, as seen in fig. 1 where there is a greenhouse on the roof of a building dating from 1930.

Temperature Trends in Major Cities

Rooftop greenhouses can help combat this temperature rise through processes like **evapotranspiration**, where plants release moisture into the air, cooling the surrounding environment. Moreover, the vegetation used in RGHs can insulate buildings, reducing the need for artificial heating in winter and cooling in summer. The following graph illustrates the steady increase in temperatures in urban areas globally, highlighting the urgency of interventions like RGHs [1], [2]. Fig. 2 shows the evolution of the temperature in the city of Paris at 2 meters above the ground, during the period 2010-2022, highlighting the increasing trend.

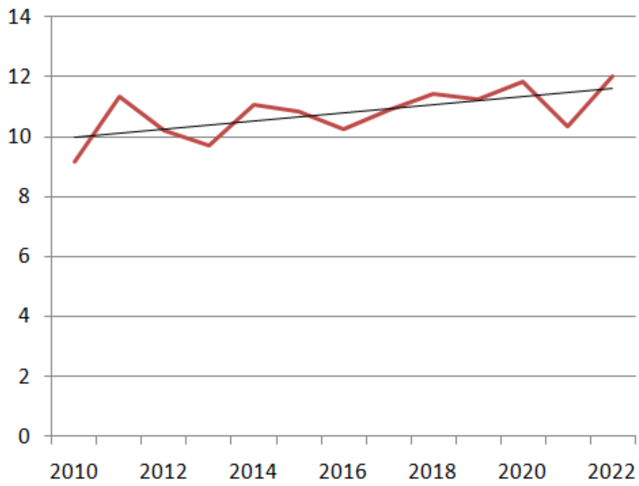

Fig. 2. *Temperature evolution in Paris, France*

Air Quality Deterioration in Urban Areas

Alongside rising temperatures, air pollution represents a significant issue for urban populations. Data from **global_air_quality_data_10000.csv** shows that cities like New Delhi, Beijing, and New York have dangerously high levels of **PM2.5**, **PM10**, and **NO_2**, pollutants linked to respiratory and cardiovascular diseases. These pollutants come largely from vehicle emissions, industrial processes, and energy production, all of which are exacerbated in dense urban environments.

Air Quality Trends in Major Cities

Rooftop greenhouses can improve air quality by acting as natural filters. Plants absorb CO_2 and other pollutants through photosynthesis, while also trapping particulate matter like PM2.5. This reduces the overall concentration of harmful substances in the air, improving public health outcomes in urban environments.

Pollutant levels in major cities can be graphed based on air quality data. Thus, in the following graph, we tracked the air quality in Mumbai, India.

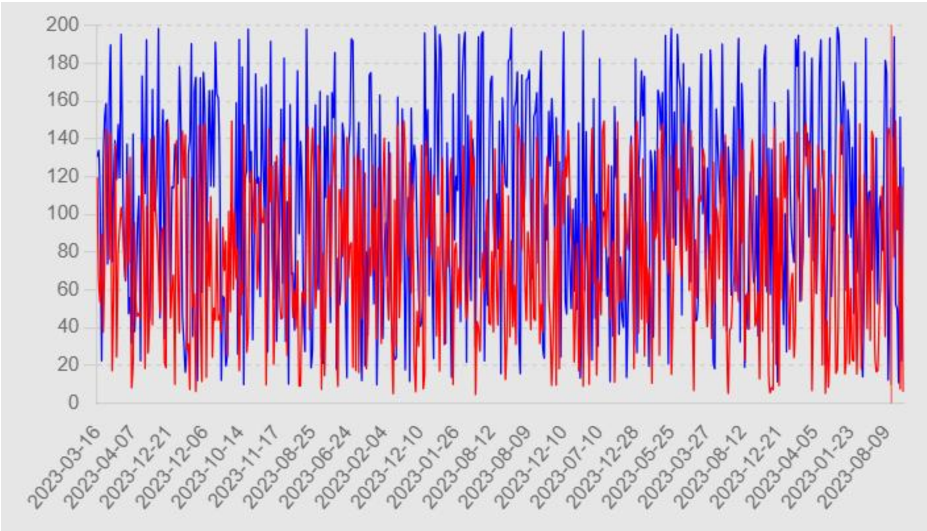

Fig. 3. *Air quality trends in Mumbai*

Fig.3 displaying the air quality trends in Mumbai, focusing on the levels of PM2.5 and PM10 pollutants. These pollutants are key indicators of air quality, with PM2.5 being particularly harmful due to its small particle size, which can penetrate deep into the lungs. The graph shows variations over time, indicating periods of higher pollution where rooftop greenhouses could help mitigate these levels by acting as natural air filters.

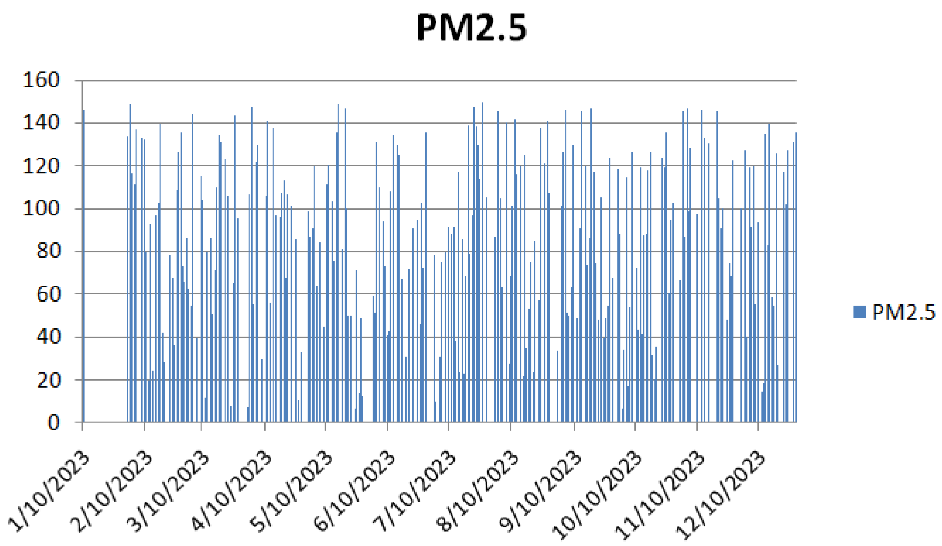

Fig. 4. *PM2.5 trends in Paris, France*

Fig.4 displaying the level of PM2.5 in Paris, France.

The Role of Rooftop Greenhouses in Temperature and Air Quality Management

The dual effect of RGHs in reducing both urban temperatures and air pollution makes them a critical tool for sustainable urban development. By covering rooftops with vegetation, cities can reduce the UHI effect, while also improving air quality through the sequestration of CO_2 and the filtration of particulate matter. The data from both temperature and air quality datasets underscore the urgency of integrating RGHs into urban planning [3].

In addition to their environmental benefits, RGHs provide **local food production**, which reduces the carbon footprint associated with transporting food to urban centers. This has a positive feedback effect, as less transportation means fewer emissions and less pollution overall.

Challenges and Opportunities for Implementation

The main challenges in implementing RGHs are related to **building structural limitations** and the **initial costs** of setting up these systems. However, advances in **lightweight materials** and **hydroponic systems** have made it easier to retrofit existing buildings with RGHs. Moreover, the long-term benefits—including reduced energy consumption, improved air quality, and enhanced urban biodiversity—outweigh the initial investment [4].

Rooftop greenhouses (RGHs) improve air quality through several key mechanisms that address urban pollution. Here's how they contribute to cleaner air in urban environments:

- Carbon Dioxide (CO_2) Absorption

Plants inside rooftop greenhouses engage in **photosynthesis**, a process where they absorb CO_2 from the atmosphere to produce oxygen and glucose. CO_2 is a major contributor to the greenhouse effect and global warming, so by reducing atmospheric CO_2 levels locally, rooftop greenhouses help decrease the overall carbon footprint of urban areas.

- Particulate Matter (PM) Filtration

Urban areas often have high levels of particulate matter (PM), including **PM2.5** (fine particles) and **PM10** (coarser particles). These particles are pollutants that arise from vehicle emissions, industrial activities, and construction. The plants in rooftop greenhouses can trap these particulates on their leaves and stems, acting as a natural filter. Over time, rain or manual watering washes these particles off the plants, effectively removing them from the air.

- Reduction of Ozone and Nitrogen Dioxide (NO_2) Levels

Ozone (O_3) and nitrogen dioxide (NO_2) are common air pollutants in cities, primarily from vehicle exhaust and industrial emissions. Rooftop greenhouses can reduce the concentration of these pollutants in two ways:

- **Plants absorb NO_2**: Nitrogen dioxide can be absorbed by plants through their stomata (tiny openings on leaves), where it is converted into less harmful compounds.
- **Reduction of ground-level ozone**: Vegetation can help reduce the formation of ground-level ozone by absorbing its precursors like volatile organic compounds (VOCs) and nitrogen oxides (NO_x).

- Temperature Reduction and Airflow Improvement

Rooftop greenhouses help lower ambient temperatures through **evapotranspiration**, where plants release water vapor into the atmosphere, cooling the surrounding air. Cooler temperatures can lead to lower levels of **secondary pollutants**, such as ozone, which form more readily in warmer conditions. By reducing the urban heat island effect, rooftop greenhouses also improve air circulation, reducing the stagnation of polluted air.

- Local Food Production Reduces Transportation Emissions

Another indirect but significant way rooftop greenhouses improve air quality is by facilitating **local food production**. This reduces the need for long-distance transportation of goods, which often involves diesel-powered trucks that emit significant amounts of CO_2, nitrogen oxides, and particulate matter. By cutting down on transportation-related emissions, RGHs contribute to better overall air quality.

- Greenhouse Gas Mitigation and Improved Biodiversity

Rooftop greenhouses create pockets of green space that can contribute to **urban biodiversity**. These green spaces act as small ecosystems that support insects, birds, and other wildlife, which can further contribute to a healthier environment. Green areas also tend to have lower air pollutant levels because plants continuously cycle gases and particulates, keeping the local environment cleaner.

In summary, rooftop greenhouses improve air quality through CO_2 absorption, particulate filtration, pollutant reduction (like NO_2 and ozone), and by mitigating transportation emissions, while also cooling urban environments. These combined effects make rooftop greenhouses a valuable tool for urban air quality management [5].

Rooftop greenhouses (RGHs) provide several economic benefits that can positively impact both individual building owners and cities as a whole. These benefits range from direct cost savings to broader economic opportunities that stem from integrating urban agriculture into the city's infrastructure. [6]. Here are the key economic advantages of rooftop greenhouses:

- Energy Cost Savings

Rooftop greenhouses can significantly reduce energy costs for the buildings on which they are installed. The benefits include:

- **Thermal insulation**: Greenhouses act as an insulating layer, helping to regulate building temperature. In winter, they trap heat, reducing the need for heating, and in summer, they cool the building through shading and evapotranspiration, reducing the need for air conditioning.
- **Reduced HVAC demand**: By lowering the demand for heating and cooling, building owners can see **energy savings of 10–30%** depending on the climate and the design of the greenhouse.

- Local Food Production and Sales

One of the most direct economic benefits of RGHs is the potential for **local food production**:

- **Urban agriculture**: RGHs allow for year-round food production, especially in cities where space for traditional agriculture is limited. The produce grown in these greenhouses can be sold locally, reducing transportation costs and increasing profit margins for urban farmers.
- **High-value crops**: Since RGHs can create controlled environments, they allow for the cultivation of high-value crops (e.g., herbs, specialty vegetables) that can be sold at premium prices in local markets, restaurants, or directly to consumers through farmers' markets or community-supported agriculture (CSA) programs.
- **Increased food security**: By producing food locally, RGHs can contribute to urban food security and help stabilize food prices, especially during supply chain disruptions.

- Job Creation and Economic Opportunities

Rooftop greenhouses can stimulate the local economy by creating new jobs and business opportunities:

- **Agricultural jobs**: Operating rooftop greenhouses requires labor, from planting and harvesting to managing the greenhouse systems. This creates job opportunities in urban farming, maintenance, and logistics.
- **Related services**: RGHs can lead to the development of related industries, such as urban farming education, consulting services for greenhouse installation and management, and the creation of new markets for locally grown produce.
- **Innovation and technology**: RGHs often employ advanced agricultural techniques such as hydroponics or aquaponics, leading to economic growth in industries that support these technologies (e.g., smart sensors, water management systems, renewable energy solutions).

- Increased Property Value

The presence of a rooftop greenhouse can increase the **property value** of a building:

- **Green infrastructure premium**: Buildings with green infrastructure (including RGHs) are often perceived as more sustainable and energy-efficient, which can increase their market value.
- **Enhanced tenant satisfaction**: In commercial or residential buildings, RGHs can be marketed as amenities, enhancing tenant satisfaction and potentially allowing landlords to charge higher rents. Green features attract environmentally-conscious tenants and businesses, particularly in cities where sustainability is a priority.

- Reduction in Food Transport Costs

By producing food locally, RGHs can reduce the costs associated with transporting food from rural areas to cities:

- **Lower transportation expenses**: The cost of transporting fresh produce from distant farms to urban markets can be significant, both in terms of fuel and labor. RGHs eliminate or drastically reduce these transportation costs.
- **Reduced spoilage and waste**: Locally produced food has a shorter supply chain, meaning it reaches consumers faster and fresher, reducing spoilage and waste. This can lead to **better profit margins** for urban farmers and retailers who rely on perishable goods.

- Tax Incentives and Subsidies

In many cities, governments provide **tax incentives**, **grants**, or **subsidies** to encourage the adoption of green infrastructure, including RGHs:

- **Green building incentives**: Cities with sustainability goals often provide incentives for green roofs, which can be extended to rooftop greenhouses. These incentives can include **tax deductions**, rebates on installation costs, or fast-tracking permits for construction.
- **Carbon credits**: In some regions, rooftop greenhouses that reduce a building's carbon footprint may qualify for **carbon credits** or other environmental subsidies, further lowering the overall cost of installation.

- Long-Term Cost Savings through Sustainability

In addition to direct financial benefits, RGHs offer long-term economic advantages by enhancing the sustainability of urban areas:

- **Mitigation of climate-related risks**: As cities face more frequent heat waves and storms due to climate change, RGHs can help mitigate some of these risks by improving building resilience (e.g., reducing the UHI effect). Lowering the energy needed to cool buildings during extreme heat events can prevent energy shortages and reduce infrastructure strain, saving cities money on emergency measures.
- **Health cost savings**: By improving air quality and reducing pollution through the filtering capabilities of plants, RGHs can contribute to better public health, which translates to **reduced healthcare costs** for both individuals and governments.

- Branding and Marketing Opportunities

For companies or organizations, rooftop greenhouses offer **branding and corporate social responsibility (CSR)** opportunities:

- **Eco-friendly image**: Businesses that invest in RGHs can market themselves as environmentally responsible, which can attract customers and investors looking for sustainable brands.
- **Community engagement**: Organizations can use RGHs as community engagement tools, offering educational programs, tours, or workshops to raise awareness about sustainability and food security.

Fortunately, there is an increasingly accentuated trend in the construction of greenhouses on roofs, and people are increasingly paying attention to the economic benefits as well. Thus the largest rooftop greenhouse in the world was opened in Montreal. Its purpose is to cover the growing demand for locally produced food.

Lufa Farms opened this greenhouse in Canada's second largest city, which has an area of 15 thousand square meters [6]. In fig.5 you can see the extent of this greenhouse on the roof.

Fig. 5. *The largest rooftop greenhouse in the world*

Rooftop greenhouses are not only a sustainable addition to urban infrastructure but also provide multiple economic benefits [7]. From reducing energy and transportation costs to creating local jobs and increasing property values, RGHs offer a strong economic case for cities and businesses looking to invest in green solutions. With growing interest in sustainable urban living, the adoption of RGHs is poised to bring both environmental and economic rewards in the years to come [8].

CONCLUSION

Rooftop greenhouses are an essential part of the solution to urban environmental problems. By addressing both rising temperatures and air pollution, they offer a sustainable and scalable way to enhance urban resilience. As cities continue to grow, the integration of RGHs into urban design will become increasingly important for the health and well-being of urban populations.

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AQUAPONICS AS AN INNOVATIVE TECHNOLOGY FOR SUSTAINABILITY AND ENVIRONMENTAL PROTECTION: CHALLENGES AND INDUSTRIAL SOLUTIONS

Research paper

Daniel Alexuță[1], Marius M. Bălaș[2],
[1]Petroleum-Gas University of Ploiesti, Ploiești Romania
[2]Aurel Vlaicu University of Arad, Arad, Romania

Abstract: Although aquaponics is not a new concept, due to technological developments it is becoming an innovative field that integrates aquaculture and hydroponics into a symbiotic system, significantly reducing water consumption and eliminating the need for chemical fertilizers. Furthermore, by implementing automation concepts, the performance of these systems increases significantly. This paper analyzes the applicability of aquaponic systems from the perspective of energy efficiency as well as industrial engineering, exploring their environmental impact and contribution to the circular economy. The challenges associated with large-scale industrial adoption, such as initial costs and technical requirements, are evaluated, and scalability solutions through technological innovation are proposed. Additionally, the paper includes a mathematical model of fish growth in aquaponic systems and discusses the importance of balancing fish growth with plant productivity.
Key words: Aquaponics, Sustainability, Automation, Resource Efficiency

INTRODUCTION

Conventional agriculture and traditional aquaculture have a significant impact on natural resources, particularly regarding water and energy consumption, as well as soil and water pollution. In this context, innovative technologies such as aquaponics become essential for addressing sustainability and environmental protection challenges, as well as for maximizing continuous development potential [1-3]. Aquaponics combines aquaculture (fish farming) with hydroponics (soil-less plant cultivation) in a closed system where fish waste is converted into nutrients for plants, and in turn, plants purify the water. This allows for efficient resource use, reducing the carbon footprint and the need for chemical fertilizers [4].

MATERIAL AND METHODS

Objectives of the paper

Analyze the benefits of aquaponics for industrial engineering.
Assess the environmental and resource impact.
Model fish growth and the balancing system with plants.
Identify challenges and solutions for large-scale implementation of aquaponic technology.

Principles of aquaponics and industrial applications

Aquaponics operates based on a natural cycle in which fish waste is converted into nutrients by nitrifying bacteria, and plants absorb these nutrients, purifying the water before it is returned to the fish tanks [4]. This technology is becoming increasingly attractive to the agricultural and industrial sectors due to its ability to optimize resources. Combined with smart building concepts, it can help reduce the CO_2 impact generated by buildings through their conversion into green buildings [5].

Commercial applications

Aquaponic systems have been adopted by industries in various regions of the world, particularly in countries such as the USA, Australia, and the Netherlands. Commercial aquaponic farms utilize IoT technology to monitor and optimize water and nutrient parameters, thereby maximizing the yield of both fish and plants simultaneously [6]. In the USA, they have developed modular systems that allow farmers to raise fish and plants in urban areas, while ensuring minimal environmental impact and contributing to CO_2 reduction by eliminating the need for long-distance transportation of produce, as it is locally grown through such aquaponic systems [7].

Fish growth modeling

An important aspect of managing aquaponics on an industrial scale is modeling and optimizing fish growth in relation to nutrient absorption by plants. The logistic growth model for fish can be used to simulate the evolution of their mass over time and the amount of food available [8].

Logistic model:

$$W(t) = \frac{W_{max}}{1 + e^{-r(t-t_0)}} \qquad (1)$$

Where:
- $W(t)$ is the weight of the fish at a given time t,
- W_{max} is the maximum weight the fish can reach,
- r is the growth rate,
- t_0 is the initial time.

This equation allows for the estimation of fish growth and the adjustment of feeding and maintenance parameters to maximize yield and maintain the balance between fish production and the nutrient needs of the plants. The model is adapted to estimate fish weight based on this logistic growth principle, which we aim to compare with other fish growth models from the specialized literature in the future.

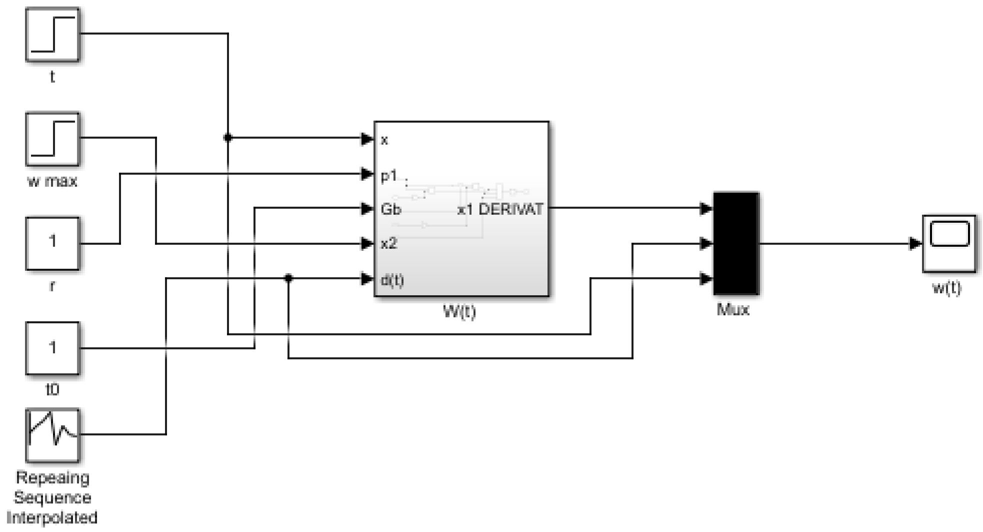

Fig. 1. *Implementation of the mathematical model in Matlab Simulink*

Model description

Among the most significant probability models is the logistic model, which can be applied to specific sports models adapted to needs, being merely a probability given certain initial conditions. In the context of aquaponics, fish growth can be limited by the amount of food available and assimilated by the fish, as well as by fish density and water quality. Using this equation, we can model how different variables affect growth and how we can adjust conditions to achieve an optimal balance between the needs of fish and plants [9].
We can also introduce corrections for variable conditions such as temperature and dissolved oxygen concentration, factors that influence both fish growth and plant health. Fish growth is directly proportional to the amount of waste produced, which in turn affects the concentration of nutrients available for plants.

Resource efficiency and ecological impact

Aquaponics is considered one of the most efficient solutions in terms of resource consumption, particularly water and energy. Aquaponic systems require only 10% of the water needed in traditional agriculture and do not use chemical fertilizers, as plants obtain their nutrients from fish waste. This closed-loop cycle prevents groundwater and soil contamination with toxic substances [10, 11].

RESULTS AND DISCUSSION

Challenges in the large-scale implementation of aquaponics, initial costs and maintenance

Although aquaponics offers long-term benefits, the initial costs are significant. The infrastructure required to create a functional aquaponic system includes fish tanks, biological filtration systems, and pumping equipment. However, as technology evolves and more affordable modular systems are developed, these costs may be reduced [12].

Technical knowledge and specialized personnel

Another major obstacle is the need for advanced technical knowledge to manage an industrial-scale aquaponic system. Well-trained personnel who understand the biochemical interactions between fish, plants, and bacteria are essential. Continuous monitoring of water parameters such as pH, dissolved oxygen, and nutrient concentration is crucial for the success of such a system [13].

Regulations and legislative challenges

Legislation regarding aquaculture and hydroponics can present a barrier to the widespread adoption of aquaponics. In many regions, food safety regulations or water usage regulations may delay or even block the development of commercial aquaponic farms.

Solutions for scaling up aquaponics to an industrial level, scalable and accessible technologies

The development of modular, accessible, and scalable systems is a solution for reducing initial costs. These systems can be adapted to meet the needs of smaller farms or gradually expanded based on market demands [14].

Fig. 2. *Monitoring the water quality parameters in the aquaculture system, alert parameters*

Fig. 3. *Monitoring the water quality parameters in the aquaculture system*

Automated monitoring technologies and intelligent control techniques

Automatic monitoring technologies, as well as intelligent control techniques or interpolative fuzzy control, using sensors for water quality, can optimize processes within aquaponic farms. Automation allows for the rapid adjustment of parameters such as pH or temperature, ensuring a stable environment for the growth of fish and plants [15, 16].

CONCLUSION

Aquaponics represents a promising solution for sustainable and efficient agriculture. The mathematical modeling of fish growth and the optimal balance between plant and fish production is essential for maximizing the productivity of aquaponic systems. Although there are challenges in large-scale implementation, technological innovations and the development of accessible solutions can make aquaponics a viable technology for the future of industrial agriculture.

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ASSESSING THE LANDSCAPE OF HAZARDOUS CHEMICALS MANAGEMENT

Review paper

Dunja Istrat[1*], Jelena Ćulibrk[2], Maja Petrović[3]
[1,2,3]University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

Abstract: Hazardous chemicals, characterized by their toxic, corrosive, or reactive properties, present significant risks to human health, environmental integrity, and animal welfare. Despite their inherent dangers, these substances are essential in various industrial applications, ranging from manufacturing to healthcare. Effective management of hazardous chemicals is critical not only for regulatory compliance but also for the protection of workers and surrounding communities. This paper conducts a comprehensive (SWOT analysis of existing methodologies for hazardous chemical management. Through a systematic review of the literature, this study identifies key strengths, including enhanced safety outcomes and improved regulatory adherence, alongside inherent weaknesses such as implementation challenges and cost implications. By synthesizing these findings, this study aims to provide a nuanced understanding of the dynamics surrounding hazardous chemical management and to propose actionable insights for industry practitioners. Moreover, this research contributes to the ongoing discourse on sustainable practices in hazardous chemical management and emphasizes the need for continuous improvement to ensure worker safety and environmental protection.
Key words: hazardous chemical, management, sustainable practices

INTRODUCTION

Hazardous chemicals, defined by their physical, chemical, or biological properties, pose significant risks to human health, animal welfare, and environmental integrity. These substances, which include acids, solvents, pesticides, heavy metals, and industrial gases, exhibit harmful characteristics such as toxicity, corrosiveness, volatility, reactivity, and carcinogenicity [1]. Despite their potential dangers, hazardous chemicals play a crucial role across various industries, including manufacturing, healthcare, construction, and engineering. Associated risks encompass chemical burns, poisoning, respiratory complications, explosions, and environmental degradation due to their solid, liquid, or gaseous states at room temperature.

The risks associated with hazardous chemicals are multifaceted and can result in chemical burns, acute poisoning, chronic respiratory complications, explosive incidents, and environmental degradation through soil and water contamination. These risks extend beyond individual exposure, affecting communities and ecosystems. As such, the management of hazardous chemicals is not only a legal requirement but also a critical component of occupational health and safety protocols aimed at protecting workers, the public, and the environment from harm. In addition to the legal imperatives governing the safe handling of hazardous chemicals, effective management practices are essential for safeguarding workers, the public, and the environment [2].

This study aims to conduct a comprehensive Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis of various methodologies employed to manage chemicals with hazardous properties. Specifically, this analysis will explore conventional methods, such as regulatory compliance and training programs, as well as innovative approaches, including green chemistry, waste minimization techniques, and advanced chemical management systems. Furthermore, the paper seeks to review the existing literature to highlight successful case studies and emerging best practices in the field.

In examining these various methodologies, this study will provide a nuanced understanding of the strengths, such as improved safety outcomes and regulatory compliance, and weaknesses, including potential cost implications and implementation challenges.

[1]Corresponding author, dunjaistrat@uns.ac.rs
[2] pavlovic.j@gmail.com, https://orcid.org/0000-0002-0630-4051
[3] majadjogo@uns.ac.rs, https://orcid.org/0000-0003-3423-6559

Additionally, opportunities for enhancing hazardous chemical management through technological advancements and stakeholder engagement will be discussed, along with threats posed by regulatory changes, economic pressures, and public perception.
This study aspires to present a holistic overview of the advantages and disadvantages inherent in the management of hazardous chemicals, thereby contributing to the ongoing discourse on sustainable practices and the promotion of safer chemical handling in industrial and commercial contexts.

