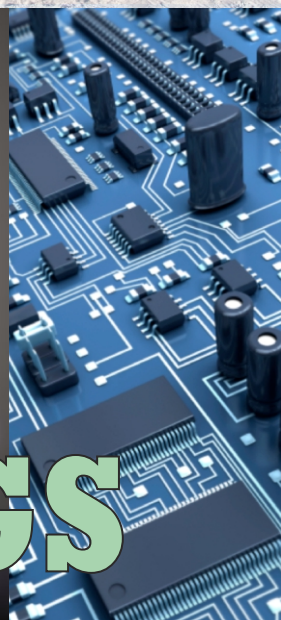




XI INTERNATIONAL SCIENTIFIC CONFERENCE HIGH TECHNOLOGIES. BUSINESS SOCIETY 2026

23-26.03.2026, BOROVETS, BULGARIA



PROCEEDINGS



ISSN 2535-0005 (PRINT)
ISSN 2535-0013 (ONLINE)

SCIENTIFIC-TECHNICAL UNION OF MECHANICAL ENGINEERING - INDUSTRY 4.0



XI INTERNATIONAL SCIENTIFIC CONFERENCE
“HIGH TECHNOLOGIES . BUSINESS . SOCIETY 2026”
23-26.03.2026, winter resort „BOROVETS”, BULGARIA

PROCEEDINGS

YEAR XI, ISSUE 1 (14), BOROVETS, BULGARIA 2026

All articles are published after peer review by two independent reviewers.

ISSN 2535-0005(PRINT
ISSN 2535-0013 (ONLINE)

PUBLISHER:

**SCIENTIFIC TECHNICAL UNION OF MECHANICAL
ENGINEERING
INDUSTRY-4.0**

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40,
office@hightechsociety.eu
www.hightechsociety.eu

INTERNATIONAL EDITORIAL BOARD

Chairman: Prof. DHC Georgi Popov

Members:

Acad. Ivan Vedyakov	RU
Acad. Jemal Katzitadze	GE
Acad. Yuriy Kuznetsov	UA
Prof. Aleksander Subic	AU
Prof. Adel Mahmud	IQ
Prof. Alimazighi Zaia	DZ
Prof. Andrzej Golabczak	PL
Prof. Gennady Bagluk	UA
Prof. Detlef Redlich	DE
Prof. Dilbar Aslanova	UZ
Prof. Dipten Misra	IN
Prof. Dmitry Kaputkin	RU
Prof. Eugene Eremin	RU
Prof. Esam Husein	KW
Prof. Franz Wotava	AT
Prof. Ivan Novy	CZ
Prof. Idilia Bachkova	BG
Prof. Khalil Khalili	IR
Prof. Lyudmila Ryabicheva	UA
Prof. Milan Vukcevic	ME

Vice Chairman: Prof. Galina Nikolcheva

Members:

Acad. Kavidolla Sarekenov	KZ
Prof. Miho Mihov	BG
Prof. Mohamed El Mansori	FR
Prof. Movlazade Vagif Zahid	AZ
Prof. Oana Dodun	RO
Prof. Peeter Burk	EE
Prof. Peter Markovic	SK
Prof. Remigijus Venckus	LT
Prof. Renato Goulart	BR
Prof. Seiji Katayama	JP
Prof. Sergej Dobatkin	RU
Prof. Sergej Nikulin	RU
Prof. Shaban Buza	KO
Prof. Svetlana Gubenko	UA
Prof. Teimuraz Kochadze	GE
Prof. Vadim Kovtun	BY
Prof. Vjeran Stahonja	HR
Prof. Volodimir Ilchenko	UA
Prof. William Singhose	USA
Prof. Yasar Pancar	TR

NATIONAL ORGANIZING COMMITTEE

Chairman:

Dr. Eng. Raycho Georgiev

Members:

Prof. Galina Nikolcheva
Assoc. Prof. Georgi Pandev
Assoc. Prof. Dimitar Karaivanov

Members:

Eng. Oleg Mihaylov
Dr. Eng. Pencho Sirakov
Eng. Radoslav Daskalov

CONTENTS

HIGH TECHNOLOGIES

A methodological framework for achieving sustainable hydrogen supply chain produced via biogas-based steam methane reforming Desislava Nikolova, Tanya Valkanova	5
Machine Learning Prediction of Mechanical Properties for Al-Mg-Si Alloys Using a Hybrid Data Synthesis Approach Mihail Kolev, Tatiana Simeonova	9
Uncertainty analysis of man B&W 6S70ME-C diesel engine based on measured operating parameters in each cylinder Mrzljak Vedran, Prpić-Oršić Jasna, Anđelić Nikola, Poljak Igor	12
Ways to reduce atmospheric air pollution from transport in the city of Kutaisi through an artificial intelligence – driven method Natia Kamkamidze, Lamara Gobejishvili, Nino Tsutskiridze, Natia Khazaradze	16

BUSINESS

Investigation of Positioning Accuracy Improvement Methods for Sigfox IoT Devices through WiFi MAC Address Analysis Masaya Watanabe, Takuya Nanjo, Tomoo Sigehuzi, Satoru Tada, Masayuki Yamauchi	18
Reconnoitering implementation barriers of industrial symbiosis through social and economic kpi's: a comparative analysis approach Blisard Zani, Almudena Muñoz Puche	25
How Data Literacy Learning Quality Shapes Student's Professional Readiness in Albania Teuta Xhindi, Dardane Nuka	30
Contemporary challenges to quality management in the context of the competitiveness of industrial enterprises Ivan Genov	35
Innovations in industrial enterprises: the role of ai, iot, and automation in enhancing competitiveness Slava Petkova	39

SOCIETY

The Persistence of Conflict: An Examination of Ten Critical Factors Why the Israeli– Palestinian Dispute Remains Unresolved Maciej Huczko	43
Improving the Living Environment in Evacuation Shelters Using Light-Emitting Diode Lanterns and Partitions Mana Oobashira, Mayumi Tanaka, Keiko Ishihara, Satoru Tada, Masayuki Yamauchi, Koji Kakugawa, Takeshi Tanaka, and Katia Vutova	48
Legal regulation problems in transport logistics: challenges and prospects Irakli Kochadze, Ana Mgeladze	54
Information Support for Interinstitutional Interaction in Cyber Incidents Ivan Hristozov, Veselina Gagamova	57
Challenges to education of engineering students in disciplines related to design and documentation Georgieva Desislava, Yaneva Svetlana	63
Connection of standardization training in the EU with the levels of the Bulgarian and European qualification frameworks for educational needs Stanchev Georgi, Ilieva Boriana, Yaneva Svetlana	67

A methodological framework for achieving sustainable hydrogen supply chain produced via biogas-based steam methane reforming

Desislava Nikolova, Tanya Valkanova
Burgas State University "Prof. dr Assen Zlatarov" – Bulgaria
desislava-nikolova@uniburgas.bg

Abstract: Growing energy and environmental challenges highlight the need for a transition to sustainable supply chains. This paper presents a methodology for assessing a hydrogen supply chain based on steam reforming of biogas (SMR), as a low-carbon alternative to conventional natural gas. The framework covers the entire life cycle, from feedstock to end use. The proposed framework supports strategic planning and provides a basis for future modeling, optimization, and assessment of environmental and socio-economic benefits.