MATERIAL AND METHODS

Selection of case studies

Figure 1 delineates the selection process employed in the analysis of research pertaining to the management of hazardous chemicals. The database ScienceDirect was utilized to identify relevant scientific papers, utilizing a targeted search strategy that incorporated three specific search terms. Following an initial review of the titles and abstracts, a comprehensive evaluation of the identified studies was conducted, resulting in the final selection of nine papers for in-depth analysis. This systematic approach ensures that the selected literature is both relevant and representative of current trends and methodologies in hazardous chemical management.

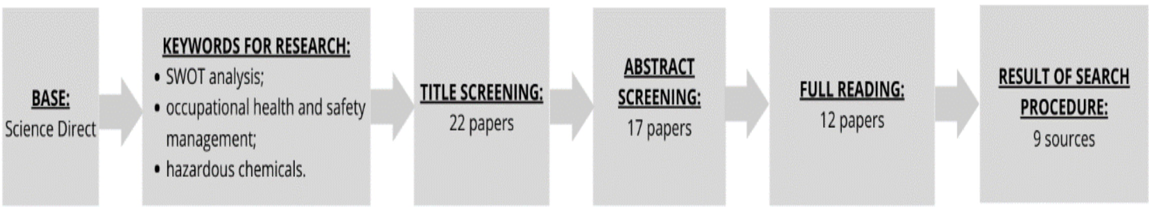

Fig. 1. *The process of selecting papers*

SWOT analysis

In this study, a SWOT analysis is employed as a systematic approach to evaluate the management of hazardous chemicals. This technique serves as a valuable framework for organizations to assess their current positioning concerning their goals and objectives. The SWOT analysis delineates four critical components: strengths, weaknesses, opportunities, and threats, facilitating a comprehensive understanding of both internal and external factors that can influence the success or failure of various management strategies related to hazardous chemicals.
Strengths and weaknesses pertain to the internal characteristics of an organization, encompassing resources, capabilities, and processes that can either enhance or hinder effective hazardous chemicals management. In contrast, opportunities and threats are derived from external environmental factors, including regulatory landscapes, market trends, and technological advancements that can present new avenues for improvement or pose challenges.
This methodology is instrumental in identifying strategic pathways and determining the current state of organizations compared to their desired future state. By synthesizing internal and external analyses, a nuanced understanding of the dynamics surrounding hazardous chemicals management is achieved. Furthermore, this review examines existing literature to substantiate the findings of the SWOT analysis, drawing on empirical evidence and case studies to highlight the multifaceted nature of hazardous chemicals management within diverse industrial contexts. Through this methodology, actionable insights are provided to inform decision-making processes and enhance the overall safety and efficacy of hazardous chemicals management strategies.

RESULTS AND DISCUSSION

A comprehensive tabular SWOT analysis (Tables 1, 2, and 3) was conducted to evaluate various safe handling practices related to hazardous chemicals. This analysis encompasses critical components such as identification and labeling, training and education, and the use of personal protective equipment (PPE).

Table 1. *SWOT Analysis of Hazardous Chemical Identification and Labeling Practices [5]*

S	**Improved safety:** Proper identification and labeling of hazardous chemicals provide clear information about the risks associated with each chemical.
	Legal framework: Labeling standards help organizations comply with regulations and save them from penalization through law.
	Clear communication: The labels provide information on safe handling, storage and first-aid measures so a worker can receive the needed information.
W	**Wrong labeling:** Incorrect labeling or giving false information leads to confusion and improper handling.
	Cost: Labeling costs can be high (numerous standards, materials and equipment).
	The complexity of the law: Navigating and updating complex and constantly changing regulations can be a challenge.
O	**Advances in technology:** New technologies (digital ways of labeling, automated management) can improve the efficiency of the chemical identification and its labeling.
	Improved standards: Global standards can harmonize labeling practices across industries and countries.
	Increased awareness: Increasing awareness can improve management practices.
T	**Penalties for non-compliance:** Failure to comply with labeling rules can induce legal consequences, which can later affect an organization's reputation and financial stability.
	Falsified labels: The risk of falsified or misleading labels can reduce the level of occupational safety and lead to serious accidents.
	Employee irresponsibility: Even with proper labeling, the risk of accidents and injuries remains high if employees do not follow safety procedures or ignore label information.

The SWOT analysis underscores the necessity of comprehensive hazardous chemical labeling practices that not only comply with legal standards but also prioritize worker safety and organizational efficiency. By leveraging strengths and opportunities while addressing weaknesses and threats, organizations can significantly enhance their hazardous chemicals management strategies, thereby fostering a safer and more sustainable work environment.
An effective approach to mitigating hazards associated with hazardous chemicals is through comprehensive training and education programs. It is essential that employees who handle these substances receive thorough education regarding the inherent risks and the appropriate methods for safe handling. Such training should encompass critical aspects, including the proper use of personal protective equipment (PPE), emergency response protocols, and best practices for safe storage. By equipping employees with the necessary knowledge and skills, organizations can significantly reduce the likelihood of accidents and

ensure compliance with health and safety regulations. This proactive educational framework not only promotes a culture of safety within the workplace but also empowers employees to take informed actions in response to potential hazards, ultimately safeguarding their health and well-being [6].

Table 2. *SWOT Analysis of training and education approaches in hazardous chemicals management [6]*

S	**Improved safety:** Adequate education and training of workers reduces the risk of injury and illness.
	Better response in case of danger: Educated workers react faster and better in case of problems.
	Increased awareness: Training programs raise awareness of the possible risks.
W	**Time-consuming:** Trainings require a lot of time, which affects the productivity of workers.
	Retention and application: It is possible that workers will not adequately retain and apply knowledge.
	Consistency: It can be difficult to provide workers with consistent training (large companies).
O	**Technological innovations:** Advances in technology (e-learning platforms, virtual reality (VR), simulation tools) offer opportunities for more engaging and effective training methods.
	Continuous education: It can help keep employees informed of new regulations, procedures and best practices.
	Partnerships and certifications: Collaboration with industry experts and certification bodies can improve the credibility and effectiveness of training programs.
T	**Legal changes:** These can require continuous updating of training programs, which can be resource-intensive and challenging to track.
	Training fatigue: Employees may experience training fatigue or resistance, leading to reduced engagement and effectiveness of training programs.
	Inadequate trainers: Poorly implemented training programs cannot effectively address critical safety issues.

While training and education are indispensable components of hazardous chemicals management, the effectiveness of these programs hinges on the identification and mitigation of their inherent weaknesses and threats. By leveraging strengths and opportunities, organizations can develop robust training frameworks that not only enhance safety and compliance but also foster a culture of continuous improvement in hazardous chemicals management. This comprehensive approach will ultimately contribute to a safer working environment and better protection for employees, the public, and the environment.

Personal Protective Equipment (PPE) plays a crucial role in safeguarding workers who handle hazardous chemicals. The selection of appropriate PPE, which may include gloves, face shields, protective clothing, and respirators, is contingent upon the specific properties and hazards associated with the chemicals in use. When properly utilized, PPE can substantially mitigate the risk of exposure to harmful substances, thereby enhancing the overall safety and health of personnel engaged in chemical handling activities. Moreover, it is imperative that organizations implement comprehensive training programs to ensure that employees are proficient in the selection, use, and maintenance of PPE, thereby maximizing its effectiveness as a protective measure. Additionally, adherence to regulatory guidelines and standards in PPE usage is essential to maintain compliance and promote a culture of safety within the workplace.

Table 3. *SWOT analysis of PPE for hazardous chemicals handling [7]*

S	**Improved protection:** Properly selected PPE protects against chemical exposure, reducing the risk of injuries such as burns, respiratory problems and skin irritation.
	Adaptability: PPE can be adapted to the specific needs of different chemical handling tasks.
	Reduced long-term costs: PPE prevent chemical-related injuries and illnesses, reducing long-term costs.
W	**Problems related to comfort and use of equipment:** PPE can be uncomfortable or restrictive, which is why workers may refuse to wear it consistently.
	Cost: High-quality PPE can be expensive.
	Maintenance and replacement: PPE requires regular maintenance and timely replacement to remain effective.
O	**Technological advances:** Innovations in materials and design (improved barrier fabrics, more comfortable ergonomic designs) can improve the effectiveness and comfort of PPE.
	Customization: Advances in technology enable more personalized PPE solutions (customizable and built-in designs).
	Increased awareness and demand: Growing awareness of workplace safety and health can increase the demand for better and more effective PPE.
T	**Non-standard products:** The presence of non-standard PPE on the market can decrease safety.
	Improper use: It can lead to ineffective protection and an increased risk of chemical exposure.
	Workplace culture: A lack of emphasis on safety culture or inadequate implementation of PPE use can lead to reduced effectiveness of protective measures.

Safe management of hazardous chemicals encompasses a range of additional methods beyond personal protective equipment (PPE), including adequate storage, effective ventilation, engineering controls, and appropriate waste disposal practices. Proper storage is crucial for minimizing the risks associated with hazardous substances. Dangerous chemicals should be stored in containers specifically designed for compatibility with their chemical properties, ensuring resistance to leaks and spills. Storage areas must be clearly marked and well-ventilated, positioned away from potential heat sources that could induce hazardous reactions. Moreover, chemicals that are reactive with one another should be stored separately to prevent potentially dangerous interactions. Compliance with local laws and environmental regulations is essential when disposing of hazardous waste, which typically involves using designated containers and following established procedures. Adequate ventilation is vital when working with hazardous chemicals, particularly volatile substances and gases, to minimize the risk of inhalation exposure. Implementing engineering controls, such as fume hoods and exhaust systems, can effectively reduce airborne contaminants and further protect workers. These controls help to create a safer working environment by actively removing hazardous substances from the air, thereby lowering the likelihood of exposure and associated health risks [8].

Despite the necessity for safe handling practices, industries encounter several challenges that can impede effective management of hazardous chemicals [9]:

- Insufficient training or lack of attention to safety protocols can significantly elevate the risk of chemical-related injuries. Ensuring that all personnel handling hazardous substances receive comprehensive training is paramount to mitigating these risks.
- Navigating the intricate landscape of regulations governing hazardous chemicals can be particularly challenging for organizations, especially those operating across multiple jurisdictions. Each region may have its own set of laws and guidelines, complicating compliance efforts and increasing the risk of violations.
- Continued research and development are necessary to enhance safety measures related to hazardous chemical management. Existing technologies may not fully address the evolving nature of hazards associated with new chemicals or complex industrial processes, necessitating innovation in safety solutions.

CONCLUSION

While various methods for the safe management of hazardous chemicals are available, their effective implementation is frequently obstructed by challenges such as worker errors, intricate regulatory frameworks, and technological limitations. A proactive strategy that encompasses continuous training, investment in safety technologies, and collaborative efforts to standardize regulations across regions is essential for enhancing the safety and effectiveness of hazardous chemical management practices in industry.

The conducted SWOT analysis underscores the necessity of adopting specific management strategies tailored to the unique needs and challenges of each industry. Organizations can significantly improve their safety measures by leveraging their strengths, addressing or mitigating weaknesses and threats, and seizing new opportunities. Key strategies include ensuring proper identification and labeling of hazardous chemicals, providing comprehensive training, utilizing appropriate PPE, maintaining proper storage conditions, implementing effective spill response protocols, and adhering to proper disposal methods.

Furthermore, ongoing education, compliance with regulatory requirements, and continuous investment in safety technologies are vital for sustaining a safe and healthy workplace. By prioritizing these elements, organizations can foster an environment that minimizes the risks associated with hazardous chemicals, ultimately protecting workers, the public, and the environment.

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NEOLIBERALISM AND CLIMATE CHANGE: TOWARDS A SUSTAINABLE ECONOMY THROUGH THE GREEN NEW DEAL

Research paper

Edi Daruši[1*]
[1]Zrenjaninska gimnazija, Zrenjanin, Serbia

Abstract: Given the magnitude of the global climate crisis, minimal taxation and market-based regulations aimed at limiting carbon dioxide emissions have proven inadequate in mitigating climate change. As such, the delegation of governmental capacities to the private sector, focused predominantly on efficiency measures, has been ineffective in addressing the complexities of climate change. What is required, therefore, is a comprehensive transformation of the economic system. Governments must prioritize investment in domestic capacities, particularly in sectors such as production, public procurement, and public-private partnerships, with the overarching aim of serving the collective public interest, rather than merely maximizing corporate profits. This necessitates an economic restructuring oriented towards ambitious objectives critical to both human and planetary well-being, while simultaneously reevaluating the framework of capitalism to confront the most pressing challenge of our era. Corporate governance must realign with public interest principles. A shift in public discourse, political rationality, and economic paradigms is imperative for fostering the development of new global values. Drawing historical parallels with the Marshall Plan and Roosevelt's New Deal is essential, as these initiatives illustrate instances where humanity demonstrated the capacity to conceptualize socio-economic change on a comparable scale.
Key words: global climate change, government, market, neoliberalism, the Green New Deal

INTRODUCTION

Global climate change is progressing at a much faster pace than projected by climatological models. If humanity continues to pollute the environment at the current rate, it will face consequences that are fundamentally incompatible with the preservation of a civilized global society. As Stephen Hawking emphasized, our resources are being depleted at an alarming rate, and we have burdened our planet with the catastrophic consequences of climate change: "Temperatures are rising, polar ice caps are shrinking, forests are being cleared, and animal species are being decimated."[1].Despite the overwhelming evidence, there remains a faction that defends the notion that climate change is either nonexistent or a fabrication of the political left [2].Numerous scholars counter this claim, arguing that the denial of climate disruption is in fact a defense of market fundamentalism and the neoliberal ideological project, whose influence on historical developments has led to the situation where "...spontaneous evolutionary processes have been replaced by planned evolution."[3]. By the late 1980s, an extreme anti-regulatory form of capitalism began to dominate the global economy, propelling us toward catastrophic climate consequences. As Naomi Klein illustratively points out: "During that period, we expanded roads from two-lane highways to carbon-emitting six-lane superhighways." [4].
Climate change represents a critical threat to the ideological framework of modern capitalism. The path to this climate crisis has been paved by corporate interests and decades of neoliberal policies that promote deregulation and resist legal oversight of corporate behavior. Efforts to address climate change through simple mechanisms, such as carbon taxes or the establishment of emission trading schemes, have proven insufficient. Markets have not autonomously discovered a green trajectory.
Given the magnitude of the global crisis, radical and comprehensive solutions are required solutions that fundamentally transform both national and global economies, and that challenge the current structure of capitalism. A new Green New Deal is essential, the one that unites stakeholders from the public, private, and civil sectors, guiding them toward long-term outcomes with the public interest as the central focs of their actions.

[1]Corresponding author, edidarusi@gmail.com

This paper explores the challenges posed by the global climate crisis, exacerbated by climate change resulting from intensive economic development centered on fossil fuel exploitation. The analysis critically examines the economic-political models that facilitate such development, highlighting the urgent need for their reform through the implementation of innovative policies that foster a green economy and promote sustainable development.

MATERIAL AND METHODS

The primary issue this paper addresses is the inadequacy of the neoliberal capitalist framework in effectively confronting climate change. This inadequacy is evident in the inefficacy of the greenhouse gas emissions trading system, which has failed to make significant contributions toward mitigating the climate crisis. Addressing this problem necessitates fundamental transformations in economic policies, alongside the mobilization of global collective efforts to ensure a sustainable future. Considering the identified problem, the following research objectives are formulated:

1. To investigate the implications of climate change on the global ecosystem, analyzing the multifaceted factors that contribute to its deterioration.
2. To critically evaluate the neoliberal capitalist system and its systemic shortcomings in providing effective responses to the challenges posed by climate change.
3. To assess alternative economic models, with a particular focus on the concept of the "Green New Deal" as a viable framework for facilitating green transitions and promoting sustainable development.
4. To propose comprehensive strategies and policies aimed at transforming the economy toward sustainable practices, including a transition to renewable energy sources, the development of sustainable infrastructure, and the adoption of environmentally responsible practices.
5. To identify key stakeholders and formulate recommendations for fostering long-term collaboration among governmental institutions, the private sector, civil society, and international organizations in response to the climate crisis.

The Runaway World

In conjunction with the positive opportunities presented by globalization and technological advancements (particularly in the realms of information technology and digitalization) numerous risks have also emerged, among which climate change is paramount. Currently, we are confronted with the prevalence of "manufactured risks" [5] which arise directly from the impact of human knowledge, technology, and economic development predicated on fossil fuel exploitation on the natural environment. Pečujlić (2005) emphasizes this point: "The immense scale of contemporary risk stems from its inherent nature. Risks do not originate from external factors, such as natural disasters, biblical floods, or earthquakes; they are a product of human actions, reflecting limited control over one's actions and their consequences. These risks are not random or incidental outcomes but rather logical consequences of the dominant model of technological-economic development. They do not result from a deficiency in technology; rather, as technology evolves, these risks do not diminish but rather increase significantly."
Global climate changes and the associated dangers represent the catastrophic repercussions of neoliberal globalization: the greenhouse effect, genetically modified organisms, epidemics, shortages of potable water, and natural calamities. According to Giddens, some manufactured risks indeed pose catastrophic threats, such as global ecological hazards, the proliferation of nuclear technology, or the potential collapse of the global economy. The neoliberal paradigm has restructured the contemporary world into a global risk society that eludes our control: "...a kind of runaway world..." [2]
Despite Nobel laureate Joseph E. Stiglitz's assertion that national governments must assume responsibility for addressing environmental degradation, inequality, and unemployment, the current model of economic neoliberal globalization does not serve the interests of most of the

humanity. During his tenure as Chief Economist at the World Bank (1997-2000), Stiglitz witnessed firsthand the devastating effects of globalization: "I saw, firsthand, the destructive eiffects of globalization..." [7]
The economic models imposed upon developing nations—formulated in the White House, the International Monetary Fund, and the World Bank—"...which all serve the objectives of multinational corporations..." (Mander, 2003), have been enacted due to ideologies that cater to the interests of individuals and multinational corporations, interconnected "...in a networked global hierarchy of power that seeks to establish a cohesive post-sovereign international order" [9]. These models have led to environmental devastation, triggering mass migrations to urban centers and the proliferation of desperate employment in exploitative factories, as underscored by Klein [10].

Climate Change and Neoliberal Economic Globalization

Despite a widespread belief among many that climate change constitutes a distant crisis, suggesting that humanity has ample time to respond, Canadian environmental activist and author Naomi Klein argues that radical transformations on our planet are already underway: "...these changes are not a matter of some distant future, they are occurring now, and their consequences are unfathomable" [11]
This leads to a perplexing determination to deny the existence of climate change and global warming. While individuals may grasp the meaning of the term "climate change", a significant portion of humanity remains ensnared in a chasm between immediate concerns and the "distant future" of climatic chaos. This dissonance gives rise to what is termed "Giddens' Paradox," where "...the vast majority of people do little or nothing to alter their everyday habits, despite the fact that these habits are the source of the dangers posed by climate change" [2]. Anthony Giddens warns that the threats posed by global warming, which are not sufficiently visible or immediate in daily life, lead many individuals to refrain from acting concerning climate change, action that may ultimately be too late when substantial measures are finally undertaken.
The actions we take (or neglect to take) today will have profound implications for future generations. Global climate change is occurring at a pace far exceeding projections made by climatological models [12]. Even with a mere one-degree Celsius rise in global temperatures, we are witnessing dramatic consequences: extinctions of numerous plant and animal species, coral bleaching, accelerated melting of the Antarctic ice sheet, ocean warming, and rising sea levels, alongside natural disasters of unprecedented magnitude. Thus, climate disturbances represent not a distant threat on the horizon, but rather a present and tangible threat of planetary proportions. If humanity continues to pollute the Earth at this rate, it is likely we will raise global temperatures by 4-5 degrees Celsius, an outcome incompatible with the preservation of a sustainable global society.
However, the defense of the position denying the existence of climate change simultaneously supports the neoliberal ideological framework and the market fundamentalism upon which it is predicated. Acknowledging the reality of the climate crisis would signal the demise of the neoliberal project. As Klein asserts, "...the entrenched neoliberal way of doing business leads to a catastrophe that threatens us as a species" (Klein, 2018). Therefore, it is imperative to confront the most powerful industries globally: "The fossil fuel companies and the banks that finance them" [13]
Klein posits that the current climatic turmoil results from corporate interests and a decades-long pivot toward exclusively neoliberal objectives focused on capital and free markets that have prevailed since the 1990s. She notes that our failure to adequately respond to the climate crisis can be attributed to the fact that it has emerged at an inopportune moment: "...in the late 1980s when capitalism was at the height of its victorious triumphalism"[14]. Consequently, we find ourselves in a state of global defeat in the struggle against climate issues, confronting a collision between climate-induced necessities and the dominance of global corporations, in conjunction with the triumph of neoliberal ideology.

Carbon Emissions Trading MarkeT

According to international institutions and certain economists, markets, particularly carbon emissions trading markets, play a crucial role in combating climate change.
At the 1992 Rio de Janeiro Summit, the UN Framework Convention on Climate Change was adopted, establishing broad consensus on the necessity of reducing harmful gas emissions to stabilize climate change. However, developed nations, such as the United States, opposed this agreement, arguing that it did not impose emission reduction obligations on developing countries. This resistance was primarily fueled by the significant influence of the industrial and energy lobbies, which were concerned that China, as a developing country not bound to reduce emissions, could undermine the competitive advantage of developed nations. Such interests significantly impacted the implementation of the Kyoto Protocol, which has largely been dismissed over time as unrealistic [2].
Regarding the European Union, it has been the most active proponent of limiting harmful gas emissions. The EU Emissions Trading System was planned as a mechanism to enable member states to fulfill their obligations. However, the business community criticized the EU's efforts, arguing that increased energy costs negatively affect the competitive positions of European companies in the global market, potentially prompting them to relocate their operations elsewhere [15].
A key question remains regarding the effectiveness of the European carbon emissions trading system. Markets should not be allowed to self-regulate, nor should they be deemed a successful concept solely based on the volume of emissions trading occurring within this market. It seems that the fundamental purpose of the carbon emissions trading system, which is to encourage green technological innovations essential for emissions reduction, is often overlooked.
Thus far, the results have not been encouraging. While the EU Emissions Trading System aims to limit the amount of carbon dioxide companies emit, it allows them to purchase rights to additional emissions from companies that do not utilize their permitted emission allowances. This approach generates significant financial flows within the market. Therefore, Mariana Mazzucato argues that markets alone are incapable of finding a "green direction". Governments, through regulation and the promotion of innovation via public-private partnerships, have a crucial role in providing the momentum necessary to effectively address climate change (Mazzucato, 2022).

The Green New Deal

Considering the unprecedented scale of the global climate crisis, minimal taxation or market regulation of carbon dioxide emissions, as Naomi Klein argues, fails to address the comprehensive transformation required across the entire economy [12]. Establishing historical parallels with initiatives such as the Marshall Plan or Roosevelt's New Deal is essential, as these examples remind us of periods when humanity demonstrated the capacity to conceive of socio-economic changes on a vast scale. The necessity for transformation across all dimensions of our economy inherently leads to resistance from numerous powerful interests within the corporate, industrial, and financial sectors. Mariana Mazzucato cautions that the challenges currently faced by neoliberal capitalist states are a direct result of a four-decade decline in the capacity of national governments to effectively manage economic and public policies. This decline has been exacerbated by a neoliberal paradigm that prioritizes market supremacy and deregulation, consequently marginalizing the roles of government (Mazzucato, 2022). As Barnet and Müller (1974) articulate, "Those who run global corporations... strive to manage the world as a unified economic whole." Thus, the pressing need for "...proper and effective management of social development" arises [17].
As previously indicated, scientific and technological advancements, bolstered by state support, will play a critical role in mitigating greenhouse gas emissions [2].

Developed nations must take the lead in reducing harmful gas emissions by transitioning to a low-carbon economy and implementing necessary social reforms grounded in climate change considerations. Governments should foster an innovative environment that nurtures the diversity of social groups capable of driving the development of long-term climate-oriented policies. Consequently, the vision for the future emerges from the synthesis of economic, social, and political dimensions: "In response to climate change... we can anticipate a multitude of technological innovations, and we should endeavor to encourage this. Without such innovations, it is impossible to envision an end to our dependence on oil, natural gas, and coal, which serve as the primary sources of environmental pollution" [2]

An avant-garde of entrepreneurs is imperative to facilitate new ventures and technologies predicated on the vision of a low-carbon future. The era of market deregulation has concluded, and any return to state control must not revert to outdated methods of managing climate change. States must invest in renewable energy sources that will not materialize under market forces, as they cannot compete with fossil fuels.

Giddens (2010) delineates the imperative tasks that governments must undertake, leveraging their authority in the struggle against climate change:

1. Foresight in Governance: Governments should promote long-term strategic thinking among corporations, civil society organizations, and individuals.
2. Crisis Management: Governments must assume responsibility for managing not only energy and climate crises but also other crises stemming from industrialization and the development of fossil fuel-dependent civilizations.
3. Preparation for Societal Transformation: Authorities need to prepare citizens, public institutions, and the economy for the socio-economic changes necessitated by a low-carbon economy through targeted economic and political measures.
4. Institutionalizing the Polluter Pays Principle: States must intervene in markets to institutionalize the "polluter pays" principle, thereby ensuring that market mechanisms contribute to climate policies by establishing prices that reflect environmental costs. Governments should integrate ecological costs into market competition.
5. Counteracting Corporate Influence: Given the predominant influence of multinational corporations in today's globalized landscape, it is vital for states to counteract corporate interests that obstruct initiatives aimed at addressing climate change.
6. Creating Economic Space for Transition: Through the endorsement of new low-carbon technologies, governments should establish a fiscal and economic framework that facilitates a rapid transition to a low-carbon economy.
7. Centrality of Climate Change in Political Discourse: Climate change must occupy a central position in political dialogue, even amidst political disagreements in other domains.
8. Proactive Adaptation to Climate Consequences: By proactively adapting to the effects of global warming, states should strive to minimize their impact to the greatest extent possible.
9. Integration of Climate Policies: Finally, the unification of local, regional, national, and global policies concerning climate change is essential for effectively addressing the challenges posed by global climate change.

Furthermore, it is imperative to redesign financial instruments. Financial institutions should direct resources toward green investments that promote technological innovations and infrastructure projects aimed at sustainability [18]

In conclusion, the era of market deregulation has ended, and any return to state control must not revert to antiquated approaches to climate change management. States must prioritize investments in renewable energy sources that will not emerge under the influence of market forces due to their inability to compete with fossil fuels. Moreover, it is essential to emphasize the necessity for pioneering entrepreneurs who can drive new initiatives and technologies based on a vision of a low-carbon future.

RESULTS AND DISCUSSION

Despite the urgent need for immediate action on climate change, green campaigns remain largely isolated, lacking a unified, globally coordinated strategy. Similarly, the innovative technology sector is primarily profit-driven, without a clear green vision. For humanity to unite in a global environmental protection movement, a broader international initiative, currently not on the horizon, must urgently be organized under the United Nations' leadership. Until then, global temperatures will continue to rise.

CONCLUSION

In summary, climate change denial serves not as a scientific debate but as an ideological construct, heavily influenced by the financial interests of multinational corporations. To effectively counter the pervasive climate crisis, a critical reassessment of the neoliberal capitalist framework that has dominated global discourse since the 1980s is essential. Research indicates a troubling link between the rejection of established climate science and the socio-economic privileges enjoyed by certain demographics: "Given the expansive threat that climate change poses to the industrial capitalist system, it is unsurprising that the resolute positions of conservative white males actively facilitate the denial of climate change"[12].
The escalating awareness of climate change and its profound repercussions—such as rising poverty, societal disintegration, forced migrations, and conflicts over dwindling resources—raises urgent questions about humanity's ability to escape the metaphorical "valley of tears." It compels us to confront the sacrifices required for meaningful change and the inevitable marginalization of vulnerable populations in the process. Jürgen Habermas underscores this urgency, asking, "...how many marginalized destinies will remain lying by the wayside, and how many irreplaceable civilizational achievements will fall victim to this creative destruction?" [19]
At its core, the challenge lies in dismantling the neoliberal economic paradigm and confronting the unfulfilled promises of deregulated market capitalism. Modern capitalism, particularly its extreme anti-regulatory form, has significantly shaped global economies since the 1980s, propelling us toward destruction (Klein, 2014).
Consequently, expecting radical shifts in multinational corporations' approaches to climate solutions, given their inherent alignment with neoliberal principles, is inherently misguided. This underscores the pressing necessity for a redefined role of the state within the framework of the Green New Deal. Such a redefinition must emphasize proactive governance that champions systemic change and fosters an inclusive climate policy agenda, ultimately addressing the dual imperatives of environmental sustainability and social equity. As we navigate this complex landscape, the state must emerge as a leader, forging pathways toward a sustainable future that prioritizes the well-being of both the planet and its inhabitants.

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EXTENDING THE APPLICATION OF VR/AR TECHNOLOGY TO IMPROVE SAFETY TRAINING IN THE CRUDE OIL INDUSTRY

Research paper

Adrijana Babić[1*], Zoran Čepić[2]
[1] University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering and Occupational Safety and Health, Trg D. Obradovića 6, Novi Sad, Serbia

Abstract: The crude oil industry is one of the most hazardous sectors, demanding rigorous and uniform safety training. The use of Virtual Reality (VR) and Augmented Reality (AR) technologies in this domain has shown significant potential in enhancing training efficiency, reducing stress, and standardizing training processes. This paper delves into the application of VR/AR in safety training, particularly during capital overhauls in crude oil refineries when the presence of over 2000 foreign workers necessitates uniform and effective training methodologies. Emphasis is placed on how VR/AR can increase competence, manage stress, and deliver consistent training practices essential for maintaining safety standards in the high-pressure environments of refinery overhauls.
Keywords: Chemical industry; AR/VR technology; Work safety

INTRODUCTION

The crude oil industry, characterized by its vast and hazardous environments, demands rigorous safety training that not only ensures competence but also reduces stress and uniformly prepares employees, including foreign workers, for high-stakes operations. In Serbia, the Ministry of Labour, Employment, Veterans and Social Affairs, Administration for Safety and Health at Work is responsible for tracking workplace injuries. The 2020 report indicates that industrial sector accounts for 17.54% of total injuries, with 88 injuries reported within the oil industry [1]. The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies into safety training programs holds promise for enhancing these metrics. This paper extends previous research on VR/AR applications by exploring recent advancements in safety training methodologies, focusing on increasing competence, lowering stress levels, and delivering uniform training during capital overhauls in crude oil refineries.

ENHANCING COMPETENCE THROUGH VR/AR TRAINING

Skill Enhancement

VR/AR technologies facilitate hands-on training experiences without the associated risks of traditional methods. Studies have shown that VR training systems significantly improve equipment manipulation accuracy and safety. After VR/AR training, employees exhibit an 18% improvement in hazard perception compared to those trained with traditional methods. [2] This immersive simulation allows workers to gain practical experience in a controlled environment, thereby enhancing their competence. [3]

Case Studies in VR Applications

One notable application of VR/AR in the oil industry is the simulated training for oil and gas drilling operations. This includes training for pipeline construction, emergency handling, and basic operation techniques. The use of VR in these scenarios reduces the potential for real-world errors and enhances trainees' operational readiness by allowing them to practice complex tasks in a safe, virtual setting. [3] [4]

[1]Corresponding author, adrijana.capko@gmail.com
[2]zorancepic@uns.ac.rs, ORCID: https://orcid.org/ 0000-0001-5853-4767

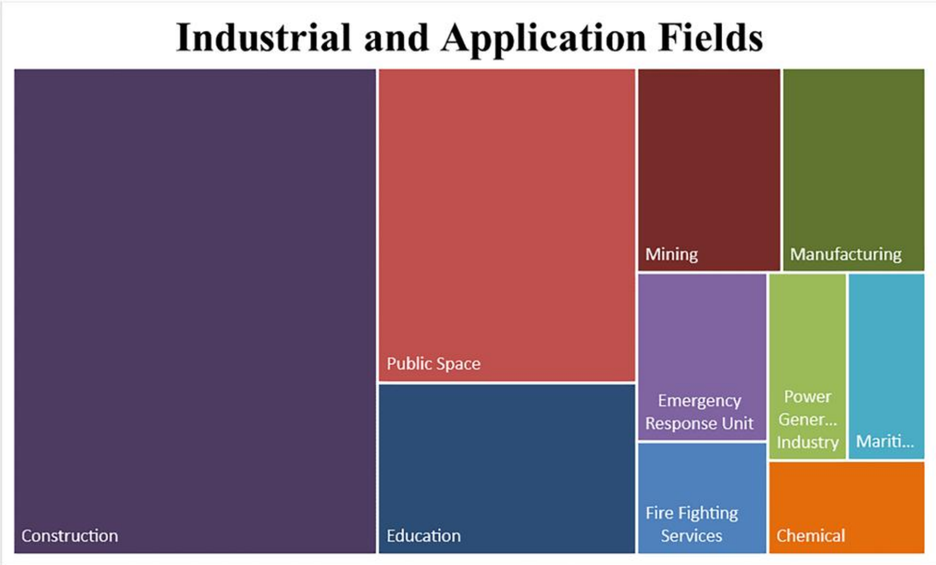

***Fig 1**, Classification based on industry and field studied. [7]*

Interactive Learning Modules

Interactive VR/AR simulations, where trainees can manipulate tools and machinery, provide a more engaging learning experience compared to conventional methods. These modules enable employees to repeatedly practice their skills until they achieve a high level of proficiency. For example, a trainee can practice the procedure of shutting down a malfunctioning unit multiple times in a VR simulation until they can perform the task seamlessly without errors. [4]

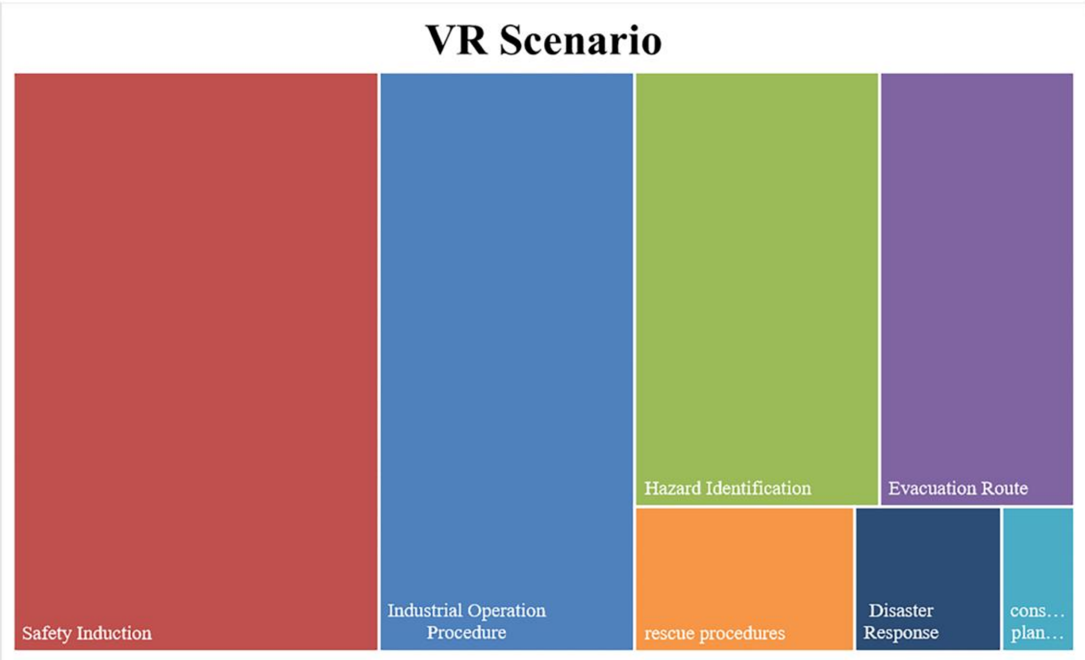

***Fig. 2**. Classification of VR scenarios. [4]*

REDUCTION OF STRESS LEVELS

Stress Management through VR/AR

Training in realistic yet risk-free environments provided by VR/AR can help mitigate the stress associated with high-risk operations. Employees can repeatedly practice emergency responses, reducing anxiety when actual emergencies occur. VR/AR training has been shown to increase trainees' confidence and self-efficacy, contributing to lower stress levels during real-world tasks. Furthermore, training systems can monitor physiological changes in operators, providing feedback and further mitigating stress.

Simulation of Emergency Scenarios

The ability to simulate emergencies like fires, equipment malfunctions, and hazardous spills helps employees prepare mentally and emotionally for these events. For example, VR-based scenarios where workers must navigate a space invaded by fire and use suppression techniques can significantly improve their readiness and reduce stress in actual emergencies.

Real-time Stress Monitoring

Advanced VR/AR systems are equipped with sensors that monitor stress indicators like heart rate and eye movement. Data from these sensors can be used to adjust the difficulty level of the simulation, ensuring that the trainee is not overwhelmed. This real-time adjustment mechanism can play a crucial role in reducing trainee stress and improving overall training effectiveness. [4]

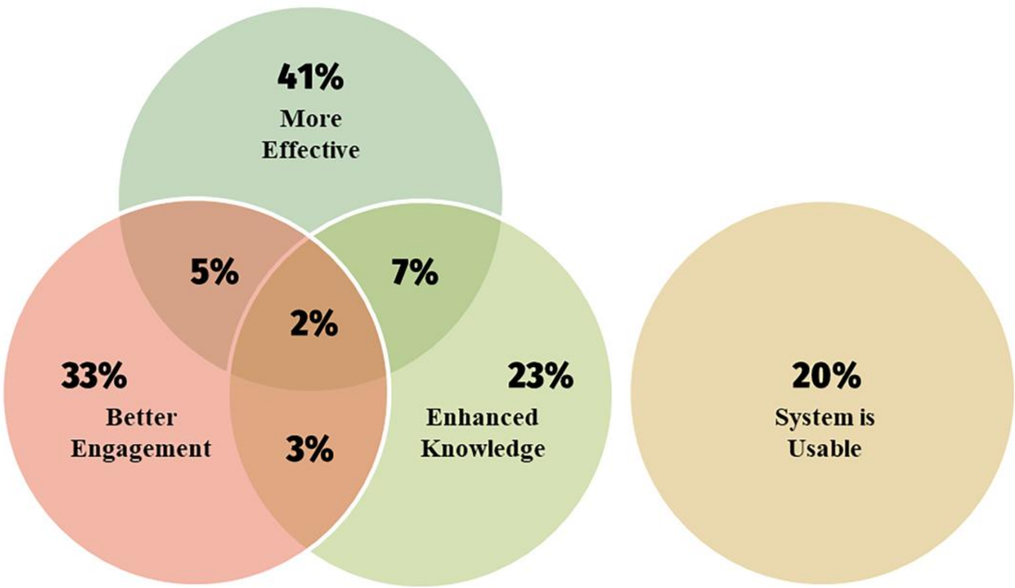

***Fig. 3**, Classification based on results. [4]*

UNIFORM TRAINING FOR FOREIGN WORKERS

Standardization of Training Modules

One of the critical challenges in training a diverse workforce is ensuring uniformity in training content and delivery. VR/AR systems can standardize safety training, ensuring all employees, regardless of their geographical or cultural background, receive the same high-quality training. The interactive and engaging nature of VR/AR training also helps in retaining the interest and comprehension of trainees from diverse backgrounds.

Language and Cultural Barriers

VR/AR training systems can be tailored to accommodate different languages and cultural contexts, thereby overcoming one of the main barriers to uniform training. For instance, instructions and interactive elements in the VR environment can be localized to the trainees' native languages, ensuring that they fully understand the safety protocols without language acting as a barrier.

Training Consistency

During a capital overhaul, a refinery may employ over 2000 foreign workers, each coming with varied levels of experience and understanding of safety protocols. VR/AR systems can deliver a consistent training experience to all these workers, ensuring everyone is trained to the same standard. This consistency is vital during high-pressure overhauls where any lapse in safety procedures can have serious consequences. On a figure 4, we can see how much participans achive better score pre and post VR/AR trainning (iSafeCom). [5]

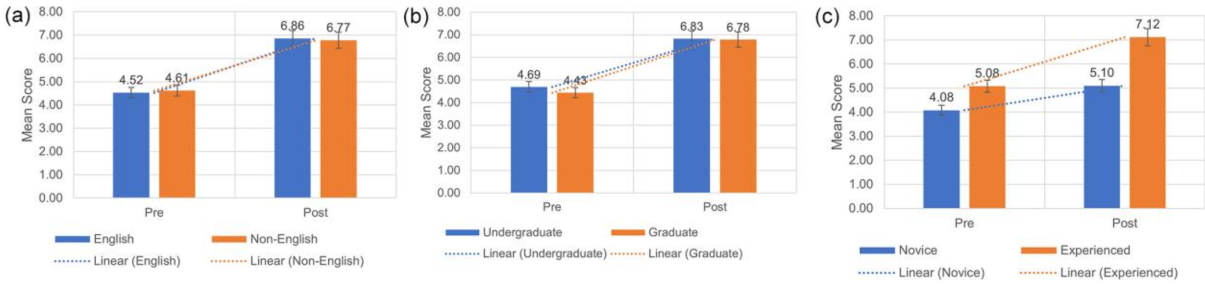

***Fig. 4**. a) Mean participants score based on language diversity b) Mean participants score based onlevel of education c) Mean participants score based on level of experience [5]*

IMPORTANCE DURING CAPITAL OVERHAULS

Efficiency and Safety

During capital overhauls, the need for efficient and safe operations is paramount. VR/AR training can significantly reduce downtime and enhance safety by preparing workers for the specific tasks they will perform during the overhaul. By simulating the exact environment and operations, workers can practice and perfect their tasks beforehand, leading to smoother and safer execution during the actual overhaul.

***Fig. 5** Participant interaction with virtual instructor: language selection and simultaneous textual support. [5]*

Real-time Feedback and Adjustments

An added advantage of VR/AR training is the ability to provide real-time feedback and make immediate adjustments to the training modules based on the trainees' performance. This iterative process ensures that workers are continuously improving and adapting to the training requirements, which is crucial during the dynamic and high-pressure environment of a capital overhaul. [6]

Cost Benefits

Capital overhauls often involve significant financial investments. VR/AR training can help reduce these costs by minimizing the likelihood of errors and accidents. Well-trained employees are less likely to make mistakes that could lead to costly downtime or repairs. In addition, the use of VR/AR technology can streamline the training process, making it faster and more efficient, thereby reducing the total time and resources required. [7]

CONCLUSION

The integration of VR/AR technology into safety training programs in the crude oil industry presents a transformative approach to enhancing workforce competence, reducing stress, and ensuring uniform training across diverse employee groups. As the industry faces increasing safety standards and the need for efficient operations during capital overhauls, VR/AR training systems offer an innovative solution to meet these challenges. Future research should focus on optimizing the technology for specific training needs and further exploring its potential in various operational scenarios within the crude oil industry.

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NEITHER ANTHROPOCENE NOR CAPITALOCENE - A PATH TOWARD AN ANTI-CAPITALIST ECOLOGY

Research paper

Dejan Mihailović[1], Alexis Toribio Dantas[2]
[1] Tecnológico de Monterrey, Ciudad México, México
[2]Rio de Janeiro State University, Rio de Janeiro, Brasil

Abstract: The relationship that capitalism establishes between the economy and nature is markedly contradictory. As a geomorphological agent, capitalism is the main sociohistorical cause of the ecological limit imposed on humanity's survival. In recent decades, innovative theoretical approaches (Anthropocene, Capitalocene, Oikeios, etc.) have emerged alongside institutional programmatic initiatives within the international system (Sustainable Development, Agenda 2030, Green New Deal). However, the progressive deterioration of the environment continues. This text aims to critique all those theoretical positions and beliefs that promote changes in environmental protection strategies without altering capitalist production relations or questioning the power structures of the capitalist world-system, which are inherently hostile to nature.
Key words: Ecopolitics, Geopolitics, Sustainable development, Environmental degradation

INTRODUCTION

One of the main tenets of capitalism centers on the assumption of a division between a natural realm, perceived as a space providing resources available for free and continuous appropriation, and an economic realm, identified as a domain of values generated by human activity. This division results from the ontological distinctions elaborated by the Eurocentric rationality of early modernity (God-Man-Nature; Subject-Object; People-Things), which culminated in the distinction between Humanity (in its spiritual, sociocultural, and historical dimensions) and Nature (non-human, conceived as material, objectively given, and ahistorical) [1]. The deepening of this division accelerated with the spread of industrial capitalism, driven by the frantic use of fossil fuels, while the agricultural sector was fueled by chemical fertilizers. This phenomenon was highlighted by Marx as a kind of "metabolic rift," where human activity (capital) becomes the main cause of irreversible deterioration of the conditions for life on Earth [2]. Marx exposed the problem of soil depletion, noting that the disruption of the material exchange between humanity and nature results from the interaction between enclosure processes, industrialization, growing urbanization, and the breaking of the nutrient cycle, which gave way to a new ecological era called the Anthropocene. During the 20th century, various schools of contemporary economics simultaneously began to propagate the idea of infinite economic growth, despite the planet's clearly limited conditions due to finite natural resources. The "ecological crisis" of our time tells us, in the first instance, that development and the promise of abundance do not consist of an endless flow of material goods but rather a sufficient quantity produced with minimal unpleasant effort. The second point is even clearer: what prevents this from happening is not nature, but politics.

Anthropocene or Capitalocene?

Neither! The concept of the "Anthropocene" was introduced to the field of environmental studies and ecological issues by the stratigraphic commission of the Geological Society in England, with the purpose of highlighting the significant global impact of human activities on terrestrial ecosystems, marking the end of the Holocene era. This proposal focuses on the accelerated deepening of the metabolic rift caused by the increasing advances in industrial production, agriculture, and urban areas, which are the main agents of waste emissions, pollution, biosphere disruption, hydrosphere impact, and atmospheric changes (climate change). The supposed end of the Holocene, a period of approximately 12,000 years since

[1] Corresponding author, dmihailo@tec.mx, ORCID: https://orcid.org/0009-0009-0355-0431
[2] alexis.dantas@gmail.com, ORCID: https://orcid.org/0000-0002-4742-7197

the last glaciation, characterized by stable and favorable climatic conditions for human development, gives way to a new geological era in which humans (anthropos) generate: "a multitude of anthropogenic environmental influences, such as the extinction, spread, and migration of animal and plant species, the increase of greenhouse gases in the atmosphere, soil degradation, ocean acidification and overfishing, as well as the pollution of soil, water, and air" [3, p.35]. On multiple occasions throughout his theoretical work, Marx insisted that capital is, above all, a type of social relationship and a way of interacting between humans and nature. If capitalism is a mode of production, capital is also a mode of destruction. It is becoming increasingly clear that "productivity gains and destructivity gains progress in parallel" [4, p.38]. This statement is used to challenge the idea that humans, simply by being human, are the cause of the ecological catastrophe. This is how the term "Capitalocene" emerges, finding in productivity and profitability the main driving force of planetary transformations in pursuit of maximizing capital valuation. Consequently, the conclusion is that our problem is not the Anthropocene but capitalism. A capitalism that has become a world-system, passing through different evolutionary phases of its own development and establishing itself on a global scale. Colonialism, industrialism, imperialism, globalization, exploitation, racism, inequality - phenomena engendered by capitalism - position the Capitalocene as a critique of the Anthropocene.
A capitalist system of production based on private property, wage labor, and the free market is clearly responsible for the majority of global emissions. Just look at the 2017 Carbon Disclosure Project report [5] showing that 100 companies are responsible for 71% of global carbon emissions since 1988, or a rigorous study by the Climate Accountability Institute identifying a select group of 20 companies responsible for 35% of all carbon dioxide and methane emissions in the global energy system since 1965 [6]. As it can be seen in Figure 1, ten countries caused 70% of global CO_2 emissions in 2021. A set of networks of material production, centers of financial, commercial, and military power nested within the corporate structure of global capitalism represent a system over which the vast majority of the world's population has no control.

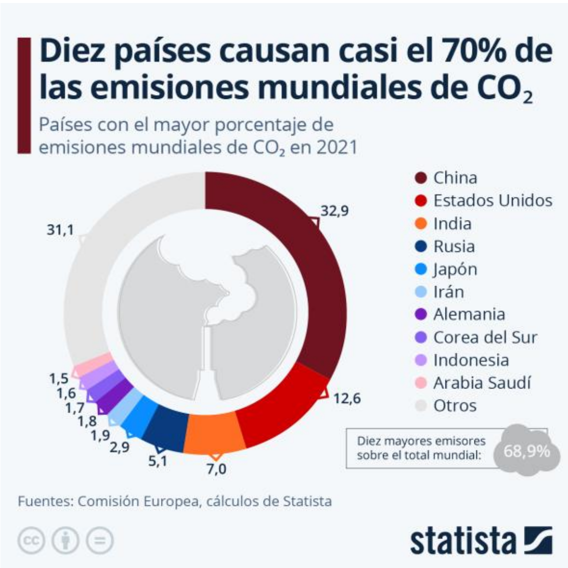

Fig. 1. *Carbon dioxide emissions [%[of the most polluting countries worldwide in 2021: China, United States, India, Russia,Japan, Iran,Germany,South corea, Indonesia,Saud Arabia, and others*

For a Trans-Environmental and Anti-Capitalist Ecology

The human welfare project, identified with the accumulation of material objects, market expansion, and unlimited economic growth, is collapsing. The capitalist world-system requires, as a condition for producing its accumulation patterns, permanent economic growth

-something that is not possible on a planet with finite resources. We are witnessing a profound crisis in the current pattern of anthropocentric, monocultural, and patriarchal global civilization, accompanied by the systemic wars of the great State-Capital machine. In such circumstances, the global institutional strategies (Sustainable Development, Green Economy, Agenda 2030) designed to reverse environmental degradation and improve the quality of human life have failed. Unable to examine the causes of environmental destruction, they neglected any careful analysis of the economic forces responsible for the deterioration of nature and the living conditions on Earth.

The current relationship between society and nature, mediated by capital, is ecologically unsustainable. Conventional economics and ecology were unable to overcome a view of nature conceived as a faucet for production inputs and a sink for waste disposal. Hence, the task is to create a new applied ecological economy, focused on the Oikeios perspective, where "civilizations (another abbreviation) do not interact with nature as a resource (or nature as a trash can); they will develop through nature as a matrix" [7, p.92]. For this, it is necessary to promote a systematic approach between the natural sciences and the social sciences, creating a new worldview, a new vision of development, and an economy that serves the people. A true global, environmental, and human change is required to integrate human systems with Mother Nature (Pacha Mama).

Capitalism was never, and will never be, "green." A "Green New Deal" as a new eco-social pact promoted by the powerful apparatus of global capital continues to propagate the idea of commodified and monetized time and space. We must confront the eco-fascist ideology that isolates and absolves a small privileged minority from the environmental crisis while involving and forcing the rest of the world's population to pay the price and suffer the consequences. The four forms of capitalist appropriation: commodification, the production of absolute surplus value, the production of relative surplus value, and the geopolitics of new imperialism, are still ongoing. This indicates that proper "environmental" protection is not possible without disrupting the institutional framework and structural dynamics of capitalist society [8, p.135]. The historical possibility of ecosocialism is becoming increasingly realistic. Its foundation must be a preventive ecopolitics concerning catastrophes, but at the same time, it must guarantee the widespread well-being of all humanity. The recovery of the "peaceful and harmonious" relationship between humans and nature must take an anti-capitalist and trans-environmental form. It is not a question of merely "being here" but of staying. We must abandon the dogmas of a capitalism based on social autophagy and natural cannibalism. An anti-capitalist ecopolitics and a post-capitalist economy will open a new path to the future that will no longer compromise the fate of future generations of humans or other forms of life on the planet.

CONCLUSION

We have attempted to analyze the relationship between capitalism, society, and nature, emphasizing the need to: a) reinvent an environmental discourse disconnected from the logic of capital and oriented towards the widespread well-being of people; b) construct an ecosocialist strategy that reintegrates human systems with nature; c) promote an ecopolitics that accelerates the end of capitalism as it has been known, opening space for a new type of society. Capitalism, as a world-system, was the first to extend globally. Therefore, our struggles and forms of resistance cannot be limited by political-ideological borders and barriers. Breaking down these barriers will be the main task of a new decentralized global geopolitics, somewhat entropic and supportive.

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EVALUATING THE BIOACCUMULATION OF HAZARDOUS POLLUTANTS FROM MUNICIPAL SOLID WASTE LANDFILL: A CASE STUDY ON BISPHENOL A AND PHTHALATES IN SERBIA

Research paper

Tijana Adamov[1*], Mladenka Novaković[2], Maja Petrović[3]
[1,2,3] University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering and Occupational Safety and Health, Trg Dositeja Obradovića 6, Novi Sad 21000, Serbia

Abstract: Municipal solid waste management has long been a critical issue for governments worldwide. In recent decades, many countries have seen significant increases in waste generation due to population growth, rapid urbanization, changing lifestyles, and heightened commercial and industrial development. Improper waste management can lead to the leaching of hazardous pollutants, contaminating both ground and surface waters, which can result in environmental harm and adverse health effects for living organisms. This research was conducted through three sampling campaigns in 2022 at a municipal solid waste landfill in Serbia. Gas chromatography-mass spectrometry analysis quantified bisphenol A, diisobutyl phthalate, di(2-ethylhexyl) phthalate, and butylbenzyl phthalate, and projected concentrations in living organisms were calculated using the bioaccumulation factor derived from literature reviews. This study provides a comprehensive overview of the potential effects of these pollutants on both aquatic and terrestrial animals. The aim of this assessment is to initiate discussions on new research directions arising from these findings, highlighting the need for further studies to fully understand the negative impacts of inadequate waste management on human health.

Keywords: landfill leachate, bioaccumulation, bisphenol A, DIBP, BBP, DEHP.

INTRODUCTION

Landfilling is a major method for the final disposal of various types of municipal solid waste, including expired or unwanted household medications and products. As a result, landfills have become repositories for a range of emerging organic contaminants (EOCs) [1]. Over recent decades, the presence of EOCs such as pharmaceuticals, personal care products (PPCPs), and endocrine-disrupting chemicals (EDCs) has raised significant environmental and public health concerns globally. EOCs are known for their bioactivity and persistence within environmental compartments and aquatic life [2]. Their occurrence in wastewater, water systems and drinking water is considered one of the biggest global environmental problems [3]. Despite regulations limiting the use of certain phthalates and bisphenol A (BPA) in some products, their pervasive nature means that exposure continues through food, water, and consumer products [4]. This ongoing exposure raises concerns about the adequacy of current health guidelines and necessitates further research to understand the full extent of their impacts on human health [5].