Keywords: HYDROGEN, BIOGAS, STEAM METHANE REFORMING, SUSTAINABLE, SUPPLY CHAIN

1. Introduction

Hydrogen is often described as the "green energy carrier of the future" because it can be used in fuel cells, where it produces electricity through oxidation without emitting carbon dioxide. This electricity could be used to power cars and buses, to carry out chemical processes, to provide backup or peak power in energy systems, etc. Unlike conventional resources such as natural gas, hydrogen does not occur freely in nature and must first be produced, which is why it is considered an energy carrier rather than a primary fuel [1]. Various feedstocks such as water, natural gas, coal, oil, biomass, biogas, waste, and industrial by-product gases can be used for hydrogen production through chemical, electrochemical, or thermochemical processes. The choice of source and method determines the efficiency, cost, and environmental impact of production. At present, the most widely used technology for industrial hydrogen production is steam methane reforming (SMR) from natural gas due to its technological maturity and economic efficiency [2]. However, the SMR process generates significant CO₂ emissions (approximately 9–12 kg CO₂-eq/kg H₂), which motivates researchers to explore the development of alternative feedstocks and processes [3]. This poses serious challenges to the sustainability of hydrogen supply chains.

One of the most promising low-carbon alternatives that is attracting increasing attention is the use of renewable gas feedstocks, among which biogas stands out as a technologically compatible substitute for natural gas in reforming processes. Analyses indicate that integrating biogas into reforming processes can reduce emissions and improve energy efficiency, particularly when the feedstock is derived from waste streams [3]. In addition, biogas quality and the degree of purification are critical factors for reforming efficiency and catalyst stability [4].

Another key aspect is the availability of biogas as a resource. Its potential is highly dependent on regional factors such as biomass waste availability, collection infrastructure, regulatory framework, and economic incentives. Therefore, the sustainability of biogas-based hydrogen systems cannot be assessed solely at the technological level but requires an integrated system analysis that includes the resource base, logistics, and market conditions.

The hydrogen supply chain is a complex system of interconnected stages, including feedstock supply, biogas production, biogas upgrading, hydrogen production and purification, transport, storage, and end use [5]. Each of these stages has specific technological, economic, and environmental characteristics that influence the overall sustainability of the system.

Modern scientific research emphasizes that the optimization of hydrogen supply chains (HSC) requires a systematic approach that considers all stages simultaneously [6]. Analyses indicate that solutions optimal for an individual stage (e.g., production) are not always optimal for the system as a whole. For example, centralized production may be more technologically efficient but can result in high transport costs and emissions. Conversely, decentralized systems reduce logistical costs but often require greater production capacity.

The main parameters influencing the configuration of hydrogen supply chains include the geographic distribution of resources, spatial distribution of consumers, transport distances, infrastructure availability, and economies of scale. Modeling such systems is often performed using optimization methods, including linear programming, mixed-integer models, and scenario analyses. These approaches enable simultaneous minimization of costs and emissions under given constraints, such as facility capacity or infrastructure limitations. A particularly important aspect is the choice of hydrogen storage and transport technology. Different options—compressed gas, liquefied hydrogen, ammonia, or liquid organic carriers—exhibit different energy losses, capital costs, and risks. Therefore, the optimal configuration of the supply chain depends on the combination of technology, distance, and production scale.

An additional factor is uncertainty in future hydrogen demand [7]. Many models show that investment decisions are highly sensitive to demand forecasts, which necessitates the integration of scenario analyses and probabilistic methods. This is especially relevant for emerging markets where stable historical data are lacking.

In this context, multi-criteria assessment methods are considered a promising tool for strategic planning, as they allow simultaneous consideration of economic, environmental, and social indicators. They support decision-making under conditions of uncertainty and complexity characteristic of the hydrogen economy.

Existing literature identifies three main limitations: the lack of integrated methodologies combining life cycle assessment (LCA) and supply chain analysis, the limited number of studies on biogas-based hydrogen, and the absence of multicriteria frameworks for strategic planning. Therefore, the development of a systematic methodological framework for assessing the sustainability of biogas-based hydrogen supply chains represents a timely and scientifically justified research need.