Over the last 20 years, BPA has become one of the most studied EDCs, because it is one of the highest volume chemicals in worldwide production, is used in a wide variety of products, and exposure is documented in virtually everyone [6]. It is found in a superfluity of common products such as water, milk and baby bottles, eyeglass lenses, sports protective equipment, and compact discs, as well as in medical, dental devices and polyvinyl chloride plastics. Thus, it is ubiquitously present in our surroundings and near food and drinks [7,8]. Inadequately disposed materials can lead to changes in environmental factors such as temperature, UV radiation, or exposure to liquids (including solvents and lipids), as well as acidic or alkaline conditions. These changes can significantly enhance the release of compounds from the polymer matrix into various environmental matrices [9].

Phthalates are ester derivatives that have been used to alter the flexibility of plastics since the 1930s, and are ubiquitous in our daily life. Increasing evidence suggests that phthalates may act as endocrine disruptors [10]. Phthalates and BPA can mimic or block hormones, particularly estrogen. This disruption can lead to reproductive problems, developmental

[1] Corresponding author: tijana.adamov@uns.ac.rs, ORCID: https://orcid.org/0009-0001-3234-5359
[2] mladenkanovakovic@uns.ac.rs, ORCID: https://orcid.org/0000-0001-5036-6682
[3] majadjogo@uns.ac.rs, ORCID: https://orcid.org/0000-0003-3423-6559

problems and cancer [4,5]. The high consumption of plastic leads to the generation of large amounts of waste, which presents significant challenges for available waste management systems [11].

Bioaccumulation of substances is typically quantified using the bioaccumulation factor (BAF), which describes the metabolism-mediated active transport of substances from the environment into living organisms, where they accumulate intracellularly. The range of organisms affected is broad, as BAFs are utilized to assess bioaccumulation in various species, including fish, insects, snails, and cattle, as well as in plant roots, leaves, and stems, and microorganisms like bacteria and microalgae. Both phthalates and BPA bioaccumulate in organisms, which can amplify their concentrations up the food chain. When fish and terrestrial animals absorb these substances, they can reach harmful levels, which can then impact human health through dietary intake [5]. Aquatic organisms, particularly fish, tend to bioaccumulate these substances due to their lipophilic nature.

This study aimed to enhance the understanding of the occurrence and fate of bisphenol A (BPA) and selected phthalates in landfill leachate, focusing on an exemplary landfill located in Vojvodina region. The research specifically examined the theoretical concentrations of these pollutants in fish and terrestrial animals, should the landfill leachate permeate or reach nearby water sources, by employing the bioaccumulation factor. The findings will provide valuable insights into the impact of endocrine-disrupting chemicals (EDCs) on surrounding environments of landfills and serve as preliminary references for future ecotoxicity research related to EDCs.

MATERIAL AND METHODS

Sampling and analysis

The sampling site in Serbia was selected based on factors such as population density, occupation, and lifestyle, with a total of three sampling campaigns conducted in 2022 during February, May, and November. The landfill is located approximately 800 meters from the nearest residential area and seven kilometers from the city center. Waste disposal at the site is organized into three distinct sections. Although the landfill is managed, it does not have a leachate collection system. Leachate samples were collected from a peripheral canal (Fig. 1), which varies in width between 7 and 11 meters. Sample preparation involved liquid-liquid extraction using dichloromethane, followed by concentration to 1 ml for analysis via gas chromatography-mass spectrometry. All sample preparation steps were carried out under a fume hood using glass laboratory equipment to minimize the risk of contamination.

Fig. 1. *Leachate sampling location*

Bioaccumulation factor

The expected concentrations of phthalates and bisphenol A in fish and terrestrial animals were calculated using Equation 1.

$$BAF = \frac{C_{substance\ in\ the\ organism}}{C_{substance\ in\ the\ matrix}} \quad (1)$$

The bioaccumulation factor (BAF) values utilized in the calculations are general estimates that reflect typical bioaccumulation patterns of phthalates and bisphenol A in both aquatic and terrestrial organisms. Research indicates that BAFs for fish can range from 1000 to 2000, depending on the species and specific exposure conditions. Documentation from the U.S. Environmental Protection Agency (EPA) also supports this range, citing BAFs for aquatic organisms between 500 and 2000 [12]. Therefore, a BAF value of 1000 was selected for fish in the calculations.
In contrast, phthalates and BPA generally exhibit lower bioaccumulation in terrestrial organisms due to reduced direct exposure to water and lower accumulation in soils and food chains. BAF values for terrestrial animals are typically much lower, as indicated by the Toxic Substances Control Act (TSCA) [13], which provides data showing BAFs for terrestrial organisms exposed to phthalates and similar chemicals often fall below 20. Furthermore, the European Chemicals Agency (ECHA) [14] reports that phthalates are less likely to bioaccumulate significantly in terrestrial animals compared to aquatic species, with estimated BAF values around 5 to 20 depending on exposure pathways. Given the limited studies available for terrestrial environments, specific BAF values for terrestrial animals are more challenging to ascertain. Nevertheless, phthalates can bioaccumulate in soil-dwelling organisms and subsequently move up the food chain, indirectly affecting terrestrial animals through the ingestion of contaminated prey or exposure to polluted water sources. Consequently, a BAF value of 10 was selected for terrestrial animals in this study, balancing the available data and understanding of bioaccumulation dynamics in these organisms.

RESULTS AND DISCUSSION

The concentrations of BPA and selected phthalates in landfill leachate are presented in Table 1. It is assumed that when leachate percolates through soil into groundwater, its constituents are diluted at a ratio of 1:100 [15]. In contrast, the typical dilution factor for natural surface waters can range from 1:100 to 1:10,000 [16]. Two plausible scenarios are considered, both of which illustrate how the concentration of contaminants in organisms is influenced by the dilution factor: direct contamination of surface water with landfill leachate and percolation of landfill leachate through soil into groundwater.

Table 1. *Concentrations of bisphenol A and phthalates in landfill leachate*

Campaign	BPA (μg/L)		DIBP (μg/L)		BBP (μg/L)		DEHP (μg/L)	
	L	S/G	L	S/G	L	S/G	L	S/G
February	5.40	0.054	2.35	0.024	2.57	0.026	0.27	0.003
March	4.40	0.044	0.37	0.004	0.02	0.000	0.64	0.006
November	9.30	0.093	0.45	0.005	0.13	0.001	0.08	0.001

L – landfill leachate, S – surface water, G – groundwater.

Both scenarios are highly probable in landfill environments lacking protective liners and leachate collection systems, which are essential components outlined in Waste Management

Standards. In such cases, the complex constituents of landfill leachate can dilute and subsequently enter nearby water sources. Several key factors influence this dilution, including the flow rate of the water body, leachate volume and concentration, as well as local hydrology and rainfall patterns [16]. For the assessment of projected concentrations of the selected organic compounds in both scenarios, a dilution factor (DF) of 1:100 was applied, given that the water body adjacent to the landfill is a peripheral canal measuring 7 to 11 meters in width. Additionally, the examined region experiences a humid continental climate, characterized by significant seasonal variations. The approximate calculated levels of selected chemical compounds in fish and terrestrial animals are summarized in Table 2.

Table 2. *Estimated concentrations of BPA and phthalates in fish and terrestrial animals via contamination of surface water and groundwater*

Campaign	**Species**	**BPA**		**DIBP**		**BBP**		**DEHP**	
		$C_{organism}$ (μg/kg)	$C_{organism}$ (mg/kg)	$C_{organism}$ (μg/kg)	$C_{organism}$ (mg/kg)	$C_{organism}$ (μg/kg)	$C_{organism}$ (mg/kg)	$C_{organism}$ (μg/kg)	$C_{organism}$ (mg/kg)
February	Fish	54	0.054	23.50	0.024	3.10	0.003	25.70	0.026
	T.A	0.540	0.001	0.24	0.0002	0.03	0.0001	0.26	0.0003
March	Fish	44	0.044	3.70	0.004	3.10	0.003	0.20	0.0002
	T.A.	0.440	0.001	0.04	0.0001	0.03	0.0001	0.002	0.00001
November	Fish	93	0.093	4.50	0.005	8.20	0.008	1.30	0.001
	T.A.	0.930	0.001	0.05	0.0001	0.08	0.0001	0.01	0.00001

T.A. – terrestrial animals, S – surface water, G - groundwater

To further elaborate the potential negative impact of these contaminants, it is crucial to note that bisphenol A (BPA) can cause adverse effects in fish at concentrations as low as 1 mg/kg of body weight. Specifically, exposure to BPA at levels between 1 and 10 mg/kg body weight has been linked to endocrine disruption, anxiety-like behavior, and neurotoxic effects [17]. The dosage affecting terrestrial animals varies by species and duration of exposure. For instance, in sheep, doses of 5 mg/kg/day of BPA have resulted in reproductive alterations and endocrine disruption [18]. While the calculated concentrations of BPA in fish and terrestrial animals are below the levels known to cause harm, it is important to recognize that

they can biomagnify through the food chain. Even low levels of BPA can lead to significant biological impacts, especially when exposure occurs during critical periods of development.
Research indicates that exposure to diisobutyl phthalate (DIBP) doses between 1 and 10 mg/kg body weight can lead to developmental toxicity, reproductive system disruptions, and hormonal imbalances. A study by Tao et al. (2024) found that the median half-lethal concentration of DIBP after 96 hours was 1.149 mg/L [19]. In terms of toxicity in rats, Jeong et al. (2022) reported that sub-acute exposure to DIBP at a dosage of 100 mg/kg affects the liver, kidney, lung, and testis, with the effects classified as modest [20]. These findings suggest that DIBP can exert severe toxic effects at moderate to high doses, particularly with chronic exposure. Given the widespread use of DIBP in various industrial and consumer products including paints, lacquers, printing inks, pulp and paper, carpets, concrete, nail polish, and cosmetics [21], the low concentrations obtained should not be overlooked.
The doses of benzyl butyl phthalate (BBP) and di(2-ethylhexyl) phthalate (DEHP) show adverse effects in fish which vary across species with concentrations bellow 50 mg/kg and 1 to 10 mg/kg body weight, respectively. These doses illustrate the potential for significant developmental and reproductive toxicity in fish at relatively low levels of exposure [22]. The highest concentrations of BBP found in all three sampling campaigns remain below the levels associated with negative health effects observed in animal studies, a pattern that holds true for DEHP as well.

CONCLUSION

This study has successfully assessed the concentrations of endocrine-disrupting compounds in fish and terrestrial animals near a selected landfill in Serbia, highlighting the need for increased awareness regarding their presence in the environment. Although the current concentrations of these contaminants do not appear to pose an immediate threat, the potential for biomagnification and chronic exposure necessitates diligent environmental monitoring. The persistence of these contaminants, coupled with their widespread use in consumer products, underscores the urgency for stricter regulations and innovative strategies to mitigate their release into ecosystems. Given their tendency to resist degradation, the accumulation of these pollutants in organisms over time can lead to significant long-term health risks, including cancer, infertility, metabolic disorders, and developmental problems.
This research provides an important overview of the potential impacts of landfill-related contaminants on both aquatic and terrestrial species, as well as the risks associated with bioaccumulation and biomagnification within the food chain, which may ultimately affect human health. The findings call for further investigation into the exposure levels and bioconcentrations of these compounds in humans to fully understand their implications.

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THE EXPERIMENTAL INVESTIGATION OF THE HEAVY METALS' MOBILITY OF THE METALLURGICAL WASTE IN TREPČA

Research paper

Jasmina Dedić[1], Jelena Djokić[2], Irma Dervišević[3], Bojan Stojčetović[4]
[1,2,3] University of Priština in Kosovska Mitrovica, Faculty of Technical Sciences Kosovska Mitrovica, Serbia
[4]Kosovo and Metohija academy of professional studies, Leposavić, Serbia

Abstract: The industrial waste deposit in Žitkovac was utilized for the disposal of various metallurgical wastes, including lead refinery byproducts. This site has been contaminated for many years; despite the company maintaining records of waste disposals, weathering processes altered the waste, leading to the mixing of byproducts from lead production. Consequently, the mineralogical composition of the waste changed, and the behavior of toxic components was affected by weathering, oxidation, and penetration into the soil. To investigate this, eight characteristic samples were collected from three depths: the surface, 300 mm, and 500 mm. Specific sampling locations were chosen based on visible differences as well as the company's records. The results indicated that lead, arsenic, and ferric compounds had penetrated the deeper layers of the soil, while copper, cadmium, and antimony remained primarily concentrated at the surface. It was noted that the gauge minerals, the agents used in refining residues, and the composition of the soil significantly influenced the behavior and penetration of pollutants within the soil column.
Key words: Mixed toxic waste, heavy metals, mobility, lead refinery

INTRODUCTION

Mining and metallurgical waste deposits pose significant environmental risks. Even after remediation efforts are undertaken, long-term heavy metal pollution can persist, affecting the soil and nearby water bodies. In this case, the metallurgical waste deposit was located in an open area between the Žitkovac tailings waste deposit and the Ibar River. Primary lead and zinc metallurgical processes generate various lead-containing wastes, including pyrite roasting residue, lead ash, slag, refinery dust, as well as lead anode slime and sludge from the zinc electrowinning process [1–3]. The predominant method for primary lead production is pyrometallurgy. This process generates industrial waste through lead sulfide roasting and lead oxide reduction in a shaft furnace. The raw lead is then refined, with impurities being separated and accumulated as residual by-products of the refining process. The unique characteristics of the metallurgical waste led to unusual behavior of heavy metals and arsenic on the soil surface and within the depth column of the industrial landfill. The tailings were generated through various processes, each employing different agents for oxidizing and refining raw lead. Lead smelting involves several elements necessary for reducing various lead compounds, primarily lead oxides and lead sulfates, into metallic lead. These processes utilize neutralizing agents such as caustic soda, soda ash, or lime, as well as fluxing agents designed to capture sulfur and enhance lead recovery. The removal of impurities and other metals from crude lead, including sulfur (S), copper (Cu), nickel (Ni), arsenic (As), antimony (Sb), bismuth (Bi), silver (Ag), and gold (Au), involves several steps. Elementary sulfur is used to eliminate copper, while tin (Sn) is subsequently removed through oxidation with either chlorine (Cl_2) or ammonium chloride (NH_4Cl), resulting in the production of tin chloride ($SnCl_2$) skims. Arsenic and antimony are selectively removed using a mixture of sodium nitrate ($NaNO_3$) and sodium hydroxide (NaOH). The resulting skims comprise a mixture of oxides, containing approximately 25% antimony, 10% arsenic, and 65% lead. Following this, silver is extracted using the Parkes Process, where excess zinc is eliminated from the de-silvered lead through vacuum distillation, followed by treatment with sodium hydroxide (NaOH). The industrial waste generated from this process was deposited

[2]Corresponding author, jelena.djokic@pr.ac.rs, https://orcid.org/ 0000-0001-8873-5092
[1]jasminavdedic@hotmail.com
[3] irma.dervisevic@pr.ac.rs, https://orcid.org/ 0000-0002-0130-3586
[4]bojan.stojcetovic@akademijakm.edu.rs, https://orcid.org/ 0000-0001-7418-6985

haphazardly, leading to variable penetration and distribution of pollutants in the soil. This study investigates the behavior of heavy metals and arsenic following remediation efforts. These contaminants were found to be associated with various forms, including sulfides, oxides, chlorides, carbonates, and complex compounds. The focus of the
investigation was to understand the behavior of heavy metals and arsenic within the soil column in relation to their mineral composition.
the operating period of "Trepča" resulted in significant environmental impacts that have been analyzed by various researchers. Milentijević et al. [4] assessed the environmental situation in the municipalities of Zvečan and Kosovska Mitrovica from 2006 to 2013, examining compliance with relevant laws and regulations during that period. Kelmendi et al. [5] conducted a survey of agricultural land, focusing on the partitioning of lead (Pb), cadmium (Cd), and zinc (Zn) in the rural areas of Mitrovica. Additionally, Prathumratana et al. [7] investigated lead contamination in the topsoil of the mining and smelting area of Mitrovica. Nannoni et al. [8] reported the results of a geochemical study examining the partitioning of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), antimony (Sb), and zinc (Zn) in soils. According to another study [9], the Trepča Mining Complex is identified as one of the most significant environmental hotspots in the region, characterized by toxic and acidic effluents, uncontained waste rock, contaminated buildings, dust emissions, and unsafe working environments, along with poorly managed and unstable tailings.
Kelmendi et al. [6] estimate that during 1990 alone, the Zvečan smelter emitted approximately 730 tons of dust, 438 tons of lead, 83 tons of zinc, and 3.6 tons of cadmium, while the total amount of accumulated waste in the Mitrovica region's landfills reached around 40 million tons. One major environmental concern is the GATER landfill, as highlighted in a study by the authors [10]. Located along the banks of the Ibar River, this landfill poses a risk of toxic material penetration through the deposited waste and alluvium, particularly during flooding events.

MATERIAL AND METHODS

Sampling area

The "Gater" landfill is situated in the alluvial plain along the Ibar River, just north of central Zvečan. Its surface primarily consists of hardened tailings, with a mixture of fine and very fine granules, giving it a sandy texture. The color ranges from reddish-brown to dark brown, with white patches indicating the presence of lead chloride.

Fig. 1. *Location of the Lead refinery waste*

Samples were taken from eight characteristic points (Figure 2), with collection from both the surface and a depth of 300 mm. The 300 mm depth was selected for secondary sampling, as it falls within the cost-effective range for thorough cleaning and material removal, ensuring relevant data for identifying potential remediation methods.

Fig. 2. *Industrial waste deposit with sampling spots*

Material Characterization

For the characterizations of the samples from the industrial waste deposit in Žitkovac three methods were used for chemical and qualitative-quantitative tests:

1. SEM-EDS
2. ASS
3. XRD.

Microstructural tests were performed using a scanning electron microscope (SEM), model JSM 6460, company JEOL with energy dispersive spectrometer (EDS), company Oxford instruments. The samples were annealed at 1000°C for drying, then homogenized, and subsequently mounted on double-sided adhesive tape to prepare them for electron microscopy analysis.

Chemical tests were performed on an ICP-AES device Thermo Scientific iCAP 6500 Duo ICP (Thermo Fisher Scientific, Cambridge, United Kingdom). The calibration standard used is ILM 05.2 ICS Stck 1, manufactured by VGH Labs, Inc-Part of LGS Standards, Manchester, USA (www.vhglabs.com). Sulfur quantification was conducted on the emission line: SI 182,034 nm, calibration curve had a coefficient correlation 0.99963. Microwave digestion, ETHOS 1, Advanced Microwave Digestion System, Milestone, Italy with HPR-1000 / 10S high pressure segmented rotor was used for sample preparation. The mass of the solid sample is 0.1 g. Reagents, 5 mL of ultrapure water, 5 mL of HNO3 (65%, Sigma Aldrich) and 3 mL of H2O2 (30%, Sigma Aldrich) were used to dissolve the samples.

Diffractometric tests or X-Ray diffractometry (XRD) were performed on a powder diffractometer D2 PHASER, company Bruker. The device is equipped with a dynamic scintillator detector and a ceramic X-ray tube made of Copper (KFL-Cu-2 K) with a 20 range from 50 to 750 with a phase shift of 0.020. TOPAS 4.2 software with ICDD PDF2 (2013) database was used to interpret the obtained diffractograms.

RESULTS AND DISCUSSION

Given the extensive nature of the laboratory reports, which cover all eight examined samples from the surface and at depths of 300 mm and 500 mm, this paper focuses on presenting the results of chemical, microstructural, and diffractometric analyses of the composite sample.

Chemical composition of Sample

Table 1 presents the chemical composition of the tested soil samples collected from the surface (H = 0 mm) and at depths of 300 mm and 500 mm, analyzed using ICP-AES. The concentrations of the detected elements are expressed in both weight percent and milligrams per kilogram of sample.

Table 1. *Chemical composition of the composite sample (ICP-AES)*

	Concentration mg/kg		
Element	Depth H=0 mm	Depth H=300 mm	Depth H=500 mm
As	62.9	162.9	7586.22
Cd	31.8	0	3
Co	54.2	0	7.8
Cr	198.6	198	9
Mn	3348	2348	624
Ni	314	131	11.1
Cu	19688.2	28298	0
Pb	74537	14837	1648
Zn	42695	4592	90

Microstructural analysis of the sample was performed on the soil surface, and the Figure 3 shows the SEM microstructure of the composite sample on the soil surface.

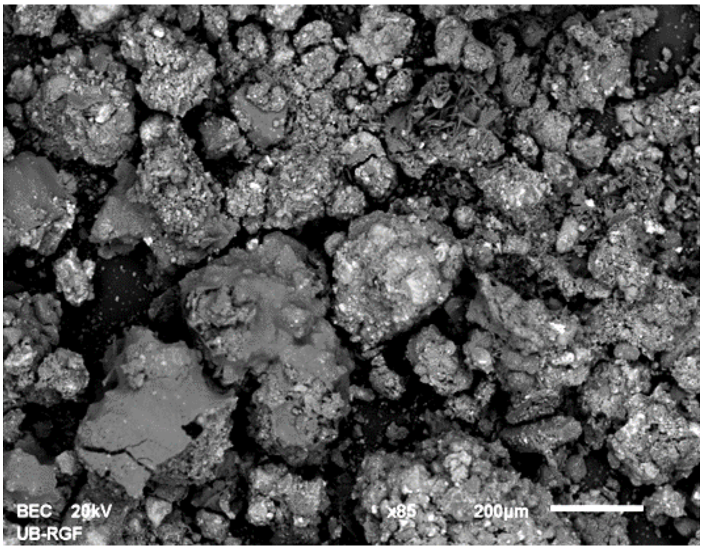

Fig. 3. *Composite surface sample SEM microstructure*

SEM analysis was conducted on the surface sample M1, with the composition of the characteristic surface detailed in Table 2. In this semi-qualitative analysis, no specific elements were pre-assigned; instead, the method allowed the device to automatically detect all elements present in the sample.

Table 2. *Semi-qualitative analysis of sample on the soil surface (in weight percent)*

	Detected elements (mass. %) on the soil surface												
	O	Na	Mg	Al	Si	S	Cl	K	Ca	Fe	Cu	Zn	Pb
M1	48.37	3.7	8.95	3.59	9.81	6.8	0.3	1,17	0.94	2.88	1.47	3.79	

Diffractometric examination of the composite sample

Diffractometric examination of the sample was performed on an XRD device. Based on the obtained diffractograms, the analysis of the present compounds was performed. The detected compounds and minerals for the surface sample are presented on the right side of Figure 4, while those for the samples taken at a depth of 300 mm are shown in Figure 5.

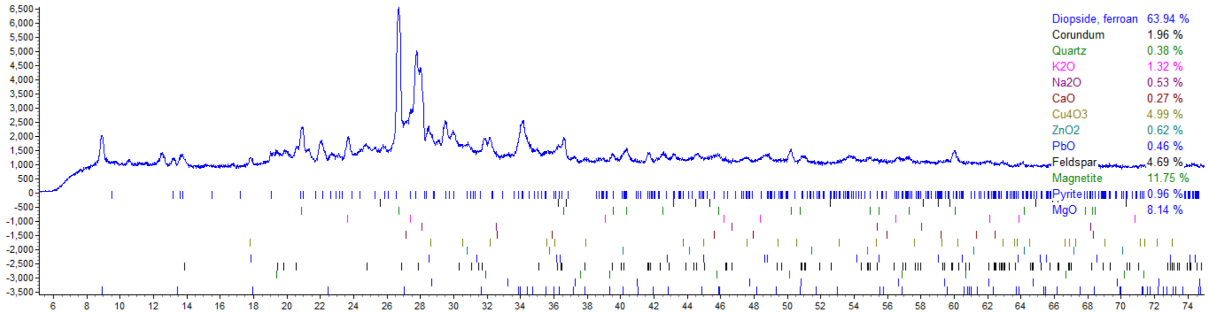

Fig. 4. *Diffractogram with detected minerals for the composite sample on the soil surface*

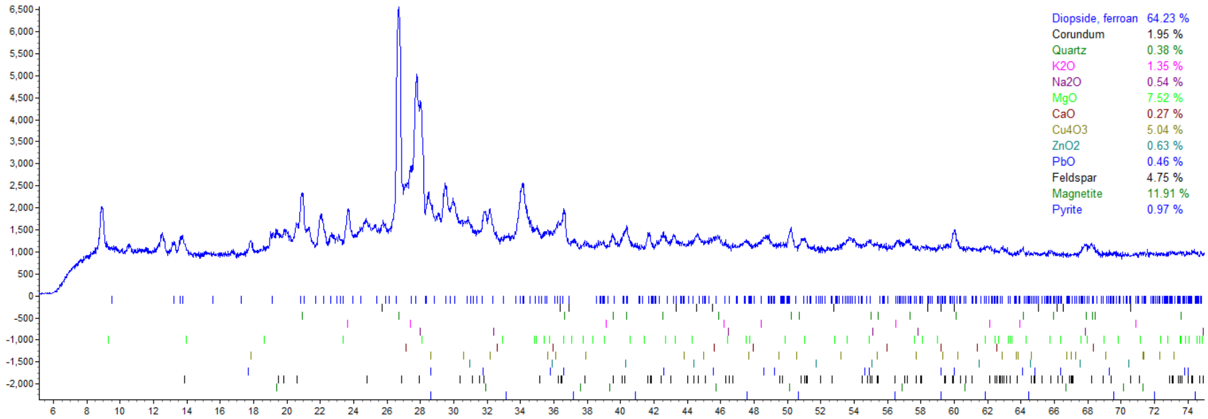

Fig. 5. *Diffractogram with detected minerals for the composite sample at 300 mm depth*

The presence of heavy metals along the depth column are presented in the Figure6.

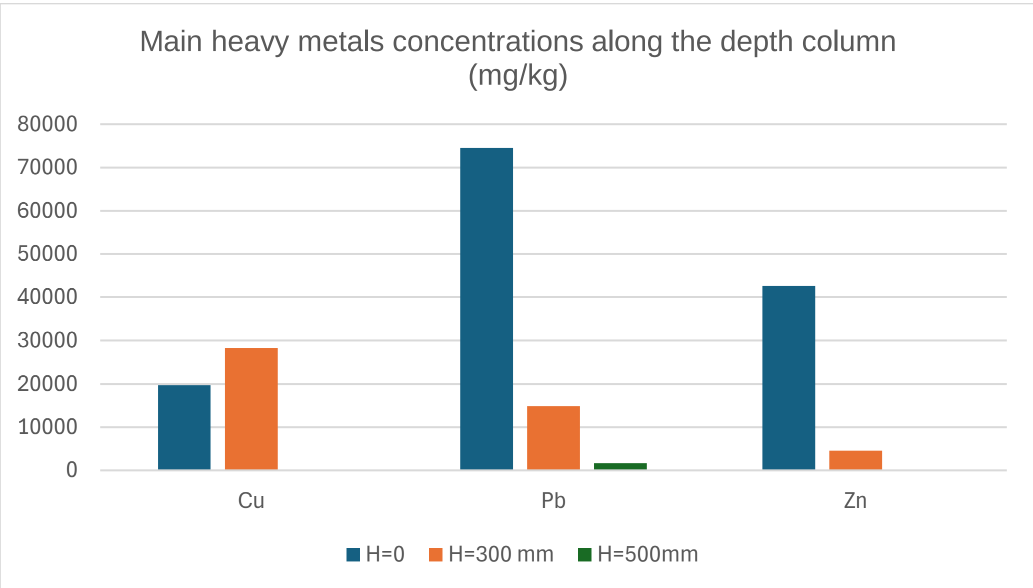

Fig.6*. Heavy metals concentrations in the composite sample*

The results indicate that not all elements penetrate the soil uniformly along the depth column. Lead, present primarily as lead oxide (PbO), exhibited proportional distribution throughout the sample. However, lead tends to remain near the surface when found in the form of carbonates and sulfates, a result of the weathering and oxidation of sulfides, particularly when associated with Diopside-Ferroan gangue minerals. In contrast, lead oxides show greater penetration into deeper soil layers. Interestingly, the concentration of pyrite, as observed in the diffractogram, does not fully account for the surface accumulation of lead. Copper, on the other hand, demonstrates higher mobility throughout the soil column, as it was detected predominantly in oxide form. When analyzing the accompanying metals, which are byproducts of lead and zinc ore processing, the distribution is further illustrated in Figure 7.

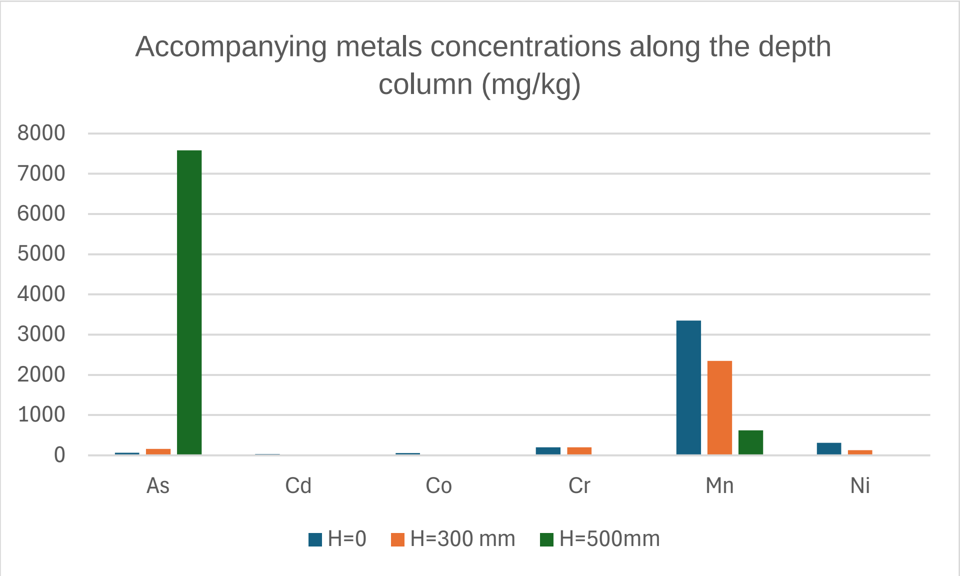

Fig.7. *Accompanying metals and Arsenic concentration distribution along the depth column*

As presented in Fig.7. cadmium is not present in the deeper layers as it is in the form of sulphate. Arsenic is largely movable along the depth column, and its concentration at the 500 mm depth is much higher than on the surface.

CONCLUSION

The study investigated the mobility of heavy metals and arsenic from mixed, non-homogeneous hazardous waste under weathering conditions. The metallurgical waste, left exposed on the ground near a river, was subjected to natural environmental factors. Measurements were taken at the surface, as well as at depths of 300 mm and 500 mm, revealing that the mobility of heavy metals and arsenic is highly influenced by factors such as the chemical nature of the compounds, particle density, solubility, and the pH and composition of the surrounding soil. The results showed varying behaviors in solute transport and penetration depth among the metals. Lead exhibited a proportional distribution down to 500 mm, while arsenic demonstrated the greatest mobility, concentrating in the deeper soil layers.

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Session 7

Environmental Management

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EU GREEN TRANSITION DOES NOT HAVE A PLANETARY APPROACH

Research paper

Milan Ivanović
Panon, think tank for strategic studies, Osijek, Croatia

Abstract: The paper provides an overview of the basic determinants of the green transition and their proposed measures. However, there are a number of dilemmas that appear in the green transition model defined in this way and point to the vagueness or weak foundations of this energy policy from a global, planetary point of view. In the conclusion, the necessary changes in the green transition strategy are indicated, with an emphasis on the planetary approach.
Key words: Energy policy, Green transition, Planetary approach, Political-economic dilemmas, Environmental policy

INTRODUCTION

Climate change and environmental degradation are an existential threat to the European Union and the world. In order to overcome these planetary challenges, the "European Green Deal" is a new EU growth strategy that should transform the EU into a modern, resource-efficient and competitive economy. The European Green Deal aims to make Europe climate neutral by 2050 and boost the economy through green technology, create sustainable industry and transport and reduce pollution. Turning climate and environmental challenges into opportunities should make the transition fair and inclusive for all, [1].

EU DETERMINANTS OF THE GREEN TRANSITION

There are six essential elements for the implementation of green transition policies. These are: sustainable development, energy, transport and mobility, environment and circular economy, research and innovation and greening of public and private finances, [2].

Sustainable development

The EU is fully committed to being a leader in the implementation of the (UN) 2030 Agenda for Sustainable Development. The 17 Sustainable Development Goals (SDGs) are about improving people's lives and protecting the planet from degradation, so that it can meet the needs of current and future generations. Since 2020, the European Commission (EC) has strengthened the analysis and monitoring of the achievement of sustainable development goals in the process of the European Semester. In parallel, member states are introducing sustainable development goals into their policies and developing targeted policies to move towards more sustainable development.

Energy

Decarbonatization of the energy system is essential for the EU to achieve its climate goals in 2030 and 2050. At the same time, energy must be secure and affordable for consumers and businesses. For this to happen, Member States must transform their energy systems into a fully integrated, digitalized and competitive EU energy market based mainly on renewable sources. In addition to regulatory reforms, member states must enable and promote further investments in clean energy, including energy efficiency. Reducing carbon emissions is the only way to avoid the worst effects of climate change. This is why the EU has committed to reducing emissions by 55% by 2030 and to a zero-carbon economy by 2050.

[1]Corresponding author, panon.institut@gmail.com,ORCID: https://orcid.org/0000-0002-4605-2901

Although governments and legislators have the primary responsibility for initiating and supporting this transition, the European Central Bank must do its part by promoting sustainable finance and greening monetary policy operations, without compromising the primary goal of price stability.

Fig. 1. Screenshot of part of the EU Green Transition website
https://reform-support.ec.europa.eu/what-we-do/green-transition_en#environment-and-the-circular-economy (Access July 7,.2024)

Transport and mobility

Transport enables people, services and goods to move freely within the EU. It is the cornerstone of EU integration, connects people in different regions and countries and makes a major contribution to the economy. The demand for transport continues and brings opportunities, but also new challenges. Namely, traffic accounts for about a quarter of greenhouse gas emissions in the EU and is one of the main causes of air pollution in cities. Member States are looking for ways to develop smart, sustainable and efficient transport solutions.

Environment and circular economy

It is expected that issues of environmental degradation will increasingly affect economic activity. It can cause extreme weather conditions, affect human health and make natural resources less available. Protecting the **EU's natural capital** (bold M.I.), transitioning to a resource-efficient economy and protecting people from environmental pressures are key priorities of the European Green Deal **(Fig.1.)**. Member states are participating in reforms to respond to these challenges by further developing their environmental protection policies and strategies.

Research and innovation

Digital technologies have a profound impact on our way of life and business. Member States must have the capacity to take advantage of our increasingly digitized society and to face the challenges it brings. This requires designing policies and implementing innovative solutions to give companies the confidence, competence and means to digitize and grow. A systematic and advanced research and innovation strategy is essential for a more productive and green economy.

Greening public and private finances

In order to achieve the ambition of the European Green Plan, significant investments are needed. The private sector will play a key role in financing the green transition. This requires consistent strategies, innovative regulatory frameworks and smart instruments. National governments will also be key in financing the transition by sending the right price signals and redirecting public spending towards sustainable policies. They should also stimulate demand for more sustainable goods and services through green public procurement and reduce the carbon footprint of public services. A strong governance framework will ensure that decision makers are accountable to future generations.

Support to national authorities

In order to respond to said challenges, the General Directorate of the European Commission for Reforms (DG REFORM) supports member states in the areas of: a) green budget and environmental taxation, b) green procurement; and c) sustainable finance and investments. DG REFORM supports national authorities in designing and implementing reforms that help address environmental degradation. An orderly transition to a green economy is an opportunity for everyone, including businesses and financial institutions, to reap the benefits of clean and cheaper energy, technological innovation and new jobs. A green economy would contribute to price stability and financial stability in the long term. An orderly transition to a green economy would, in the long term, reduce climate-related risks for the entire economy and financial system, as well as for inflation prospects and assets on the Euro system's balance sheet. As a result, this would contribute to long-term price and financial stability, [3].

A just transition

All EU member states, regions and sectors must contribute to the transition towards a climate-neutral economy. However, the scale of challenges is not the same for everyone. Regions dependent on fossil fuels and with carbon-intensive industries will be particularly affected and will undergo profound economic, environmental and social changes. DG REFORM is helping Member States to mobilize resources and take action to ensure targeted support to the regions and sectors most affected by this transition. The Directorate General for Reforms also supports states in preparing their territorial justice transition plans that each member state will have to draw up in order to access funding from the Just Transition Mechanism, [4].
The Just Transition Fund (JTF) is the first pillar of the Just Transition Mechanism (JTM). It will be a key tool to support the areas most affected by the transition to climate neutrality by providing them with tailored support. It is implemented under shared management, within the general framework of the cohesion policy, which is the EU's main policy for reducing the Fund will mitigate the socioeconomic costs caused by the climate transition, supporting economic diversification and conversion of the respective territories. This means supporting productive investment in small and medium-sized enterprises, new business creation, research and innovation, environmental restoration, clean energy, training and reskilling of workers, job search assistance and active involvement programs for job seekers, as well as the transformation of existing carbon-intensive plants when these investments lead to a significant reduction in emissions and protection of jobs. It is expected to mobilize close to 30 billion euros of investment, [5].

PLANETARY ACCESS IS MISSING

There are a number of rigid elements in the climate policies of developed Western countries: Here, two will be pointed out: (a) the planetary approach and (b) the issue of an economy based on private profit interest.

EU measures are one-dimensional

All the measures of the EU and other Western and developed countries are one-dimensional, that is, they lack a planetary approach. On the one hand, e.g. electro-mobility is promoted, financial resources are provided for the development of electro-transportation, for their production and procurement, but there is no balance on the planetary level as it endangers the planet (nature) in the entire value chain - from copper mines, production cables, lithium mining (for electric batteries), etc. The EU made a plan for Swedes, Dutch and other Europeans to drive elegantly in electric cars, without considering the overall (a) energy, (b) material and (c) climate balance; EU institutions do not care about natives in Chile, Colombia, Australia, China. Niger (e.g.) and soon also in non-EU countries in Europe (e.g. Serbia - lithium mining). That is, there is no planetary approach.

All strategic documents are governed by a one-dimensional logic - only the interest of the EU is taken care of, and there is no indication of the planetary consequences of such a green transition. One of the essential features of the EU green transition is the "Protection of the natural **capital of the EU**" (but **no**t the protection of natural **capital of the planet** (!).

Fig. 2. Chuquicamata - copper mine (Chile)
Photo: Diego Delso; license: CC BY-SA 4.0;
https://commons.wikimedia.org/w/index.php?curid=47636972 (Access. July 7,.2024)

It is interesting that the fundamental strategic document "The European Green Deal" talks about the green transition only in the EU countries. But, in order not to say that there is no planetary approach - there is another document "Climate Actions of the EU around the World in which the activities of EU institutions regarding climate change and green transition are considered. The EU authors state in the text: *"Climate change is a global phenomenon. We must reduce global greenhouse gas emissions – reducing them only in the EU is not enough. That is why the EU strives to promote climate action around the world. We work with countries outside the EU bilaterally (one on one) and multilaterally (as a group)".* This section talks about multilateral climate action and lists the activities carried out regarding: UN Climate Convention (UNFCCC, 1992), Kyoto Protocol (1997), Paris Agreement (2015), COP28 (Dubai, 2023), Intergovernmental Panel on Climate Change (IPCC), etc. The EU and its member states play an active role in promoting and sponsoring specific initiatives to mitigate and adapt to climate change worldwide. This part of the description of the EU climate policy describes the engagement of the EU in climate actions with non-EU countries, Priorities for bilateral climate engagement with neighboring EU countries, EU climate cooperation with the Asia-Pacific region, Priorities for bilateral climate engagement with the countries of the Asia-Pacific region, climate cooperation of the EU with the countries of North and Latin America, climate cooperation of the EU with Africa, [6].

It should be emphasized here that there are few scientific papers on the dark side of renewable energy sources or the green transition. What little has been published considers the issue of diurnal-seasonal oscillations in electricity production in wind and solar power plants. There are no politico-economic analyzes or global ecological doubts regarding the said questions about the green transition. However, a series of documentaries and newspaper articles appear in which environmental activists and some scientists point to the devastation of nature, the total pollution of rivers and fertile land, the destruction of forests and the extinction of a number of animal species.

Figure 2 shows an open pit mine in Chile; Chuquicamata the largest copper mine in the world by mined area with a production of 500,000 tons of copper per year. In the documentary film "The Dark Side of Green Energy" - which was broadcast on November 13, 2020 on "Al Jazeera Balkans" television, it is pointed out, among other things, the total pollution of the only river in that region where the surface mine of the world's largest copper mine in Chile is so the water from the river (which is used to wash the copper ore) is destroyed for the living world. This is also discussed in a scientific paper under the title, [7]. The paper analyzes the consequence of the operation of the sulfide processing plant in Chuquicamata. In 1952, the mine increased water demands, limiting the supply of drinking water to the regional population, and misguided public policy forced the region's population to consume arsenic-poisoned Toconca River water, causing severe health consequences for the inhabitants of the Atacama Desert.

The small number of papers on the dark side of the green transition is a consequence of neoliberalism and profit relations in science; scientists are dependent on getting funding for projects and don't want to go against the political structures, [8].

- Cobus van Staden, director of the China Global South Project warned that the green transition has a dirty secret – an insatiable hunger for resources from poorer countries. The systematic extraction of raw materials from Africa, Latin America, Asia and the Middle East has already incredibly enriched the developed part of the world and caused the destruction of the environment, violation of human rights and left the global south on the margins of the global economy. Van Staden points out that there is currently no way to produce enough lithium, nickel, cobalt, manganese, palladium and other materials needed for batteries, and that these are some of the dirtiest technologies in the world. Moreover, the race of great powers in the energy transition threatens to renew colonialist relations, he asserted. In Latin America and Asia, mining countries are already paying a high ecological and human price to allow the West to switch to green energy, [9].
- Likewise - the paper from the magazine Current Biology should be cited: "*Mining is a key driver of land-use change and environmental degradation globally, with the variety of mineral extraction methods used impacting biodiversity across scales. We use IUCN Red List threat assessments of all vertebrates to quantify the current biodiversity threat from mineral extraction, map the global hotspots of threatened biodiversity, and investigate the links between species' habitat use and life-history traits and threat from mineral extraction. Nearly 8% (4,642) of vertebrates are assessed as threatened by mineral extraction, especially mining and quarrying, with fish at particularly high risk. The hotspots of mineral extraction-induced threat are pantropical, as well as a large proportion of regional diversity threatened in northern South America, West Africa, and the Arctic. Species using freshwater habitats are particularly at risk, while the effects of other ecological traits vary between taxa*", [10].

The pernicious profit policy of private property

The capitalist policy of profit of private property in industry and mining has greatly influenced the planetary devastation of nature in the last 200 years, and it is surprising that this civilization does not give up this economic model even in the climate and ecological crisis. To paraphrase Einstein – We cannot solve a problem using the same mindset as when we created the problem, [8]. Let's start with a banal example of access to scientific works that consider climate change and energy transition. The authors of the works give their works to magazines (publishing houses) for free, which then the publishing houses sell those works for about 25 dollars. "According to CBC News, the largest for-profit scientific publishers report profit margins of nearly 40 percent, making some of those margins even higher than those of companies like Apple and Google", [11]. In this way, a number of scientists are limited in their work for contribution to the green transition.

Now we can point out that there are far greater amounts of profit and greater negative consequences of the profit relationship when it comes to the mining of green raw materials or products that should reduce the carbon footprint. And this is where enormous profits are made, again at the expense of the state, underdeveloped countries and/or natural resources. The planet (climate, etc.) is being destroyed, but the profit for private investors is not being given up.

CONCLUSION

Our discussion pointed to two major failings in the concept and processes of the green transition in relation to climate change:
a) One-dimensionality of measures in the green transition, i.e. the absence of a planetary approach, because the complete input-output chain of materials and energy has not been calculated.
b) The perniciousness of private property profit policy in green transition activities.
- When it comes to the planetary approach, energy analyzes (making a material balance and calculation of the energy chain) are needed for all key activities - in order to show or prove the final effectiveness of the planned measures at the planetary level. Because
- When it comes to: (a) the extraction (mining) of strategic raw materials, (b) the construction of large energy plants and (c) access to scientific works on the green transition - the existing profit policy of private ownership should be replaced by another model with state-owned companies based on the principle of home business, which does not imply monetary profit, because it is about efforts to achieve civilizational planetary goals - where profit has no place.
- In many analyzes of the material balance and energy chains, it will be shown that for a number of projects and operations in the green transition, the planetary climate balance is negative, while many private investors in the West will accumulate large sums of money to the detriment of humanity.
It is necessary to start a planetary scientific debate on the mentioned questions. Exclusively scientific discussion; politics and private profit have shown their face and are not welcome here, [12].

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PSYCHOSOCIAL RISKS AND STRESS IN THE WORKPLACE

Research paper

Dijana Vašaš Kručev[1*], Milica Bogdanov[2], Jasmina Poštin[3], Sanja Stankov[4], Milan Nikolić[5]
[1,3]University "Union – Nikola Tesla", Beograd, "Faculty of Management", Sremski Karlovci, Serbia
[2]University of Belgrade, Faculty of Philosophy, Belgrade, Serbia
[4,5]University of Novi Sad, Technical Faculty "Mihajlo Pupin," Zrenjanin, Serbia

Abstract: Workplace stress is becoming one of the key issues in modern work environments due to its serious consequences on employee health and business performance. Psychosocial risks, stemming from inadequate job organization, poor communication, and excessive demands, further exacerbate working conditions, increasing stress levels among employees. European occupational health and safety directives provide a framework for mitigating these risks, but their implementation is often insufficient. This paper analyzes the key factors influencing workplace stress, with a particular focus on various industrial sectors. It concludes that multidisciplinary approaches, prevention, and holistic strategies are essential for reducing stress and preserving employees' mental health, which directly contributes to improved organizational efficiency. Additionally, continuous education and support for employees play a vital role in reducing stress-related risks.
Keywords: workplace stress, psychosocial risks, mental health.

INTRODUCTION

Workplace stress is becoming one of the most important issues in modern work environments, both across different countries and in various job roles [1]. The negative effects of stress can be far-reaching, including the development of cardiovascular diseases, gastrointestinal issues, and a range of other physical and psychosomatic problems [1]. Additionally, stress significantly impacts employee productivity, further complicating business processes. Therefore, it is necessary to focus on improving working conditions and job organization, to reduce stress and implement concrete measures to overcome stressful situations [1].
The growing importance of psychosocial risks in workplaces emphasizes the necessity of prioritizing employees' mental well-being [2]. These risks, stemming from inadequate work design and organization, result in significant negative outcomes across various sectors. Managing psychosocial risks requires a collective commitment to creating a work environment that supports health. A comprehensive evaluation, supported by strong tools and health monitoring, safeguards mental well-being and fosters a culture aligned with both psychological and physical health [2].
The stress response is the body's biological reaction [3]. When a stressor arises, such as a past threat from predators, the body quickly mobilizes its reserves to allow for an adequate physical response, such as fight or flight [3]. Hormones like adrenaline and norepinephrine, known as fight-or-flight hormones, accelerate heart rate, affect circulation, and prepare the body for action [3]. However, this protective mechanism, which was appropriate in earlier stages of human evolution, has become problematic in modern work conditions, where constant stress can lead to long-term health issues, such as improper fat and sugar storage in the body [3]. Negative psychological states significantly affect health, with strong evidence supporting this claim. For example, stress can contribute to the development of various illnesses as it disrupts the body's internal balance, while anxiety may eventually lead to digestive system disorders [4,5]. Moreover, it is important to create a supportive climate for reporting possible workplace violence, protecting the victim, and adequately punishing the

[1] Corresponding author, dijana.vasas@gmail.com
[2] milica_bogdanov@yahoo.com
[3] famzr.edu@gmail.com, ORCID: https://orcid.org/0000-0003-3707-7522
[4] sssanja89@gmail.com, ORCID: https://orcid.org/0000-0002-0537-6782
[5] milan.nikolic@tfzr.rs, ORCID: https://orcid.org/0000-0001-6643-1442

perpetrator, to reduce psychosocial risks and stress in the work environment [6]. In modern workplaces, reduced organizational identification and trust among employees can further exacerbate stress and psychosocial risks, indicating the need for clear task definitions and improving interpersonal relations in teams [7].
European directives play a key role in regulating work planning and developing occupational safety measures [3]. These directives set minimum requirements for all member states, ensuring that work is organized in a way that reduces risks to physical and mental health. This is particularly important in industries like construction, where complex projects and inadequate management of activities can lead to serious psychosocial risks [3]. Issues such as a lack of job control, monotonous tasks, exclusion from decision-making, and a lack of rewards for invested effort, can further contribute to workplace stress.
When implementing measures, it is crucial to determine precisely responsibilities for specific tasks, including the duties of supervisors, line managers, and other responsible departments. Each activity requires considering four levels of action [3, p.16]:

- Individual level – What actions can workers take?
- Hierarchical level – What are the management’s responsibilities?
- Organizational level – What can another department or unit do?
- Internal or external expertise – What additional knowledge is required?

For this reason, it is essential to apply holistic strategies that will reduce workplace stressors and ensure the long-term preservation of employees' mental and physical health.

MATERIALS AND METHODS

The methodological approach of this paper is based on the use of relevant literature, international standards, and recommendations regarding workplace stress and psychosocial risks. The paper encompasses an analysis of European directives, research from various sectors, and a synthesis of existing scientific studies addressing the impact of stress on employee health and productivity. The sources are used to provide a comprehensive overview of current measures for improving working conditions and reducing psychosocial risks, with particular emphasis on key factors such as job organization, management responsibilities, and the implementation of appropriate safety measures.

RESULTS AND DISCUSSION

In the analysis of psychosocial risks across various sectors, especially in construction projects, it can be observed that, although they are diverse and complex, each activity carries similar characteristics that require a consistent approach from all involved parties. This approach is essential for the protection of workers' well-being and the reduction of psychosocial risks. Poorly planned and managed construction activities can lead to a variety of problematic situations, including the following psychosocial risks [3, p.4]:

- workers who have little control over their job or working methods (including shift schedules);
- workers who are unable to fully utilize their skills;
- workers who are excluded from decision-making processes that concern them;
- workers expected to perform only repetitive and/or monotonous tasks;
- jobs that depend on machines or systems (and are potentially inadequately monitored);
- demands that seem unnecessary;
- the creation of work systems or patterns that limit opportunities for social interaction;
- jobs involving high effort, which are neither rewarded nor appreciated (resources, compensation, self-esteem, status).

A study investigating the perceptions of multidisciplinary experts from different regions, according to the World Health Organization (WHO) definition, focused on psychosocial risks and work-related stress [8]. The results showed that these risks are often considered interchangeable and represent a significant concern for the workforce in developing countries. Workplace priorities include the prevention of stress, injuries, and risky behaviors, while the lack of research in this area hampers adequate actions [8].

Global development is marked by the intensification of interaction processes through travel, trade, migration, and the spread of knowledge, which has shaped the world's progress over millennia [8]. These changes have led to more insecure forms of employment, reduced trade oversight, and cuts in public spending, while in developing countries, workers are increasingly exposed to traditional (such as heavy physical labor) and new professional risks [8]. Although data on research is lacking, rapid industrialization and globalization emphasize the importance of addressing psychosocial risks and work-related stress in these countries. Approximately 30-50% of workers report hazardous working conditions, while an equal number report psychological overload caused by stress, further confirming the need for urgent resolution of these risks [9].

On the other hand, small and medium-sized enterprises, especially in rural areas, face additional risk challenges [10]. Managers and employees in these enterprises often lack adequate training in occupational safety, making them vulnerable to psychosocial risks [10]. In addition to physical, chemical, ergonomic, and biological factors, work-related psychosocial stress is one of the main risks for the development of metabolic syndrome (MS) [11]. Research has shown that there is a causal link between work-related psychosocial stress and MS, regardless of intervening factors such as age, gender, socio-economic status, lifestyle, and poor habits [11].

According to the global definition, the most stressful jobs are those that demand too much from workers while providing them with little control over the situation or support from colleagues, and their knowledge and skills are not adequately utilized [12]. In Latin America, positive shifts have been observed, with increasing awareness of psychosocial risks and their consequences for workers. Research on burnout syndrome is becoming more frequent, with rates ranging from 16% to 30% among employees in the service sectors [13].

In the automotive industry, psychosocial risks are also present and affect all sectors [2]. The prevalence of sleep disorders is 28% among workers, while work-related stress affects 41%, and depression 7%. Additionally, 21% of workers reported being victims of workplace harassment. These results highlight the importance of occupational medicine for the prevention and early detection of psychosocial risks to avoid more serious mental health conditions [2]. Psychosocial risks arise from inadequate design, organization, and management, which can lead to serious psychological, physical, and social consequences in all employment sectors [14].

The link between workplace violence and high levels of stress, as well as burnout [15,16], clearly indicates the need to develop coping and stress management strategies that will affect the prevention of psychological disorders, particularly in situations with lower psycho-traumatic impact [2]. Therefore, an integrated and multidisciplinary approach becomes crucial in addressing the complexity of psychosocial risk. Within occupational health services, forming interdisciplinary teams, including occupational physicians, psychologists, therapists, and ergonomists, can significantly contribute to the assessment and management of psychosocial risks [17].

The design of work tasks defines both the necessary skills and potential psychosocial risks. A "human" task should be feasible, safe, and error-free, and promote the personal development of workers. Autonomy, task completeness, skill variety, social interaction, and room for independent decision-making are also important in terms of workers' motivation. Good management of these aspects determines the quality of completed work.

Table 1. *Work Tasks: Potential Critical Points and Measures for Work Design [3, p.24-25]*

Possible Critical Points	Measures for Designing Work
Short deadlines and time constraints.	Flexible time for breaks. Influence of workers on shift planning.
Increased time pressure due to precisely defined duration and/or deadlines for task completion, even though a more flexible work plan might be possible.	Teamwork that allows for breaks by slightly extending working hours. Allow for interruptions/breaks if necessary and engage workers as substitutes.
Without the option for a short work stoppage.	Teamwork that allows for breaks by slightly extending working hours. Allow for interruptions/breaks if necessary, and engage workers as substitutes.
Without affecting the way of working or fixed specifications that determine how the job must be done, i.e., the methods of work and equipment are defined.	Offer workers at least two different work methods and tools they can choose from. Ensure task completeness for each worker (with set goals, schedules, individual preparation, activities/execution, and checks with feedback). Experienced staff know how to implement processes and which instruments to choose. Form independent, decentralized work groups that can make their own decisions on group tasks and coordinate rather than break the work into small tasks. Reduce emotional effort (e.g., by being kind to aggressive individuals) by establishing clear behavioral rules regarding what is expected from staff and how they are allowed to behave.
Frequent repetition in individual tasks, always the same tasks, e.g., for highly monotonous activities.	Check whether monotonous or physically demanding work can be organized differently. Avoid work with short repetition times, such as painting, constant shoveling, cleaning, or laying tiles. Reduce prolonged work that requires intense concentration. Change activities throughout the workday. Increase responsibility for activities.