This study focuses on developing a methodology for evaluating the sustainability of a supply chain based on hydrogen production via biogas-based steam methane reforming. The object of the study is a hydrogen supply chain encompassing feedstock supply, biogas production, biogas upgrading, hydrogen production and purification, transport, storage, and end use. The approach adopted in this work is based on a systems-level consideration of the chain and life cycle analysis, integrated within a multicriteria framework for sustainability assessment. The aim of the developed methodological approach is to support strategic planning and provide a foundation for future quantitative modeling and optimization.

2. Hydrogen production via biogas-based steam methane reforming

Before considering the technological process of producing hydrogen based on biogas (biohydrogen), it is important to analyze the raw material itself (biogas) - composition, potential and challenges.

2.1 Biogas as a feedstock for hydrogen

Biogas is a biogenic gas produced through the anaerobic decomposition of organic matter by microbial cultures [8]. It is typically obtained from municipal solid waste landfills, wastewater treatment plants, agricultural facilities fermenting animal residues, and industrial and food-processing waste.

Biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), along with trace impurities such as hydrogen sulfide (H_2S), water vapor, nitrogen, and other volatile components. Table 1 presents the compositional profile of biogas as a feedstock for hydrogen production via SMR [9]. The high methane content in biogas makes it a suitable feedstock for hydrogen production.

Table 1: Component composition of biogas, [9].

Components of biogas	Molar Fraction	Mass Fraction
CH_4	59.75%	35.05%
CO_2	40.00%	64.60%
N_2	0.20%	0.20%
O_2	0.02%	0.05%
H_2S	725 ppmv	900ppm

The composition of biogas can vary depending on the source and production conditions, but it usually contains about 50-70% methane, 30-50% carbon dioxide and up to a few percent of impurities. Impurities such as hydrogen sulfide and siloxanes can be corrosive and reduce the efficiency of subsequent technological processes, requiring preliminary upgrading [4].

The use of biogas as a feedstock for hydrogen production offers several key advantages [10]:

- *Low-carbon profile*

Biogas can significantly reduce life cycle greenhouse gas emissions compared to natural gas, particularly when derived from waste streams that would otherwise release methane into the atmosphere.

- *Utilization of waste resources*

The use of biogas in hydrogen production turns an environmental problem associated with waste from landfills, farms and sewage treatment plants into a valuable resource. The conversion of organic waste into energy and hydrogen contributes to the development of a circular economy, while reducing the need for landfilling and open fermentation.

- *Use of existing infrastructure*

Hydrogen production from biogas is achieved using established and widely applied steam methane reforming technology. Since biogas (after upgrading to biomethane) is nearly identical to natural gas, existing facilities can be used without major new investments in technology.

- *Continuous production*

Unlike “green hydrogen”, which is produced by electrolysis and is dependent on the availability of sun or wind, biogas-based hydrogen can be produced continuously. This makes hydrogen supplies predictable and stable for industry and transport.

- *Decentralization*

Biogas plants can be located close to waste sources, in agricultural areas or near urban centers. This allows hydrogen to be produced close to the point of consumption, reducing both transport costs and emissions.

- *Flexibility*

Biogas can be used either independently or blended with natural gas, allowing technological processes to be adapted according to feedstock availability.

According to the International Energy Agency (IEA) [10] and the International Renewable Energy Agency (IRENA) [11], biohydrogen provides reliable production with the potential for a negative carbon footprint, making it more environmentally friendly than gray hydrogen and more accessible than green hydrogen. Furthermore, biogas-based technology supports the circular economy by converting waste into a resource for clean energy. Table 2 presents a comparative profile of hydrogen production pathways.

Table 2: Hydrogen production pathways: a comparative profile

Characteristic	Grey Hydrogen (Natural Gas)	Bio-Hydrogen (Biogas/Bio methane)	Green Hydrogen (Electrolysis)
CO2 Emissions	High (Fossil-based)	Neutral to Negative	Zero (Renewable-only)
Availability	Constant (24/7)	Constant (Base load)	Intermittent (Weather-dependent)
Production Cost	Low	Medium	High
Raw Material	Fossil Methane	Organic Waste / Biomass	Water + Renewable Electricity
Energy Cycle	Linear (One-way)	Circular (Closed-loop)	Circular (Closed-loop)

Despite the potential benefits of using biogas as a feedstock for hydrogen production, several technological and economic challenges exist, including the need for biogas upgrading, compositional variability, infrastructure requirements, and others [3]. These limitations could be addressed through the development of a methodological framework for achieving a sustainable hydrogen supply chain.

2.2 Hydrogen production from biogas

The conversion of biogas into hydrogen is a multi-step thermochemical process that integrates biogas production, gas upgrading, and subsequent catalytic conversion [3]. Biogas is typically produced through the anaerobic degradation of organic waste under mesophilic conditions.

The first technological step is the preliminary upgrading of biogas, which involves the removal of sulfur compounds, moisture, and silicon-containing components, as these can deactivate catalysts and reduce process efficiency. If necessary, CO_2 is partially removed to produce biomethane with a higher CH_4 content.

The main conversion step is steam methane reforming in which a mixture of methane and steam reacts catalytically at high temperatures (typically 700–900 °C) in the presence of a nickel catalyst, forming syngas—a mixture of H_2 , CO , CO_2 , CH_4 , and water vapor. The reaction is highly endothermic and requires an external heat source. The composition of the resulting syngas depends on temperature, pressure, and the $\text{CH}_4/\text{CO}_2/\text{H}_2\text{O}$ ratio in the feed.

After reforming, the gas mixture undergoes a water–gas shift (WGS) reaction, in which carbon monoxide reacts with steam to produce hydrogen and carbon dioxide. In industrial practice, this stage is carried out in two consecutive reactors—a high-temperature reactor (≈300–400 °C) and a low-temperature reactor (≈200–300 °C)—to maximize CO conversion and increase H_2 yield.

The final technological step is hydrogen purification. Methods such as chemical absorption of CO_2 , methanation, membrane separation, or Pressure Swing Adsorption (PSA) are employed.

Modern systems often combine PSA and membranes, as this allows the production of high-purity hydrogen (over 99%) with relatively moderate energy consumption.

In addition to conventional SMR, biogas also allows the application of dry reforming, in which methane reacts directly with the CO₂ present in the feedstock. This approach is environmentally attractive, as it utilizes carbon dioxide as a reactant and potentially reduces overall emissions.

3. Hydrogen supply chain

The hydrogen supply chain for biogas-based hydrogen produced via steam methane reforming represents an integrated system of technological, logistical, and infrastructural stages. It covers the entire pathway—from feedstock to end user. The main stages are:

- *Feedstock supply*

This is the stage of waste biomass collection, transport to the anaerobic plant and preliminary preparation (grinding, homogenization, humidity control).

- *Biogas production and upgrading*

This stage includes the anaerobic digestion of biomass in the production of raw biogas and the subsequent biogas upgrading process.

- *Hydrogen production*

This is the stage of converting biogas into biohydrogen through a steam reforming process, in which the main process (SMR), Water-Gas Shift reaction and gas purification are carried out to obtain high-purity hydrogen.