The analysis presented in the table clearly illustrates the complexity and diversity of psychosocial risks that occur in various sectors. These risks affect not only work efficiency and productivity but also the overall well-being of workers, making their understanding and management essential. Considering the wide range of challenges, from a lack of control over work methods to emotional overload, it becomes evident that comprehensive strategies are needed to prevent and manage these risks. These strategies would not only contribute to safer and healthier working conditions but would also enhance employees' motivation and satisfaction. Therefore, an integrated approach that involves collaboration among different disciplines, such as occupational medicine, psychology, and ergonomics, can significantly improve the effectiveness of protective measures and encourage positive changes in the working environment.

CONCLUSION

Psychosocial risks and workplace stress represent serious challenges that modern enterprises face. In light of rapid changes in the business environment, it is important to understand that stress is not just an individual problem but also a collective responsibility.

Stress negatively impacts work efficiency, employee satisfaction, and overall mental health, resulting in decreased productivity and increased absenteeism.

Effective management of psychosocial risks requires an integrated approach that includes identifying stressors, providing adequate support to employees, and creating a positive working environment. This involves not only organizational-level interventions but also empowering individuals with the tools to cope with stress.

Empowered employees are key to the success of any organization. Investing in their mental health not only improves their well-being but also contributes to the development of more resilient and productive work teams. Therefore, a collective commitment to reducing workplace stress can bring long-term benefits for all parties involved.

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THE IMPACT OF TRAINING AND EDUCATION ON REDUCING WORKPLACE INJURIES

Review paper

Milica Bogdanov[1]*, Dijana Vašaš Kručev[2], Jasmina Poštin[3], Sanja Stankov[4], Milan Nikolić[5]
[1]University of Belgrade, Faculty of Philosophy, Belgrade, Serbia
[2,3]University “Union – Nikola Tesla”, Beograd, “Faculty of Management”, Sremski Karlovci, Serbia
[4,5]University of Novi Sad, Technical Faculty "Mihajlo Pupin," Zrenjanin, Serbia

Abstract: Workplace safety and health are priorities in modern work environments, and one of the key factors influencing the reduction of injuries is adequate training and education of employees. This paper investigates the impact of various forms of training on reducing the risk of workplace injuries. It also aims to demonstrate, through the analysis of existing theoretical frameworks and empirical studies, how continuous employee education contributes to the development of awareness regarding safety procedures and the proper use of work equipment.
Keywords: workplace safety, employee training.

INTRODUCTION

Safety and health at work represent key priorities in modern work environments. According to the methodology of the European Statistics on Accidents at Work (ESAW), "work accident" or "work injury" is defined as a discrete event during the work process that results in physical or mental injury and absence from work for more than three days [1]. Every year, millions of workers worldwide experience work-related injuries, which can result in fatalities, serious injuries, job loss, and broad social consequences [2]. Despite advancements in safety measures, the frequency of injuries, particularly work-related head injuries, remains high [3].

Training and education of employees play a crucial role in preventing injuries. By providing knowledge and skills for recognizing hazards and properly responding in risky situations, training can significantly contribute to reducing the number of injuries. These procedures include detailed development and implementation of safety protocols that cover all aspects of the work process, such as handling hazardous materials, safe use of machines and tools, and steps for emergencies and evacuations.

Regular updates and revisions of safety protocols are essential to ensure compliance with the latest standards and regulations. It is also important that all employees are trained in these procedures, with systematic monitoring and evaluation of their implementation to identify potential shortcomings and adjust existing processes.

It is necessary to continuously improve procedures to enhance occupational safety and health (OSH) standards in companies. This involves implementing measures, monitoring their effectiveness, and regularly aligning with legal and internal regulations. Compliance assessments should be conducted monthly, documenting all discrepancies between the current state and the prescribed standards, as well as monitoring the implementation of corrective measures until they are fully realized.

The person responsible for occupational safety must be continuously informed about changes in legal regulations. These changes are discussed at Safety Committee meetings, and new activity plans are created. All employees should be regularly informed of their obligations through bulletin boards, emails, and Safety Committee meetings.

Checking the implementation of OSH measures in production facilities is crucial for preventing hazardous work practices and equipment failures. These checks include assessing workplaces, equipment, work methods, and processes to identify and eliminate all

[1] Corresponding author, milica_bogdanov@yahoo.com
[2] dijana.vasas@gmail.com,
[3] famzr.edu@gmail.com, ORCID: https://orcid.org/0000-0003-3707-7522
[4] sssanja89@gmail.com, ORCID: https://orcid.org/0000-0002-0537-6782
[5] milan.nikolic@tfzr.rs, ORCID: https://orcid.org/0000-0001-6643-1442

unsafe situations. Immediate supervisors and maintenance workers should conduct these checks daily, and in the case of significant deviations, the person responsible for OSH should be immediately notified.

Training employees in the area of OSH is mandatory for all supervisors, engineers, and workers. The goal of the training is to equip employees with the knowledge and skills necessary to safely perform tasks and to verify the acquired knowledge through theoretical and practical tests. Training programs should be tailored to the specifics of the workplace and include regular checks and retraining in the event of unsuccessful testing or after returning from extended absences.

Active participation of all employees in the implementation of OSH measures is of paramount importance. All workers should adhere to safety regulations, participate in the work of the Safety Committee, provide suggestions for improvement, engage in risk assessment, and offer first aid in case of injuries. Factory management should support these activities by attending meetings and actively engaging in the implementation of OSH measures.

Effective communication of information between all levels of the organization is crucial for the success of implementing OSH measures. This procedure includes regularly informing employees through bulletin boards, emails, accident data charts, and posters warning about hazards and protective measures. The frequency of injuries, severity of injuries, and absenteeism rates are monitored and analyzed to take appropriate measures to improve safety.

These procedures aim to achieve a safe and healthy working environment in which all employees are educated, informed, and actively involved in the implementation of OSH measures.

MATERIALS AND METHODS

In this research, relevant published studies and investigations were utilized to identify the key factors associated with work-related injuries. The collected data from these sources was analyzed through a literature review, aiming to formulate proposals and recommendations for reducing the frequency of work-related injuries. Special attention was given to demographic, administrative, and occupational characteristics that influence the incidence of injuries, as well as existing health and safety measures at work.

RESULTS AND DISCUSSION

There is a wealth of information available that can help employers identify which groups of workers should receive notifications, education, and training on occupational health and safety, as well as which workers should be prioritized. Research has also indicated the following factors associated with a higher risk of injuries and illnesses in the workplace [4]:

- Workers' age (younger workers have a higher risk of injury)
- Length of service (newly hired employees have a higher injury rate)
- Company size (medium-sized companies report more injuries compared to smaller or larger firms)
- Type of work (the frequency and severity of injuries vary significantly by industry classification [SIC] code)
- The use of hazardous substances (according to SIC codes).

This study is followed by another investigation that also showed that young workers, particularly in the construction industry, are particularly at risk for injuries [5]. In Norway, where young people can start working in the construction sector at the age of 18, the study examined how these workers are received in the workplace, with a particular focus on safety training [5]. The research was conducted as a qualitative case study and included young workers or apprentices, their colleagues, immediate supervisors, safety managers, and safety representatives from the company. The results showed that large companies have better-formalized routines for training young workers compared to small firms. However, these routines often depend more on legal requirements than on the size of the company [5]. This study emphasizes the importance of systematic safety training, especially for young workers who are in the process of adapting to the work environment. Training plays a crucial role in reducing the risk of injuries, as it helps young workers better understand and apply safety standards and procedures. Adequate training not only improves workplace safety but also contributes to an overall reduction in accidents and injuries at work. Customized and formalized training routines can significantly enhance the safety culture in the work environment and protect workers, especially those who have just started their careers.

A study that investigated how many Canadian employees receive safety training during the first year of a new job analyzed data from three national surveys in Canada (1999, 2001, 2003), covering 59,159 respondents from the Workplace and Employee Survey, of whom 5,671 were in their first year of employment [6]. Only 12% of women and 16% of men reported receiving safety training in the past 12 months. Employees in their first year were more likely to receive training compared to those with more than five years of experience, but still, only one in five new employees received training from their current employer. In a customized regression model, a higher likelihood of training was observed among employees with access to family programs, among women in medium-sized workplaces and manufacturing, as well as men in large workplaces and those working part-time. No increased likelihood of training was found among younger workers or those in jobs with higher physical demands. The results indicate that only one in five Canadian employees in the first year of a new job receives safety training and that the provision of training does not significantly depend on the level of risk in occupations [6].

Occupational Safety and Health training programs (OSH) that are not properly designed by qualified and educated professionals lead to poor safety measures and an increased number of injuries and fatalities due to hazardous practices [2]. Millions of workers around the world experience work-related injuries, resulting in death, injuries, job loss, and broader social implications. A study that analyzed factors related to workplace injuries relied on U.S. databases and the General Social Survey (GSS), covering the period from 2002 to 2014 [2]. The sample included 5,914 workers from various sectors, divided between women and men, aged over 18. The analysis covered several dimensions: demographic data, job-related characteristics, administrative factors, and health and safety measures. The study specifically focuses on assessing the frequency of three common workplace injuries: non-fatal injuries, back pain, and hand pain [2]. Factors such as age, gender, race, working hours, overtime, trust in management, support from colleagues, and workflow efficiency have been identified as having a significant impact on workplace injuries. For each model, the study quantifies these impacts through odds ratios and relative effects [2]. For example, in the non-fatal injury model, the relative effects of age show that workers older than 65 years have a 2.56% reduction in the frequency of non-fatal injuries compared to younger workers. Furthermore, in the back pain model, the estimated odds of experiencing back pain in men are 0.90 times lower than in women. Also, in the hand pain model, workers who have enough time to complete their tasks have estimated odds of experiencing hand pain that is 0.85 lower than those who do not have enough time, etc.

Organizations can utilize the results of this study to reduce workplace injuries. Flexible work arrangements, tailored training programs, and ergonomic improvements should emphasize factors such as age, gender, and working hours. Enhancing communication, promoting a positive work culture, and prioritizing safety and health measures can help mitigate risks related to trust in management and support from colleagues. Analyzing the cost-benefit relationship, along with ongoing monitoring, will ensure the effectiveness of these interventions, reduce incidents of back and hand pain, minimize costs, and create a safer work environment, contributing to the overall well-being of workers and the success of the organization.

In the European Union, in 2018, only 6% of all bodily injury cases in non-fatal workplace accidents were related to head injuries [3]. However, 24% of fatal workplace injuries involved head injuries [7], and head injuries are a common cause of death and disability [8,9]. Education and training on occupational health and safety play a key role in reducing the risk of workplace injuries, including traumatic brain injury (TBI). More information is available about TBI than other head injuries at work, with a particular focus on the primary and construction industries, where the risk is particularly high among male workers, and falls are the most common cause of these injuries [10]. Industries where head injuries, including TBI, are common often include education and training, healthcare, social assistance, manufacturing, and transportation [9]. Through adequate safety and health training, workers can develop the skills and knowledge needed to recognize and prevent hazards, which directly reduces the frequency of workplace injuries. Finland, with a workforce of 2.5 million people, has an inclusive social security system, a high degree of coverage for mandatory worker insurance, and well-developed occupational health services [3]. Training and occupational safety play a crucial role in reducing the risk of workplace injuries, and specific differences among industries highlight the need for tailored approaches in different sectors. The construction industry, for example, records the highest frequency of head injuries, indicating the need for targeted training to reduce these risks. Educating employees in this industry, focusing on fall prevention and proper use of protective equipment, can significantly contribute to reducing the number of injuries [3].

It has been noted that eye injuries are the most common among head injuries, while injuries caused by violence are particularly prevalent in healthcare and social services. These observations highlight the importance of training that emphasizes the prevention of specific injuries, such as eye protection in industry and training on procedures in cases of violence in health and social services.

One of the strengths of this study is the extensive database of 32,898 workplace injuries, based on the national system of mandatory insurance and reporting [3]. The low percentage of unreported injuries allows for precise analysis, which is crucial for improving training and preventive measures [3].

The reliability of workplace injury data varies among countries, and in countries with developed insurance systems, such as Finland, the reporting rate is high. This allows for more precise training programs based on actual data. In contrast, in countries with weaker reporting systems, the lack of data makes it difficult to develop effective preventive strategies [3].

International comparisons of workplace injury data can be challenging due to different practices in collecting and recording information. The harmonization of these data, as attempted with the European ESAW system, improves consistency, but there are still challenges with coding and interpreting individual variables [3].

The importance of insurance and training systems is particularly emphasized in countries like Finland, where worker insurance is a priority. Thanks to this system, less than 10% of employees are uninsured, and the available data allow for detailed analysis of injuries and adequate compensation for victims. Effective training can directly contribute to reducing injuries and increasing awareness of safety risks.

Although efforts to improve safety are ongoing, a significant number of head injuries still occur. This highlights the need for continuous training and education for employees. It is particularly important to encourage accurate reporting of injuries, as detailed and precise data collection enables the development of better prevention strategies.

All these points emphasize the importance of training as a key means of reducing workplace injuries, improving reporting systems, and increasing the effectiveness of preventive measures in occupational safety and health. Understanding specific risks in different industries helps create tailored training programs that can significantly enhance employee safety [3].

Young workers, especially those under the age of 25, represent a vulnerable workforce due to an increased risk of injuries and potential exposure to carcinogens. Sectors such as construction, outdoor professions, and agriculture have been identified as the most hazardous, as they employ a large number of young workers who are exposed to carcinogenic substances. In addition, specific patterns of risky behavior characteristic of these jobs further increase the risk of health problems. Although there are currently no concrete data on assessments of carcinogen exposure among young workers, these findings indicate the need for further investigation and improvement of health and safety protections in the workplace, particularly for young workers in construction, agriculture, and outdoor professions.

Exposure to carcinogens in the workplace remains a persistent challenge in Canada and around the world. It is extremely important to consider groups that may be more frequently or intensely exposed to carcinogens and to direct efforts toward cancer prevention for these groups [11]. For several reasons, young workers (under 25 years old) exposed to carcinogens are at an increased risk of negative health outcomes compared to adult workers. First, young workers are biologically more vulnerable as they are still undergoing physical and cognitive changes [12]. However, several studies have investigated increased injury rates among young workers, particularly among young men [13,14].

The essence of this text is that young workers are often exposed to hazardous chemicals and toxic substances, but chronic exposure to these substances has not been sufficiently researched. Long-term exposure can lead to serious health issues such as skin and respiratory diseases, as well as cancer [15,16]. Research shows that a significant percentage of young workers come into contact with potentially carcinogenic substances, but data on the level and duration of exposure is often lacking, making it difficult to assess their risk [17].

Young workers often perform entry-level jobs with minimal skill requirements, which exposes them to various hazards [17]. These jobs involve the use of chemicals such as cleaning agents, solvents, caustic materials, and pesticides, all of which can pose a significant health risk [16]. Additionally, these jobs are often casual or seasonal, which can contribute to a poor safety culture and hinder workers from acquiring job-specific skills as well as appropriate safe working habits [20]. Although organizations and advocacy groups provide information about safety risks associated with jobs performed by young workers, this information often has low priority due to the limited job options available to young workers [16].

Young workers typically hold entry-level positions with minimal skill requirements. These jobs are often casual or seasonal, which can contribute to a poor safety culture and reduce the workers’ ability to acquire specific skills and safe working habits [18]. Labor organizations and advocacy groups inform young workers and their parents about safety risks, but this information often has low priority in decision-making, given the limited employment opportunities for young workers [16].

Furthermore, young workers often do not receive adequate safety training. Extensive studies have shown that only 20% of young women and 23% of young men report having received any safety training during their first year of work [6]. Research from the SAFE Workers of Tomorrow organization indicates that 31% of young workers who attended safety training seminars were only informed about minimal hazards in their workplace [19]. The lack of safety training leads to young workers having little knowledge of hazards and risk-reduction strategies, making them particularly vulnerable compared to adult workers.

The use of personal protective equipment (PPE) among young workers is also concerning. A study from the United States shows that among teenagers (aged 14–17) employed in retail and service sectors, only 35% of those who received PPE training use protection, while 26% of those who did not receive training use PPE [15]. Older workers often believe that young workers feel a sense of "invincibility" or do not understand the seriousness of injuries or illnesses that can arise if appropriate protective measures are not taken [20]. However, many young workers report that they have not developed safe working habits or do not realize that they need protective equipment [20]. Additionally, the size and style of PPE are often not tailored to young workers, which can lead to young workers, especially young women, not using PPE because they find it uncomfortable or excessive [20].

CONCLUSION

The research clearly indicates that adequate training and education of employees are key components in reducing the risk of workplace injuries. Continuous improvement of employees' knowledge and skills contributes to the development of awareness regarding safety procedures, which directly affects the safe use of work equipment and reduces the frequency of accidents. The frequency of injuries, particularly among young and newly hired workers, requires special attention, as these workers are often exposed to higher risks.
The importance of systematic training, tailored to the specifics of the workplace and regularly updated according to legal regulations, cannot be overstated. Although progress has been made in the development of safety protocols, effective implementation and active employee participation are crucial for enhancing safety. Organizations should continue investing in the education and training of employees to create a safer working environment, reduce the number of injuries, and improve productivity and workers' well-being.

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GREEN TECHNOLOGIES AND THEIR ROLE IN URBAN SUSTAINABILITY INITIATIVES

Research paper

Mihalj Bakator[1], Luka Đorđević[2], Borivoj Novaković[3], Velibor Premčevski[4], Stefan Ugrinov[5]
[1,2,3,4,5]University of Novi Sad, Technical faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Abstract: This paper analyzes the integration of green technologies and sustainable practices within urban sustainability initiatives. It focuses on the role of renewable energy sources, sustainable transportation systems, and green building practices in enhancing urban sustainability. By adopting these strategies, urban areas can significantly reduce their environmental impact, promote energy efficiency, and support healthy living environments. The study develops a theoretical model that illustrates how these elements interact to achieve urban sustainability. Key components of this model include the deployment of advanced technologies, supportive infrastructure, and collaborative governance. The model addresses challenges such as resource management, technological adoption, and community engagement, providing a holistic framework for sustainable urban development. The research suggests that governments, enterprises, and individuals must work together to implement comprehensive sustainability strategies. This paper contributes to the existing literature by offering a structured approach to integrating green technologies in urban settings and provides a foundation for future empirical studies.
Key words: green technologies, urban sustainability, sustainable initiatives, strategies.

INTRODUCTION

Urban areas are increasingly turning to renewable energy sources as part of their efforts to achieve sustainability. The integration of solar, wind, and geothermal energy into city infrastructures represents a significant shift from traditional fossil fuel reliance. Solar panels on rooftops, wind turbines in strategic locations, and geothermal systems for heating and cooling are becoming more common in urban landscapes. These renewable energy solutions not only reduce greenhouse gas emissions but also lower energy costs over time. Additionally, the implementation of microgrids and energy storage technologies improves the reliability and resilience of urban energy systems, ensuring a stable supply even during peak demand or disruptions [1].
Sustainable transportation systems are another important element in urban sustainability initiatives. Cities are adopting a range of green transportation options to reduce their carbon footprints and alleviate traffic congestion. Electric vehicles, supported by an expanding network of charging stations, offer a cleaner alternative to traditional internal combustion engine cars. Public transit systems, including buses, trams, and subways, are increasingly powered by renewable energy, providing efficient and eco-friendly mobility solutions [2].
Green building practices play a important role in creating sustainable urban environments. The construction industry is embracing eco-friendly methods and materials to minimize environmental impact. Green buildings are designed with energy efficiency in mind, incorporating features such as high-performance insulation, energy-efficient windows, and advanced heating, ventilation, and air conditioning systems [3].
The current body of literature lacks a comprehensive framework that integrates renewable energy, sustainable transportation, and green building practices within urban sustainability initiatives. This paper aims to fill this gap by developing a theoretical model that demonstrates the interconnectedness of these elements in supporting sustainable urban environments. The paper is structured into five main sections: Introduction, Renewable Energy and Sustainable Transport in Urban Areas, Innovations in Green Building and Urban

[1] Corresponding author, mihalj.bakator@tfzr.rs, ORCID: https://orcid.org/0000-0001-8540-2460
[2] luka.djordjevic@tfzr.rs, ORCID: https://orcid.org/0000-0003-4578-9060
[3] borivoj.novakovic@tfzr.rs, ORCID: https://orcid.org/0000-0003-2816-3584
[4] velibor.premcevski@tfzr.rs, ORCID: https://orcid.org/0000-0002-2883-6956
[5] stefan.ugrinov@tfzr.rs, ORCID: https://orcid.org/0009-0000-7206-655X

Biodiversity, Theoretical Model and Discussion, and finally, Suggestions and Guidelines. Each section provides an in-depth analysis of the respective topics, building towards the development of the theoretical model presented in the fourth section. The paper concludes with practical suggestions and guidelines for governments, enterprises, and individuals to implement sustainable practices effectively.

RENEWABLE ENERGY SOURCES IN URBAN AREAS AND SUSTAINABLE TRANSPORT

The transition to renewable energy sources in urban areas is a important aspect of modern sustainability initiatives. Cities are increasingly leveraging solar power as a primary renewable energy source due to its accessibility and declining cost. Photovoltaic panels are commonly installed on rooftops, providing a decentralized energy generation method that reduces reliance on traditional power grids. Large-scale solar farms, although more typical in rural areas, are also being integrated into urban settings where space permits. Wind energy, while more challenging to implement in densely populated areas due to space constraints and aesthetic considerations, is utilized through strategically placed turbines in locations such as waterfronts or industrial zones. Additionally, advancements in technology have led to the development of smaller, more efficient turbines suitable for urban environments [4].
Geothermal energy is another viable option for urban renewable energy. Cities located in geothermal hotspots are harnessing this resource for heating and cooling purposes. Geothermal heat pumps, for instance, can significantly reduce the energy required for temperature regulation in buildings. This not only provides a renewable energy source but also addresses waste management issues, creating a circular economy within urban ecosystems [1].
Sustainable transport is equally important in the pursuit of urban sustainability. Electric vehicles (EVs) are at the forefront of this transition, with cities investing in extensive charging infrastructure to support the growing number of EVs on the road. Public transportation systems are also being electrified, with electric buses and trains replacing their diesel counterparts. These initiatives contribute significantly to the reduction of urban air pollution and greenhouse gas emissions. Cities are implementing policies to encourage the use of public transportation, such as subsidized fares and improved service frequency, making it a more attractive option for commuters [5].
Active transportation modes, including cycling and walking, are promoted through the development of dedicated bike lanes and pedestrian zones. Bike-sharing programs have been introduced in many cities, providing a convenient and sustainable alternative to motorized transport. The integration of these programs with public transit systems ensures seamless mobility for urban residents. Additionally, advancements in technology are supporting the adoption of autonomous electric vehicles and shared mobility services, further reducing the reliance on private car ownership and contributing to more efficient use of urban space [6].
The shift towards renewable energy sources and sustainable transport is transforming urban areas into more resilient and environmentally friendly spaces. These initiatives not only reduce carbon footprints and mitigate climate change impacts but also improve the quality of life for urban residents by creating cleaner, healthier, and more sustainable living environments [7].

INNOVATIONS IN GREEN BUILDING AND BIODIVERSITY IN URBAN AREAS

Innovations in green building are significantly transforming urban landscapes by integrating sustainable practices and advanced materials into the design, construction, and operation of buildings. One of the key focuses of green building innovation is energy efficiency. High-performance insulation materials, such as spray foam and rigid foam boards, provide superior thermal resistance compared to traditional insulation, reducing the amount of energy required to heat and cool buildings. Double or triple-glazed windows are designed to minimize heat transfer, helping to maintain consistent indoor temperatures and reduce energy consumption. Energy-efficient HVAC systems, including variable refrigerant flow systems and geothermal heat pumps, offer precise temperature control while consuming less energy [8].

Smart building technologies are at the forefront of optimizing energy use. Automated systems for lighting, heating, and cooling can adjust settings based on occupancy and weather conditions, ensuring that energy is not wasted. These systems often utilize sensors and IoT (Internet of Things) technology to monitor building performance in real-time and make necessary adjustments. Renewable energy sources are also being seamlessly integrated into building designs. Solar panels, both rooftop and building-integrated, harness sunlight to generate electricity. Wind turbines, though more common in rural areas, are being adapted for urban use with vertical-axis designs that can operate efficiently in the variable wind conditions typical of cities. Geothermal systems provide a reliable and sustainable source of heating and cooling by tapping into the earth's natural temperature stability [9].The selection of materials is important in green building practices, emphasizing sustainability and reduced environmental impact. Recycled steel, reclaimed wood, and low-VOC (volatile organic compounds) paints and finishes are increasingly used to minimize the ecological footprint of construction. Locally sourced materials are preferred to reduce transportation emissions and support regional economies. Green roofs and walls are significant innovations that offer multiple environmental benefits. These living structures provide insulation, reducing the energy needed for heating and cooling. They also help manage stormwater by absorbing rainfall, which reduces runoff and the risk of flooding. Furthermore, green roofs and walls improve air quality by filtering pollutants and producing oxygen. These structures create habitats for birds, insects, and other wildlife, contributing to urban biodiversity and ecological health [10].

Water conservation is another important aspect of green building. Rainwater harvesting systems collect and store rainwater for non-potable uses, such as irrigation and toilet flushing, reducing the demand on municipal water supplies. Low-flow fixtures, including faucets, showerheads, and toilets, use less water while maintaining performance, helping to conserve water resources. Greywater recycling systems treat and reuse water from sinks, showers, and laundry for landscaping and other non-potable applications, further enhancing water efficiency [11].

Promoting biodiversity in urban areas involves creating and enhancing green spaces that support a wide range of plant and animal species. Parks, community gardens, and green corridors are designed to provide habitats and promote ecological balance. Native plant species are often chosen for landscaping because they are adapted to local conditions and provide food and shelter for native wildlife. Urban planners are incorporating green infrastructure into city designs, which includes green roofs, walls, and streetscapes that support biodiversity and contribute to the ecological network of urban areas. These green spaces not only improve the aesthetic appeal of cities but also offer recreational opportunities and improve the quality of life for residents [12].

Efforts to increase biodiversity in cities also include the restoration of natural habitats that have been degraded or lost due to urbanization. Wetland restoration projects aim to re-establish important habitats for various species, providing benefits such as flood control and water purification. Urban forestry programs focus on planting and maintaining diverse tree species, which improve air quality, provide shade, and create habitats for birds and other wildlife. Trees also offer significant psychological and physical health benefits to urban residents, reducing stress and promoting outdoor activity [13].

Educational programs and community involvement are essential components of urban biodiversity initiatives. Public awareness campaigns and workshops inform residents about the importance of biodiversity and sustainable practices. Community gardens and volunteer tree planting events engage residents in hands-on conservation efforts, supporting a sense of stewardship and connection to the natural environment. Schools and universities often participate in urban biodiversity projects, incorporating them into curricula and research programs, which helps to cultivate a new generation of environmentally conscious citizens [14].

The combination of green building innovations and biodiversity improvement is transforming urban areas into more sustainable, resilient, and livable spaces. These efforts not only mitigate the environmental impacts of urbanization but also create healthier, more vibrant communities. By prioritizing sustainability and ecological health, cities are not only addressing immediate environmental challenges but also laying the groundwork for a more sustainable future. As more urban areas adopt these practices, the cumulative impact will contribute significantly to global efforts to combat climate change and preserve natural ecosystems [15].
Based on the analyzed literature, a comprehensive model for improving urban sustainability through the integration of green technologies and sustainable practices is developed. The model is presented in Figure 1. It highlights the interrelations between renewable energy sources, sustainable transportation, and green building practices, with a focus on supporting infrastructure and technology as important enablers. This model serves as a conceptual framework for understanding how these elements contribute to the overarching goal of urban sustainability. The diagram emphasizes the importance of integrated planning and policy-making to address environmental challenges in urban areas effectively.

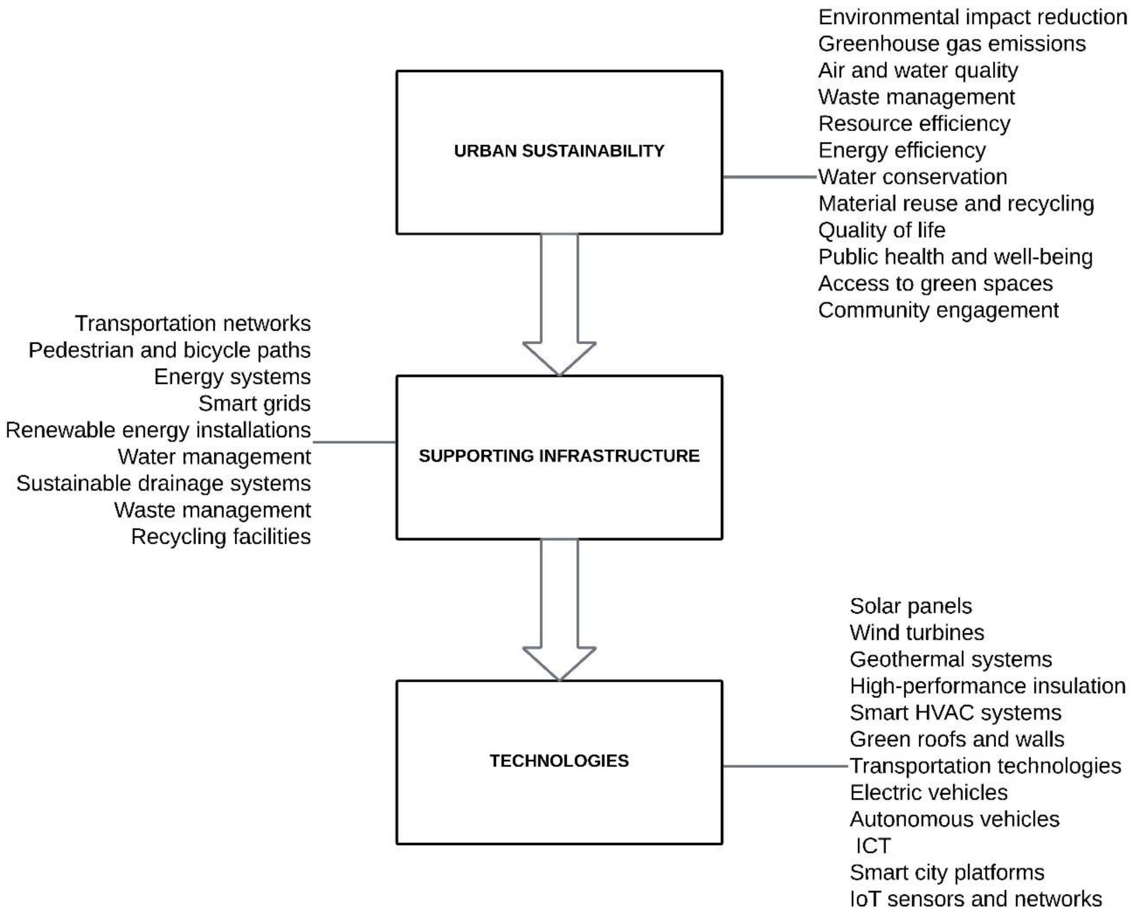

Fig. 1. *Model for improving urban sustainability*

The concept of urban sustainability serves as the core focus, with each sub-element and main element interacting dynamically to support a more sustainable urban environment. Supporting infrastructure and technologies are important in driving these interactions and achieving the overarching goal of urban sustainability. Environmental impact reduction is closely linked to various aspects of supporting infrastructure and technologies. For instance, the implementation of public transit systems, pedestrian and bicycle paths, and electric vehicle charging stations within transportation networks significantly reduces greenhouse gas emissions. These systems encourage the use of low-emission and non-motorized transport options, leading to better air quality and reduced traffic congestion. Technologies such as electric and autonomous vehicles further improve these benefits by minimizing reliance on fosil fuels and optimizing traffic flow .Resource efficiency in urban sustainability is bolstered through advanced energy systems and building technologies. Smart grids and distributed energy resources, including renewable energy installations like solar panels and wind turbines, enable cities to use energy more efficiently and reduce their dependence on non-renewable sources. These systems support the integration of renewable energy into the urban grid, facilitating a steady and reliable energy supply. High-performance insulation, smart HVAC systems, and green roofs and walls in buildings minimize energy consumption, ensuring that resources are utilized effectively and sustainably. Water conservation efforts, aided by rainwater harvesting systems and sustainable drainage systems, ensure efficient water use and management, important for maintaining a balance in urban resource utilization.

Quality of life improvements are significantly influenced by supporting infrastructure that promotes public health, well-being, and access to green spaces. Well-designed public transit systems, pedestrian-friendly pathways, and bike lanes not only reduce emissions but also promote physical activity and reduce stress among urban residents. Access to green spaces, supported by community gardens and parks, improves mental health and provides recreational opportunities, supporting a sense of community. Green roofs and walls contribute to creating these green spaces within densely built environments, offering aesthetic and ecological benefits. Technologies such as real-time public transit information systems and smart city platforms improve the efficiency and convenience of urban living, making cities more livable and resident-friendly.

Supporting infrastructure in water management, including rainwater harvesting, wastewater treatment, and sustainable drainage systems, plays a important role in maintaining environmental sustainability. These systems manage water resources efficiently, reduce the risk of flooding, and ensure a consistent supply of clean water. Technologies like IoT sensors and networks, combined with data analytics and artificial intelligence, enable real-time monitoring and management of water systems, ensuring optimal performance and quick response to issues.

Waste management infrastructure, comprising recycling facilities, composting programs, and waste-to-energy plants, is essential for reducing the environmental impact of urban waste. These systems facilitate the effective recycling and reuse of materials, minimizing landfill use and resource extraction. Composting programs convert organic waste into valuable compost, enriching urban soils and supporting local agriculture. Waste-to-energy plants transform non-recyclable waste into energy, providing a renewable energy source while reducing waste volumes. Advanced technologies such as smart waste management systems and IoT-enabled waste bins optimize waste collection and processing, enhancing efficiency and reducing environmental footprints.

SUGGESTIONS AND GUIDELINES

Based on the developed model presented in Figure 1, and the reviewed literature, the following guidelines and suggestions are proposed to improve urban sustainability through green technologies and sustainable practices:

- Implement comprehensive public transit systems
- Promote the use of renewable energy sources
- Develop and enforce green building standards
- Improve urban green spaces

- Invest in water management infrastructure
- Strengthen waste management programs
- Facilitate public awareness campaigns
- Implement sustainable transportation policies
- Engage in corporate social responsibility initiatives
- Improve waste reduction and recycling efforts
- Promote sustainable supply chain practices
- Use sustainable transportation methods
- Participate in local sustainability initiatives

CONCLUSION

Urban sustainability is an imperative for modern cities facing the challenges of rapid urbanization, climate change, and resource depletion. The integration of renewable energy sources into urban infrastructures, including solar, wind, and geothermal systems, demonstrates a significant shift towards reducing greenhouse gas emissions and promoting energy efficiency. These technologies, alongside advanced smart grid systems and energy-efficient building designs, highlight the potential for urban areas to become self-sufficient in energy while minimizing their environmental impact.

The collective efforts of governments, enterprises, and individuals can create a synergistic effect that propels urban sustainability forward. By implementing comprehensive strategies that encompass renewable energy, sustainable transportation, green building practices, and efficient resource management, urban areas can become models of sustainability. This holistic approach not only addresses the immediate environmental challenges but also ensures that cities remain resilient and vibrant places for future generations.

Future research should focus on conducting empirical studies that analyze the impact of implementing green technologies in various urban settings. Longitudinal studies that track the effectiveness of renewable energy, sustainable transportation, and green building initiatives over time would provide valuable insights into their long-term benefits. Additionally, exploring the role of policy frameworks and community engagement in the successful adoption of these practices would contribute significantly to the field. Further research should also investigate the economic and social implications of these technologies to develop a comprehensive understanding of their impact on urban sustainability.

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SUSTAINABILITY AS A CORE COMPONENT OF QUALITY STANDARDS IN MODERN BUSINESSES

Research paper

Dragan Ćoćkalo[1], Mihalj Bakator[2], Milan Nikolić[3], Sanja Stanisavljev[4], Verica Gluvakov[5]
[1,2,3,4,5]University of Novi Sad, Technical faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Abstract: This paper analyzes the integration of Artificial Intelligence (AI) and Big Data into quality management systems to improve sustainability and business competitiveness. AI technologies, such as predictive analytics, automated quality inspections, and process optimization, combined with Big Data analytics, enable businesses to proactively manage quality and sustainability. The study focuses on developing a theoretical model that integrates AI and Big Data within quality management frameworks to improve environmental and social performance alongside product and service quality. Key strategies include investing in sustainable technologies, supporting a culture of continuous improvement, and implementing robust data governance practices. Challenges identified include technical complexities, data integration issues, and ethical concerns, which are mitigated through regulatory support, education initiatives, and collaboration among stakeholders. Businesses and individuals play important roles by adopting sustainable practices and leveraging technology for quality improvements. This study provides a framework for future advancements in quality management and sustainability through the effective use of AI and Big Data.

Key words: Sustainability, AI, Big data, quality management systems.

INTRODUCTION

Sustainable practices and quality standards in business have become increasingly intertwined in recent years. As organizations face growing pressure from stakeholders, regulatory bodies, and consumers, the integration of sustainability into core business strategies has emerged as a important aspect of maintaining and improving quality standards. The concept of sustainability in business encompasses a wide range of practices aimed at minimizing environmental impact, promoting social responsibility, and ensuring economic viability. These practices not only address immediate environmental and social concerns but also contribute to the long-term success and resilience of businesses [1]. Modern businesses are recognizing that sustainable practices can drive innovation, improve efficiency, and improve brand reputation. Implementing sustainable practices involves adopting measures such as reducing waste, conserving energy, sourcing materials responsibly, and supporting fair labor practices. These efforts contribute to the overall quality of products and services by ensuring they are produced in a manner that respects environmental limits and societal needs. Quality standards, which traditionally focused on product reliability and performance, are evolving to include sustainability criteria, reflecting a holistic approach to quality management [2]. As sustainability becomes a core component of quality standards, businesses are better positioned to meet the demands of a conscientious market and comply with increasingly stringent regulatory requirements [3]. Incorporating sustainability into quality standards is not without its challenges. Businesses must navigate complex supply chains, invest in new technologies, and often undertake significant organizational change. However, the benefits of such integration are substantial, offering opportunities for cost savings, risk mitigation, and competitive advantage. As the business landscape continues to evolve, the commitment to sustainability and quality will be essential for organizations aiming to achieve long-term success and make a positive impact on society and the environment [4].

[1] dragan.cockalo@tfzr.rs, ORCID: https://orcid.org/0000-0003-2085-5420
[2] Corresponding author, mihalj.bakator@tfzr.rs, ORCID: https://orcid.org/0000-0001-8540-2460
[3] milan.nikolic@tfzr.rs, ORCID: https://orcid.org/0000-0001-6643-1442
[4] sanja.stanisavljev@tfzr.rs, ORCID: https://orcid.org/0000-0003-3565-2597
[5] verica.gluvakov@tfzr.rs, ORCID: https://orcid.org/0000-0003-1083-0203

The current body of literature lacks comprehensive studies on the simultaneous integration of AI and Big Data into quality management systems aimed at enhancing sustainability and competitiveness. This paper fills this gap by proposing a theoretical model that serves as a basis for future research. The paper is organized into five sections: Introduction, Integration of AI and Big Data into Quality Management Systems, Challenges and Opportunities, Guidelines and Recommendations, and finally, Conclusion. Each section provides a detailed examination of the role of AI and Big Data in transforming quality management practices to align with sustainability goals.

SUSTAINABILITY AND QUALITY STANDARDS

Sustainability and quality standards are increasingly seen as complementary and essential components of modern business practices. As global awareness of environmental issues and social responsibility grows, businesses are compelled to align their operations with sustainable principles to ensure long-term viability and success. This alignment involves integrating sustainability into every aspect of the business, from production processes to supply chain management, and even customer engagement [5]. Sustainability in business encompasses a variety of practices aimed at reducing environmental impact, conserving resources, and promoting social equity. These practices include reducing emissions, minimizing waste, improving energy efficiency, and sourcing materials ethically. Businesses that prioritize sustainability often adopt a life-cycle approach, considering the environmental and social impacts of their products and services from raw material extraction to disposal. This holistic perspective ensures that sustainability is embedded in the core operations rather than treated as an afterthought [6, 7].

Quality standards, traditionally focused on product performance, safety, and reliability, are evolving to incorporate sustainability criteria. This evolution reflects a broader understanding of quality that includes environmental stewardship and social responsibility. Incorporating sustainability into quality standards involves setting benchmarks for sustainable practices and ensuring that products and services meet these benchmarks consistently [3].

The integration of sustainability into quality standards requires a systematic approach to management and continuous improvement. Businesses must develop and implement comprehensive sustainability strategies that are aligned with their overall quality management systems. This involves setting clear, measurable goals for sustainability, regularly monitoring progress, and making adjustments as needed. Stakeholder engagement is also important, as businesses must communicate their sustainability efforts transparently and involve stakeholders in the decision-making process [8].

Challenges in integrating sustainability with quality standards are significant but manageable. These challenges include the complexity of measuring sustainability impacts, the need for significant investment in new technologies and processes, and the necessity of supporting a culture of sustainability within the organization. Despite these challenges, the benefits of integrating sustainability into quality standards are substantial. Businesses can achieve cost savings through resource efficiency, mitigate risks associated with environmental and social issues, and improve their reputation and competitiveness in the market [9].

Sustainability and quality standards, when effectively integrated, provide a framework for businesses to operate responsibly and efficiently. This integration supports the creation of products and services that meet high standards of quality while also contributing positively to environmental and social outcomes. As the global business environment continues to evolve, the commitment to sustainability and quality will be a key driver of innovation, resilience, and success [10].

ENVIRONMENTAL IMPACT AND CORPORATE RESPONSIBILITY

Environmental impact and corporate responsibility have become central themes in the contemporary business landscape, reflecting a profound shift towards sustainable and ethical practices. Companies are now expected to consider the environmental consequences of their operations and to take proactive steps to minimize negative impacts. This comprehensive approach encompasses managing resources efficiently, reducing waste, lowering emissions, and supporting a culture of sustainability across all facets of business activity [2].

Understanding environmental impact necessitates a thorough evaluation of the entire lifecycle of business operations. This includes raw material extraction, manufacturing processes, distribution, product use, and end-of-life disposal. A life-cycle analysis enables businesses to pinpoint areas where environmental harm is most pronounced and identify opportunities for improvement. For instance, reducing greenhouse gas emissions can be achieved through energy-efficient manufacturing processes, the adoption of renewable energy sources, and the development of low-carbon technologies. Waste reduction is addressed through recycling programs, product redesign for durability, and minimizing packaging materials [11].

Corporate responsibility transcends compliance with environmental regulations, embodying a commitment to sustainable practices that exceed legal requirements. This dedication involves crafting corporate policies and strategies explicitly aimed at sustainability. Companies often set ambitious targets for reducing their carbon footprint, invest in cutting-edge green technologies, and participate in carbon offset programs to mitigate their environmental impact. These efforts reflect a broader ethical stance that values long-term environmental health over short-term gains [12].

Stakeholder engagement is a important aspect of corporate responsibility. Transparent communication of environmental policies, goals, and achievements is essential to build trust and credibility with customers, employees, investors, and local communities. Companies that openly share their sustainability initiatives and progress reports support a sense of accountability and involvement among stakeholders. This transparency can significantly improve a company's reputation, making it more attractive to socially conscious consumers and investors. Engaging stakeholders also facilitates innovative solutions and collaborative efforts, which can amplify the positive impact of environmental initiatives [13].

Economic benefits are another significant driver for companies to embrace corporate responsibility and mitigate their environmental impact. Sustainable practices often lead to cost savings through increased operational efficiency and reduced resource consumption. For example, implementing energy-efficient technologies can lower energy bills, while waste reduction initiatives can decrease disposal costs and material expenses[14].

Integrating corporate responsibility into the core business strategy requires establishing clear governance structures to oversee environmental initiatives. This includes setting measurable goals, regularly monitoring progress, and publicly reporting outcomes. Many companies adopt recognized frameworks such as the Global Reporting Initiative (GRI) or the Carbon Disclosure Project (CDP) to standardize their sustainability reporting and benchmark their performance against industry peers. These frameworks provide a structured approach to measuring and communicating environmental performance, helping companies stay accountable and continuously improve their practices [15].

Education and training play a important role in supporting a culture of environmental responsibility within organizations. Employees at all levels must understand the importance of sustainable practices and be equipped with the necessary knowledge and skills to implement them. This cultural shift can be supported through regular training programs, sustainability workshops, and incentive structures that reward environmentally responsible behavior [16].

Environmental impact assessments (EIAs) are another important tool in corporate responsibility. EIAs involve systematically evaluating the potential environmental consequences of proposed projects or activities before they are carried out. This process helps businesses anticipate and mitigate negative environmental impacts, ensuring that new developments are aligned with sustainability objectives. Conducting thorough EIAs demonstrates a company's commitment to proactive environmental stewardship and informed decision-making [17].

Corporate responsibility also involves collaboration with external partners, including suppliers, customers, non-governmental organizations (NGOs), and government agencies. Building strong relationships with these stakeholders enables companies to leverage external expertise, resources, and networks to improve their sustainability efforts. For example, partnering with suppliers who share the same commitment to sustainability can ensure that materials are sourced responsibly, further reducing the company's overall environmental footprint. Collaboration with NGOs and government bodies can also provide valuable insights and support for implementing effective environmental strategies [18].

Innovation plays a important role in advancing corporate responsibility and reducing environmental impact. Companies are increasingly investing in research and development to create sustainable products and processes. Innovations such as biodegradable packaging, renewable energy solutions, and circular economy models not only reduce environmental harm but also open up new market opportunities. [19].

Proactive compliance with environmental regulations can also position companies as leaders in sustainability, enhancing their competitive advantage and attracting environmentally conscious customers and investors [12].

Corporate responsibility regarding environmental impact is an ongoing journey that requires continuous adaptation and improvement. As scientific understanding of environmental issues evolves and societal expectations rise, companies must remain agile and committed to advancing their sustainability efforts. This commitment involves regularly reviewing and updating environmental policies, setting new sustainability targets, and engaging in ongoing dialogue with stakeholders. Continuous improvement ensures that companies can effectively address emerging environmental challenges and contribute to the broader goal of sustainable development [20]. Based on the reviewed literature, a model for improving business competitiveness in the context of sustainability and quality standards is developed. The model, as illustrated in Figure 1, outlines the interaction between AI-enabled quality processes and Big Data-driven decision-making in achieving sustainable quality standards.

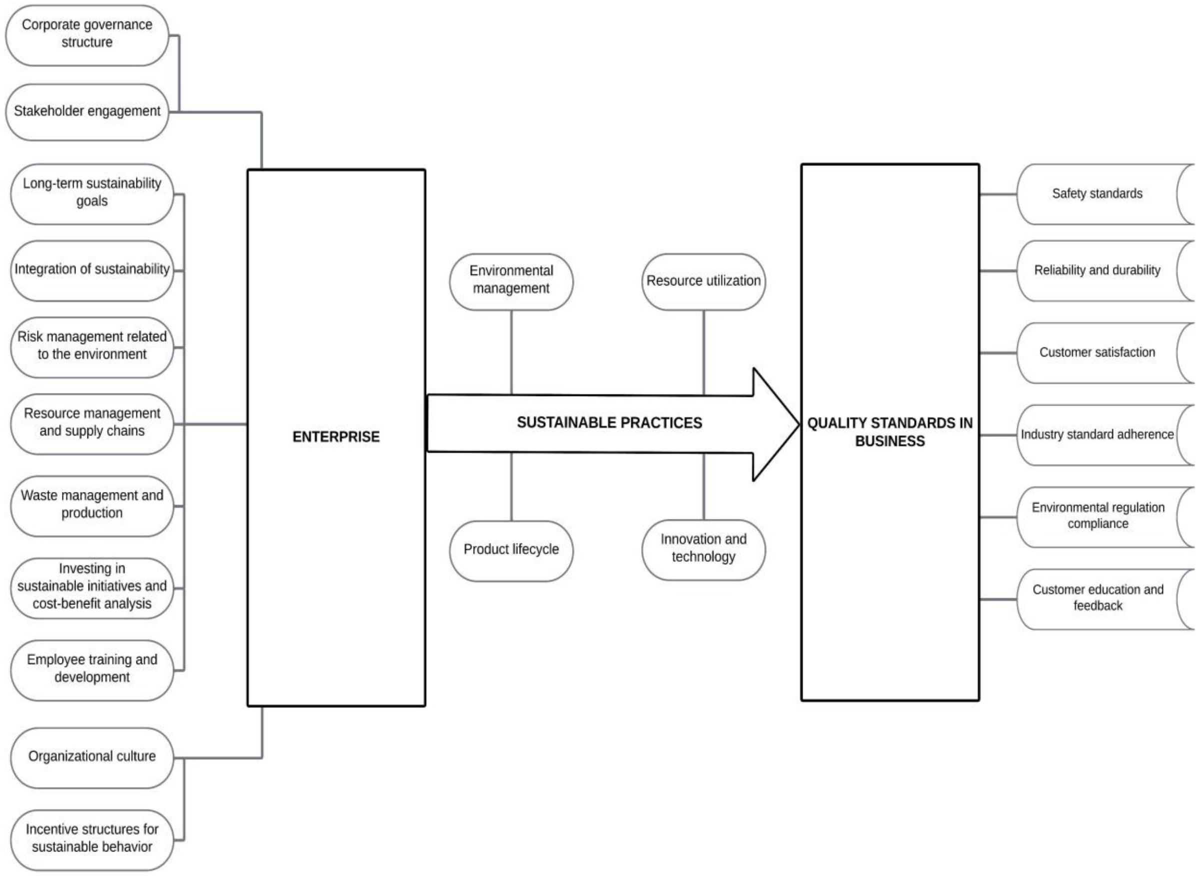

Fig. 1. *Model for improving business competitiveness in the context of sustainability and quality standards*

Leadership and governance within an enterprise play a important role in setting the tone for sustainability and quality standards. Executive commitment to sustainability ensures that environmental and social considerations are integrated into the decision-making process. Corporate governance structures, including boards and committees, oversee the implementation of these practices, ensuring alignment with overall business objectives. Ethical decision-making frameworks guide leaders in balancing profitability with sustainability goals, influencing the entire organization's approach to sustainable practices.

The enterprise's strategy and objectives are fundamental in integrating sustainable practices into the core business strategy. Setting long-term sustainability goals provides a roadmap for operational changes and resource allocation.

Operational practices within an enterprise directly affect the implementation of sustainable practices and adherence to quality standards. Efficient resource management, sustainable supply chain logistics, and optimized production processes are important for reducing the environmental footprint. Waste management systems ensure that waste is minimized and managed responsibly. These operational efficiencies not only support sustainability goals but also improve product quality and reliability, contributing to overall business success.

Financial performance is influenced by the enterprise's investment in sustainable initiatives. Cost-benefit analyses of sustainability practices help justify investments in green technologies and processes, demonstrating their long-term economic viability. Economic impact assessments provide insights into how sustainability efforts contribute to overall financial health, balancing short-term costs with long-term benefits.

Human resources play a important role in supporting a culture of sustainability within the enterprise. Employee training and development programs ensure that all staff members are equipped with the knowledge and skills necessary to implement sustainable practices. Cultivating an organizational culture that prioritizes sustainability encourages employees to actively contribute to these efforts. Incentive structures that reward environmentally responsible behavior further reinforce this culture, driving continuous improvement in sustainability practices.

Environmental management as a sub-element of sustainable practices influences the enterprise's overall environmental impact. Energy efficiency measures, water conservation strategies, and pollution control initiatives help reduce the environmental footprint. Biodiversity conservation efforts protect ecosystems, supporting long-term ecological health. These practices not only mitigate negative environmental impacts but also align with quality standards by ensuring that products and processes are sustainable and responsible.

Resource utilization practices, such as sustainable sourcing and circular economy initiatives, directly impact the enterprise's supply chain and production processes. Responsible sourcing ensures that raw materials are obtained in an environmentally and socially responsible manner. Circular economy practices, including recycling and reusing materials, reduce waste and resource consumption. These efforts contribute to both sustainability and quality by ensuring that products are produced efficiently and with minimal environmental impact.

The product lifecycle perspective emphasizes the importance of sustainable design and end-of-life management. Eco-design principles guide the development of products that are sustainable throughout their lifecycle, from production to disposal. Lifecycle analysis and assessment help identify areas for improvement, ensuring that products meet high sustainability and quality standards. Effective end-of-life management, including recycling and disposal, reduces environmental impact and supports the enterprise's sustainability goals.

Corporate social responsibility (CSR) initiatives improve the enterprise's social and environmental impact. Community engagement and development programs build strong relationships with local communities, supporting goodwill and support. Fair labor practices ensure that workers are treated ethically and fairly, aligning with both sustainability and quality standards. Ethical supply chain management ensures that suppliers adhere to the same high standards, further reinforcing the enterprise's commitment to sustainability.

Innovation and technology drive advancements in sustainable practices and quality standards. Investing in research and development leads to the creation of green technologies and sustainable products. Renewable energy solutions reduce the enterprise's reliance on fossil fuels, lowering carbon emissions. These innovations not only support sustainability goals but also improve product quality and operational efficiency.

Regulatory compliance is essential for maintaining quality standards and achieving sustainability goals. Adherence to industry regulations ensures that products and processes meet established safety and performance criteria. Environmental regulations compliance demonstrates the enterprise's commitment to responsible practices, building trust with stakeholders. Certification and accreditation, such as ISO standards, provide a recognized benchmark for quality and sustainability, reinforcing the enterprise's reputation and competitive advantage.

Performance measurement through key performance indicators (KPIs), auditing, and inspection processes ensures continuous improvement in both sustainability and quality. Regular monitoring and reporting provide insights into the effectiveness of sustainability initiatives, guiding adjustments and improvements. Feedback loops and corrective actions address any issues promptly, maintaining high standards of quality and sustainability.

SUGGESTIONS AND GUIDELINES

Based on the developed model presented in Figure 1 and the literature analysis, the following guidelines and suggestions for integrating AI and Big Data into quality management systems are provided:

- Enforce stricter environmental and quality standards across industries to ensure compliance and fair competition. Establish mandatory reporting requirements for corporate sustainability efforts to improve transparency.
- Fund educational programs focused on sustainability and environmental management to build a knowledgeable workforce. Promote vocational training in green technologies and sustainable practices to meet the demand for skilled labor.
- Invest in sustainable infrastructure such as renewable energy sources and efficient public transportation systems. Improve waste management and recycling facilities to support circular economy practices and reduce environmental impact.
- Set clear, measurable sustainability goals aligned with business objectives to drive long-term success. Incorporate sustainability metrics into key performance indicators (KPIs) and performance reviews to ensure accountability.
- Source materials responsibly, prioritizing suppliers with strong environmental and social standards to improve product quality and sustainability. Implement circular economy principles, such as recycling and reusing materials, to reduce waste and improve resource efficiency.
- Develop and adopt new technologies that reduce environmental impact and improve operational efficiency. Allocate resources to research and development of sustainable products and processes to stay competitive in the market.
- Provide ongoing training and development programs for employees on sustainability practices to build a knowledgeable workforce. Create incentive structures that reward environmentally responsible behavior to support a culture of sustainability.
- Regularly publish sustainability reports detailing progress towards goals and areas for improvement to maintain stakeholder trust. Engage stakeholders through transparent communication about sustainability initiatives to build a strong brand reputation.