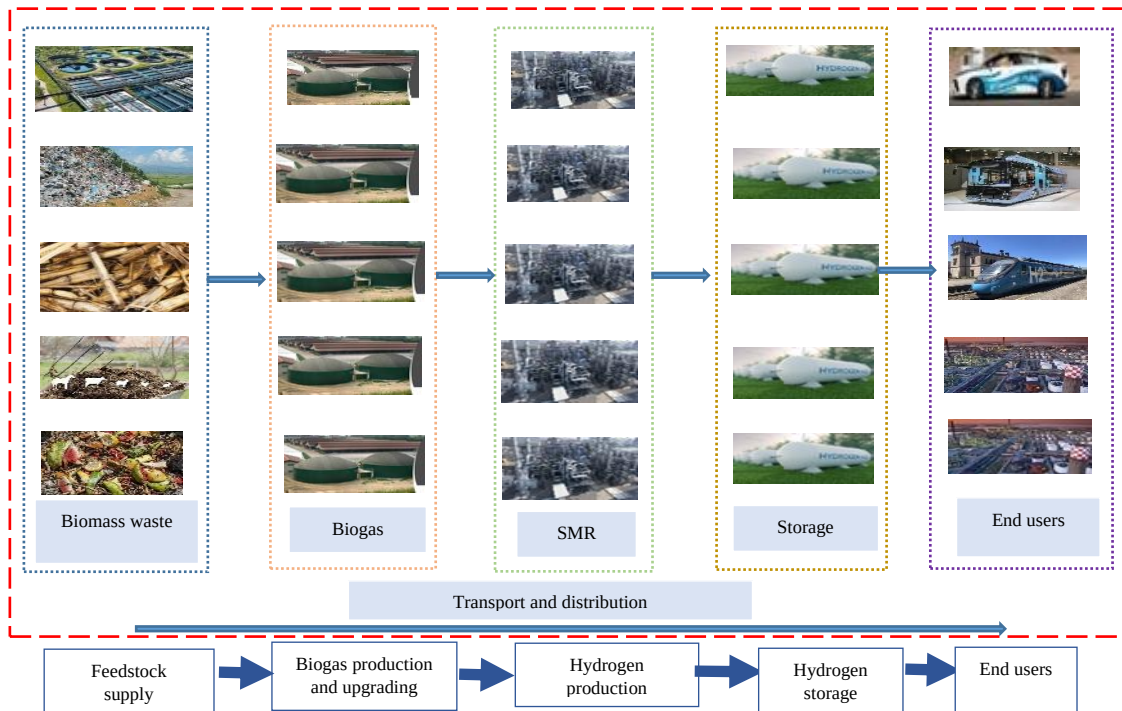


Fig. 1. Supply chain of hydrogen produced via biogas-based SMR

- *Hydrogen storage*

Hydrogen can be stored in liquid or gaseous form in buffer tanks at the production facility or at the end points of consumption.

- *Transport and distribution*

Transport and distribution of hydrogen can be carried out using specialized tube trailers or pipelines.

- *End use*

Biohydrogen can be utilized at hydrogen refueling stations for cars and buses, as well as in industry, energy systems, and other applications.

Fig. 1 presents the proposed superstructure of the hydrogen supply chain produced via biogas-based steam methane reforming, which considers the entire life cycle of the process—from feedstock to end user.

4. A methodological framework

The research methodological framework of the study is presented in Fig. 2 and is adapted from the framework proposed in [12]. The proposed in current work framework is structured into three main blocks: input data, optimization model, and output results, which together form a systematic architecture to support decision-making in the design and assessment of a sustainable hydrogen supply chain based on biogas resources. This framework allows for the integration of technological, economic, and environmental parameters, enabling a comprehensive evaluation of alternative configurations and their impact on overall system sustainability. By providing a structured approach, it facilitates strategic planning and supports the identification of trade-offs between cost, efficiency, and environmental performance.