CONCLUSION

Addressing the interplay between sustainability and quality standards is essential for enhancing business competitiveness in today's market. Governments, enterprises, and individuals all have significant roles to play in supporting an environment where sustainable practices are prioritized and integrated into the core strategies of businesses.

The collaborative effort of governments, enterprises, and individuals is paramount to achieving a sustainable future. As businesses align their practices with sustainability goals and quality standards, they not only mitigate environmental impacts but also improve their competitiveness in the market. This integrated approach ensures that economic growth is achieved without compromising the well-being of future generations, paving the way for a more resilient and responsible business landscape.

Future research should focus on empirical studies that analyze the application of AI and Big Data in enterprises that have successfully integrated these technologies into their quality management practices. Such studies would provide significant insights into the practical challenges and benefits, contributing to the refinement of the proposed theoretical model. Additionally, exploring the impact of AI and Big Data on different industries and their specific quality standards could offer a broader understanding of how these technologies can be leveraged to achieve both sustainability and business excellence.

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ANALYSIS OF RISK ASSESSMENT CONDUCTED IN THE GARMENT INDUSTRY IN NORTH MACEDONIA

Research paper

Monika Lutovska[1*], Vladimir Mijakovski[2]
[1]Faculty of Technical Sciences, "Mother Teresa" University, Skopje, MK
[2]Faculty of Technical Sciences, University „St. Kliment Ohridski", Bitola, MK

Abstract: Exposure to dangers and hazards often causes occupational injuries and diseases, that affect workers' physical and mental abilities and social well-being in varying degrees of severity. On average, almost every third employee in the garment industry in North Macedonia has a change in health status and a certain medical diagnosis. The main objective of this paper is to assess the risks generated by dangers and hazards in this sector, which will reveal the reasons for the alarmingly poor working conditions and numerous injuries, illnesses and disabilities.
To conduct the risk assessment, a qualitative-quantitative PILZ method was used, and the final value of the estimated risk is obtained as a product of four parameters calculated according to individual scales at multiple levels.
The analyzes and results of the evaluation provide data and information that will serve to develop effective strategies to improve the Occupational Safety and Health (OSH) situation and reduce injuries in the global supply chains of garment industry.
Key words: garment industry, dangers/hazards, risk assessment, OSH

INTRODUCTION

The rapid development of the industry is one of the main drivers of the overall economic development and technical progress, [1]. Textile industry in North Macedonia is one of the leading processing industries with a significant impact on the Gross domestic product (GDP) formation and high labor force absorption, [2]. Its share in GDP is 2.3%, with officially registered 1076 legal entities actively involved in various levels of production and around 35000 employees, [3]. On the other hand the textile industry is known to present significant hazards and risks, [4]. Due to the low attention given to OSH in this sector, occupational injuries are an important cause of morbidity and mortality especially in low-income countries [5].
If in the latest report of Eurostat for 2021 [6], there were 1516 non-fatal accidents per 100000 persons employed across the EU, then in our country the Macedonian Association for Safety at Work (MZZPR) in its annual report for 2023 [7], announces that according to the data received from the State Labor Inspectorate, the incidence rate of injuries in our country is 323 for 2023. Additionally, in North Macedonia there is no official system for collecting and processing cross data to determine the OSH situation and the impact of working conditions on the health of exposed workers. This clearly indicates that we have a serious problem that is systematically ignored, cyclically supported by every government.
Regarding the OSH situation in the garment industry over the past three decades, it is at lowest possible level, or within the minimum required by the law in North Macedonia. However, the main problem is that almost every third employee in this industry has changes in the health and a certain medical diagnosis. Sewing machine operators in formal enterprises are often guaranteed minimum wages for their regular hours worked and can earn a production-based bonus for exceeding a production target. [8]. If we consider these lowest paid wages and the large number of overtime hours, the reason why many employers have made this industry unattractive for young people is obvious, [3].
In parallel, Accession Strategy towards EU imposes the need to accelerate the process of implementing the action OSH plans and improve the capacity of the State Labor Inspectorate

[1]Corresponding author, monika.lutovska@unt.edu.mk, https://orcid.org/0000-0002-4101-405X
[2]vladimir.mijakovski@tfb.uklo.edu.mk, https://orcid.org/000-0002-1967-7340

and other state institutions in the field of health and safety, in order to ensure higher OSH management level, [9].

MATERIAL AND METHODS

Identifying occupational dangers/hazards

The production process is characterized by a wide range of machines and equipment that are connected to automatic or manual transport systems. These systems connect not only machines, but also places of residence and storage, so, in order to minimize or eliminate accidents at work, special attention should be paid to active and passive safety systems. The identification of hazards and dangers at the workplace and in the working environment starts from the existing state of safety and health at work, through insight and analysis of:

- valid expert reports for performed inspections and tests of work equipment,
- examinations of the working environment conditions,
- reports on previous and periodic medical examinations of employees,
- data on injuries, occupational diseases and illnesses related to work,
- information on personal protective equipment (PPE),
- analysis of measures taken to prevent injuries, occupational diseases and illnesses,
- inspection reports on inspections performed,
- instructions for safe work

The identification of dangers and hazards, as a basic step in the implementation of risk assessment, includes the recognition of the following parameters (Table 1):

***Table 1**. Identifying dangers/hazards*

Condition (Characteristics)		Dangers/hazard
1	Mechanical dangers	Movable parts of machines and equipment
		Sharp parts, blades or needles
		Internal transport in the production hall
2	Hazards due to the characteristics of workplace	A messy workspace cluttered with materials
		Waste from cut materials or pieces
3	Electrical dangers	Unsafe wiring, obsolete electrical systems
4	Chemical hazards	Dyeing, printing and finishing of clothes, as well as removing stains from finished products
5	Physical hazards	Disturbing noise, vibration, inadequate lighting
6	Microclimatic conditions	Inadequate air humidity or temperature, air flow
7	Biological hazards	Infectious agents, microorganisms, allergens and bacteria, the presence of many people in one place
9	Psycho-physiological exertions	Prolonged standing, sitting, kneeling, lifting, pushing, pulling
10	Organization of work	Shift work, overtime work
		Lack of education about the safety of one's workplace and the importance of taking care of oneself and one's colleagues
		Communication with superiors

The system of safety and health at work in North Macedonia is based on the Law on Safety and Health at Work [10], which promotes the principle of prevention of occupational risks and regulates the employer's obligation to adopt a risk assessment Act in written form. The goal is to reduce the number of people injured during work, occupational diseases and disorders. The risk assessment considers the work organization, work process, equipment, materials used in technological and work processes, PPE, and other factors that can cause a risk of injury, damage to the health or illness.

Conducting a risk assessment is an obligatory duty of each employer. It is primarily an empirical process of making engineering decisions based on knowledge and experience in order to improve OSH using selected and thus well-known and recognized methods. None of the risk assessment methods prescribes a choice of protective measures to reduce, eliminate, or prevent the risk. The correct choice of risk assessment method will enable the application of appropriate measures that will achieve a safer workplace and work environment and less probability of occupational diseases and injuries to employees, [11].

PILZ method

Among the methods with tabular approach to risk assessment that use existing methods of formed tables with qualitative descriptions combined with quantitative, numerical values of all risk factors required for risk assessment, is the PILZ method, [12] where four factors are used. By multiplying the values of these factors, the final risk value is obtained:

$$RISK = VP \times ZI \times P \times BL$$

where: VP is probability of injury / disease; ZI - frequency, time of exposure; P - consequence/severity of possible injury or disease; BL - Number of persons exposed to the danger/hazard.

To define each of the factors in the formula, appropriate multi-level scales with different coefficients in each level are used. According to the obtained value, the calculated risk is ranked in 5 levels, (Table 2).

***Table 2**. Risk ranking*

RISK ranking			
Level	Numeric value	Qualitative description of risk level	
1	0 - 5	Acceptable risk	Very low risk – no risk reduction activities required
2	6 - 50		Low risk – no risk reduction activities required, but care should be taken to monitor the risk
3	51 - 250		Moderate risk –measures for risk reduction need to be defined
4	251 - 500	Unacceptable risk	High risk – urgent measures need to be taken
5	over 500		Very high risk – stop working immediately, until measures are taken to reduce the estimated risk

RESULTS AND DISCUSSION

This research analyzes the risks caused by dangers and hazards in garment industry, and emphasizes the importance of their proper detection and evaluation, in order to prevent accidents before they occur. The data from the association "Glasen tekstilec" research, [3] show that deviations in the health condition were found in 28.2% of workers in the textile sector. This means that on average, almost every third employee in this industry has a change in health status and a certain medical diagnosis.

A risk assessment for a textile worker was conducted by OSH experts from Mother Teresa University in Skopje. The methodology used for risk assessment is a tabular technique that combines qualitative and quantitative methodology. The estimated risks, the factors involved in the calculation of each risk and the risk ranking are given in the table below (Table 3).

***Table 3**. Risk assessment for a textile worker*

Description of the technological process and work tasks: The main feature of this industry, which makes it diverse in terms of production and OSH, is its production base consisting of a wide variety of fibers/yarns of natural origin such as yarn, jute, silk and wool to man-made fibers such as viscose, polyester, nylon and acrylic. The textile industry consists of a large number of units engaged in spinning, weaving, dyeing, printing, finishing and transformation of these products into finished fabric or clothing.						
Calculated risk						
	RISK	Danger / hazard	Probability of injury / disease	Frequency, time of exposure	Consequence/severity of possible injury or disease	Number of persons exposed
			(VP)	**(ZI)**	**(P)**	**(BL)**

1	M	Insufficient safety due to moving machine parts	8.0	5.0	6.0	1.0
2	M	Needlestick injuries	8.0	5.0	2.0	1.0
3	M	Cuts when handling manual or electric scissors	8.0	5.0	6.0	1.0
4	M	limb injuries – crushing from machines/ tools	5.0	5.0	6.0	1.0
5	M	Internal transport/ movable transport device	5.0	5.0	6.0	1.0
6	M	Unsafe wiring, obsolete electrical systems	5.0	5.0	6.0	1.0
7	M	Slipping, tripping	5.0	5.0	4.0	1.0
8	L	Untidy working environment	8.0	5.0	0.5	1.0
9	M	Disturbing noise	5.0	5.0	6.0	1.0
10	M	Improper lighting level	5.0	5.0	6.0	1.0
11	L	Vibration	2.0	5.0	4.0	1.0
12	L	Inadequate microclimatic conditions (insufficient ventilation, high ambient temperature)	5.0	5.0	0.5	1.0
13	M	Exposure to cotton dust	5.0	5.0	4.0	1.0
14	M	Dangerous chemicals arising from liquids, solids, dust, fumes, vapors and gases	5.0	5.0	10.0	1.0
15	L	Exposure to bacteria, viruses	5.0	5.0	0.5	1.0
16	L	Poor nutrition	2.0	2.5	4.0	1.0
17	M	Stress	8.0	5.0	6.0	1.0
18	M	Mobbing	8.0	5.0	6.0	1.0
19	M	Abuse/ Harassment	5.0	5.0	4.0	1.0
20	M	Monotony	8.0	5.0	6.0	1.0
21	M	Poor ergonomic design of workplace	5.0	5.0	6.0	1.0
22	L	Badly designed machinery	2.0	5.0	4.0	1.0
23	L	Lifting loads, manipulative movements	2.0	5.0	4.0	1.0
24	M	Prolonged sitting/ standing	5.0	5.0	10.0	1.0
25	M	Extended working hours	8.0	2.5	6.0	1.0
26	L	Hazardous equipment/cause of explosion, fire	1.5	5.0	6.0	1.0

* L – low risk, M – moderate risk

** In the risk assessment, the value of the BL factor refers to one person exposed to the hazard

It can be seen from the risk assessment, that although there are no high risks to cause extremely severe mechanical injuries and immediately threaten the life of the worker, still the largest number or 2/3 of the risks are in the moderate risk range.
This mostly refers to long-term exposures to various hazards (chemical, physical and biological hazards, exposure to cotton dust, ergonomic problems, stress and monotony in work) which over a long period of time can result in chronic diseases and seriously threaten the health of the worker.
Of the assessed risks, ranked in moderate level, the risks due to exposure to chemical hazards and long-term sitting/standing at the workplace have the highest value.

CONCLUSION

Production Workers in the textile industry have serious consequences for their health, which are caused primarily by the nature of the work, poor working conditions, psychological pressure due to the amount of work, but also the inferior position of the worker. These, mostly female workforce is further marginalized due to the lowest wages paid, illegal circumvention of work contracts, health and pension insurance, maternity absence, and the huge number of overtime hours. This is compounded by the low OSH awareness level, the informal education they usually have and the limited access to information, which very likely generates a low level of awareness of the demand for labor rights. Analyzes in the assessment show that the problems these workers often face are related to exposure to hazards over a very long period, lasting decades. These problems are due to exposure to chemical hazards (liquids, solids, dust, fumes, vapors and gases) accompanied by severe lung diseases, physical harm (disturbing noise, inadequate lighting) followed by vision and hearing impairment.
Psychophysiological stress due to poor ergonomic conditions (long-term sitting/standing) should also be taken into account, which after long years of work inevitably lead to serious

musculoskeletal diseases and permanent disability. This situation imposes the need to strengthen initiatives to improve working conditions, modernization and investment in companies, technical-technological processes, organization and design of workplaces. However, the implementation of OSH training is equally important, which will contribute to information and education, as well as to raising the level of awareness among these workers to demand their labor rights and equality in the society.

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INTEGRATING LEAN PRINCIPLES WITH ENVIRONMENTAL SUSTAINABILITY FOR ENHANCED ECOLOGICAL PERFORMANCE

Review paper

Jasmina Naerac[1], Nemanja Sremčev[2], Danijela Ćirić Lalić[3]
[1,2,3]University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

Abstract: Lean Management is a strategic approach that aims to eliminate inefficiencies within organizations, enhancing overall performance and responsiveness to customer demands. Lean practices can significantly mitigate the financial burdens and ecological deficits stemming from waste and inefficiencies. As industries face competitive pressures, resource scarcity, and environmental concerns, Lean Management has emerged as a vital tool for achieving greater efficiency and sustainability. This paper explores the synergies between Lean principles and environmental management. The integration of environmental considerations into Lean methodologies has gained traction, leading to improved ecological performance and enhanced corporate social responsibility. This paper further discusses the role of Lean Six Sigma in environmental protection, particularly for small and medium-sized enterprises (SMEs), where systematic waste reduction and quality control can foster both economic and ecological sustainability. The advantages of integrating Lean principles into environmental protection strategies are multifaceted, ranging from improved resource efficiency and reduced waste generation to enhanced energy efficiency and compliance with regulatory standards. This review highlights how Lean Management cultivates a culture of continuous improvement and innovation, empowering employees to identify inefficiencies and develop sustainable practices.

Key words: lean, lean six sigma, environmental protection, sustainability

INTRODUCTION

Lean Management is a strategic approach aimed at eliminating inefficiencies within organizations to enhance overall performance and improve responsiveness to customer demands [1]. This methodology is grounded in five core principles: simplifying work processes, mapping the value stream, identifying customer value, standardizing simplified workflows, and fostering continuous improvement [2]. The prevalence of waste and inefficiencies often imposes significant financial burdens on companies while also contributing to ecological deficits. In the face of competitive market pressures, resource scarcity, and material wastage, industries are increasingly compelled to pursue greater efficiency and sustainability. Lean Management has emerged as a powerful tool in addressing these challenges [3]. The relationship between Lean principles and environmental management is gaining traction in contemporary discourse. By optimizing resource utilization and minimizing waste, Lean practices can significantly bolster sustainable organizational management [4]. Lean Management is a comprehensive model that governs production, development, and product creation with the primary objective of eliminating unnecessary waste and enhancing value for goods, customers, and services. The concept of Lean was pioneered by Taiichi Ohno, who led the Toyota Production System (TPS) in the post-war era [5]. A defining characteristic of Lean Management is its stringent focus on delivering precisely what is needed, when it is needed, and in the required quantity, thereby minimizing excess and maximizing efficiency [6]. Lean experts have identified seven major types of waste prevalent in business processes, which are critical for organizations aiming to enhance operational efficiency [7]: overproduction, transportation, waiting/bottlenecks, over-processing, inventory, unnecessary movements, errors/defects.

[1] Corresponding author, jasjas@gmail.com
[2] nextesla@uns.ac.rs, https://orcid.org/0000-0003-2552-1008
[3] danijelaciric@uns.ac.rs, https://orcid.org/0000-0002-4834-6487

By systematically addressing these forms of waste, Lean Management not only enhances operational efficiency but also contributes to more sustainable practices, aligning with the goals of environmental engineering. In addition to the previously mentioned forms of waste, Lean Management also addresses inadequate product design processes that fail to meet user requirements, missed opportunities, and the underutilization of employees' intellectual potential.

To eliminate activities that do not contribute to efficient process development and do not add value to the product, Lean Management is guided by several key principles [8]: value of a product from the customer's perspective, value stream that involves identifying all activities associated with the flow of materials and information from suppliers to customers, flow of products through the value chain to the end customer, pull which advocates for production to occur only in response to actual customer demand, thereby minimizing excess inventory and aligning production schedules with market needs and perfection which has the aspiration to eliminate all forms of waste continually.

The Lean methodology emphasizes waste reduction, respect for individuals, and the pursuit of continuous improvement as its core tenets. Adopting these principles can yield significant benefits, including reduced delivery times, enhanced product quality, lower inventory levels, and increased customer satisfaction. By focusing on the elimination of non-value-added activities and the optimization of value streams, organizations can achieve greater agility and efficiency in responding to dynamic market demands. Moreover, Lean empowers employees at all levels to identify and address inefficiencies, cultivating resilience and innovation within the organization and reinforcing a culture of continuous improvement [9].

This paper will examine the foundational principles of Lean Management and its critical contribution to advancing environmental protection.

CONNECTION BETWEEN LEAN MANAGEMENT AND ENVIRONMENTAL PROTECTION

A substantial number of companies have adopted Lean measures to enhance their manufacturing processes, thereby mitigating negative environmental impacts. The Lean methodology facilitates the reduction of energy and material resources required per unit of product, decreases production-related waste, including emissions to air and water, and minimizes the generation of hazardous and solid waste. Given the positive environmental outcomes associated with Lean practices, many organizations have opted to integrate these methods into their operations [10, 11].

By incorporating environmental considerations into their Lean manufacturing processes, companies can achieve long-term benefits, such as enhanced environmental sustainability and recognition as responsible corporate citizens. As a result, businesses are increasingly embracing Lean practices to diminish their ecological footprint and bolster their public image [12].

Green lean concept and the Impact of lean production on ecological performance

In contemporary discourse, environmental efficiency and the carbon footprint of manufacturing companies are paramount concerns, closely aligned with the concept of green manufacturing. This concept seeks to continuously enhance ecological conditions within manufacturing operations to mitigate negative impacts on water, air, and soil. Pollution remains a critical issue, and the Lean methodology can play a significant role in addressing it through a series of activities focused on measuring, identifying, assessing, and managing ecological waste generated across various stages of manufacturing, from planning and design to production [13].

Green manufacturing encompasses perspectives on both processes and products. From a product perspective, the goal is to develop environmentally friendly products, minimize resource utilization, and employ non-harmful materials. In contrast, the process perspective emphasizes minimizing the release of hazardous substances, reducing waste generation, and conserving energy and raw materials [14].

Growing environmental concerns regarding degradation, climate change, and the depletion of natural resources have prompted manufacturing facilities to adopt strategies that extend beyond organizational quality to embrace more sustainable practices. Consequently, the study of green and Lean manufacturing has become integral to environmental protection agendas. Lean manufacturing, with its foundational principle of zero waste, contributes to pollution reduction by minimizing operational waste, including discarded materials and excessive consumption of water and energy. Specifically, Lean's objectives to eliminate waste are inherently ecological; for example, reducing the unnecessary transportation of raw materials and products diminishes resource use, while simultaneously lowering operational costs and reducing excessive inventory, yielding both ecological and economic benefits.

Organizations that implement the Lean system are increasingly inclined to adopt ecological innovations. Lean practices influence pollution through two primary avenues: by lowering pollution levels via reduced marginal costs of pollution-reduction activities, or by discovering new methods to prevent pollution entirely. Numerous studies indicate that the application of Lean practices enhances business performance, although elevated search costs may hinder managers from concentrating on contemporary opportunities for environmental protection and investing accordingly [13].

The Lean approach employs various practices that facilitate the achievement of its objectives. The "Just in Time" (JIT) methodology is particularly prominent within the Lean framework, serving as a valuable tool for identifying ecological waste in production. In conjunction with JIT, the "Kaizen" method is extensively utilized in Lean management to uncover and eliminate hidden waste, optimize water usage, reduce the reliance on hazardous chemicals, conserve water, and mitigate water pollution, as well as enhance air quality. Another notable Lean practice is Total Productive Maintenance (TPM), which positively impacts material usage by optimizing the condition of production equipment, thereby supporting more efficient raw material utilization with less waste. Meanwhile, JIT reduces material consumption through quality improvements and inventory reduction. Additionally, Value Stream Mapping, an actively employed Lean practice, generates fewer air emissions and positively influences the quantities of solid waste, hazardous substances, and water consumption, while also reducing energy usage [13].

The integration of Lean principles with environmental sustainability has given rise to the Green Lean concept, which emphasizes the simultaneous operational efficiency and ecological responsibility.

One of the fundamental tenets of Lean is the elimination of waste, which inherently contributes to more efficient resource utilization. In the context of green manufacturing, this includes minimizing the consumption of energy and raw materials, which directly reduces the environmental impact associated with resource extraction and processing. Studies have shown that implementing Lean practices can lead to a reduction in energy consumption by 20-30% in manufacturing settings [14].

Just in Time (JIT) and Total Productive Maintenance (TPM), facilitate the minimization of waste, including emissions to air and water. By optimizing processes and reducing excess inventory, companies can decrease the generation of pollutants and hazardous waste. Research indicates that organizations that implement Lean practices report a significant decrease in carbon emissions, with reductions of up to 50% in some cases [15].

The Green Lean approach can be complemented by Life Cycle Assessment (LCA), a systematic method for evaluating the environmental impacts associated with all stages of a product's life, from raw material extraction through production, use, and disposal. By integrating LCA into Lean processes, companies can identify opportunities for reducing environmental impacts throughout the product life cycle, leading to more sustainable product design and manufacturing practices [16].

The synergy between Lean and environmental sustainability fosters eco-innovation, where organizations not only improve their existing processes but also develop new, more sustainable technologies and practices. This can include the adoption of renewable energy sources, the implementation of closed-loop systems, and the redesign of products for recyclability and reduced environmental impact [17].

Lean practices emphasize the importance of employee engagement and continuous improvement. By involving employees, organizations can foster a culture of environmental responsibility. This cultural shift can lead to increased awareness of environmental issues and encourage innovative thinking among employees, further enhancing the effectiveness of Green Lean initiatives [18].
As environmental regulations become increasingly stringent, adopting Green Lean practices can help organizations not only comply with legal requirements but also enhance their corporate social responsibility (CSR) profiles. Companies that demonstrate a commitment to sustainability through Lean practices can improve their public image, attract environmentally conscious consumers, and gain a competitive advantage in the marketplace [19].

Lean six sigma in environmental protection

Lean Six Sigma is a synergistic approach that integrates the principles of Lean Management and Six Sigma methodologies, specifically tailored to enhance environmental performance within small and medium-sized enterprises (SMEs). The primary objective of this approach is to systematically identify and eliminate sources of waste, inefficiency, and defects in organizational processes, thereby fostering both economic and ecological sustainability.
In the context of environmental protection, Lean Six Sigma is particularly beneficial for SMEs striving to mitigate their ecological footprint. By employing this methodology, organizations can effectively reduce waste generation, pinpoint pollution sources, and promote sustainable practices throughout their operations. Moreover, Lean Six Sigma facilitates improvements in energy efficiency, which not only enhances operational effectiveness but also ensures compliance with increasingly stringent regulatory requirements related to environmental sustainability [20].
The foundational principles of Lean Six Sigma are derived from its constituent methodologies. Lean Management emphasizes the systematic elimination of waste, defined as any activity that does not add value to the product or service. It seeks to enhance process flow by minimizing inflexibility and variability, based on the premise that understanding and removing losses is essential for improved performance [21]. Conversely, the Six Sigma framework concentrates on the statistical control of processes to minimize defects and enhance quality. This approach enables precise measurement of process performance, thus ensuring that products or services meet customer expectations with high reliability [22].
Implementing Lean Six Sigma cultivates a culture of continuous improvement within organizations, necessitating comprehensive employee training. This training equips personnel with essential skills in problem-solving, project management, and data analysis, which are crucial for addressing environmental challenges. The development of these competencies not only benefits the organization in terms of enhanced operational efficiency but also fosters professional growth among employees, leading to a more engaged and capable workforce [23].

Advantages of integrating lean principles in environmental protection

Integrating Lean principles into environmental protection strategies offers numerous advantages that contribute to sustainable operational practices. The following points outline the key benefits of this integration:
Lean methodologies focus on the systematic elimination of waste, which directly correlates with improved resource efficiency. By optimizing processes and minimizing unnecessary resource consumption, organizations can significantly reduce their ecological footprint [24].
The Lean approach encourages organizations to identify and eliminate activities that do not add value, which extends to waste generation. By adopting Lean principles, organizations can reduce the quantity of hazardous and non-hazardous waste produced during manufacturing and operational processes. This waste reduction leads to lower disposal costs and mitigates environmental contamination [25].

Lean practices promote energy efficiency by streamlining operations and minimizing energy-intensive processes. This reduction in energy consumption not only lowers operational costs but also contributes to decreased greenhouse gas emissions, thus aligning with global sustainability goals [26]. Research indicates that companies implementing Lean strategies experience significant improvements in energy efficiency, leading to both economic and environmental benefits [27].
As environmental regulations become more stringent, organizations that integrate Lean principles are better positioned to comply with these requirements. Lean practices inherently promote a culture of continuous improvement, which can help organizations proactively address environmental concerns and maintain compliance with regulatory standards [27].
The Lean approach encourages organizations to foster a culture of continuous improvement and innovation. By empowering employees to identify inefficiencies and propose solutions, organizations can develop new, environmentally friendly practices and technologies [27].
Organizations that prioritize environmental protection through Lean practices often experience enhanced relationships with stakeholders, including customers, employees, and regulatory bodies. By demonstrating a commitment to sustainability, companies can improve their public image and strengthen their brand reputation, ultimately leading to increased customer loyalty and market share [28].

CONCLUSION

The integration of Lean principles within the framework of environmental protection presents a compelling paradigm for organizations striving to enhance operational efficiency while minimizing their ecological footprint. By systematically eliminating waste and optimizing resource utilization, Lean Management not only addresses economic inefficiencies but also significantly contributes to sustainable practices. The strategic alignment of Lean with environmental objectives fosters a culture of continuous improvement, encouraging organizations to innovate and adapt to the evolving demands of regulatory frameworks and societal expectations.
The synergy between Lean methodologies and environmental sustainability empowers organizations to improve their operational processes while simultaneously enhancing their corporate social responsibility profiles. By adopting Green Lean practices, companies can mitigate their negative environmental impacts, reduce costs, and bolster their reputations as responsible corporate citizens.
As the challenges of resource scarcity and climate change intensify, the importance of integrating Lean principles with environmental management will only grow. This integration not only equips organizations with the tools to comply with stringent environmental regulations but also positions them competitively in a market increasingly driven by sustainability.
Future research should focus on developing robust metrics for assessing the environmental performance of Lean practices and exploring innovative applications of Lean principles in emerging sectors, thereby further enhancing their relevance in the quest for sustainable development.

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