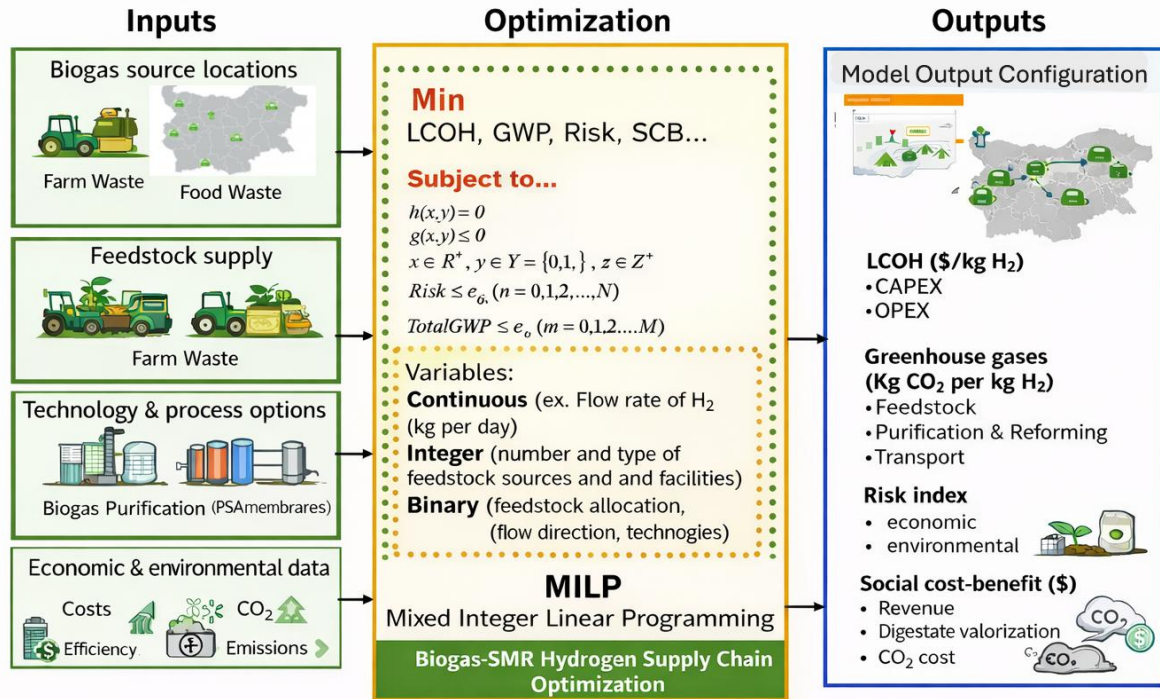


Fig. 2. Biogas-SMR hydrogen production methodological framework

The input block corresponds to all the databases, hypotheses, and scenarios. This stage collects the necessary information for system modeling, including the location of biomass waste sources, data on the quantity and type of available biomass, technological process parameters, as well as economic and environmental data. The purpose of this block is to initialize the model with consistent and realistic information, enabling both deterministic calculations and scenario-based analysis.

The optimization block integrates the mathematical model and the multi-objective optimization approach, constituting the core of the framework. The problem is formulated in terms of Mixed Integer Linear Programming (MILP). The proposed methodological framework aims to minimize key indicators such as economic efficiency, environmental impact, social benefits, and risks, while satisfying a set of constraints (e.g., technological, transport, material, environmental, logical, and others). This formulation allows for the analysis of trade-offs between conflicting objectives and helps identify optimal system configurations under different scenarios.

The outputs block corresponds to all results according economic, ecologic and risk and social benefits, so as to ensure a sustainable hydrogen supply chain. The set of results obtained allows a quantitative assessment of the sustainability of the system and supports decision-making processes.

5. Conclusion

This study presents an integrated framework for the analysis and design of the production and supply chain of hydrogen from biogas via steam methane reforming. The proposed approach combines resource assessment, process modeling, and systems analysis within a unified methodological structure, considering the entire system as an interconnected chain—from feedstock to end user. Sustainability is addressed comprehensively by simultaneously accounting for technological, economic, environmental, and social indicators. The developed framework can serve as a decision-support tool for planning, optimization, and scenario evaluation for the implementation of biogas-based hydrogen systems under varying regional and technological conditions.

Acknowledgments

The study has been carried out by the financial support of National Science Fund, Ministry of Education and Science of the Republic of Bulgaria, Contract № KII-06-H89/6/09.12.2024

5. References

1. K. Willquist, Science in School, **2**, 12–16 (2012).
2. Dincer, I.; Acar, C, Int. J. Hydrogen Energy, **40**, 1661- 1676, (2026)
3. A. Iulianelli, A. Basile, et al., Int. J. Hydrogen Energy, **41**, 6064–6075 (2016). <https://doi.org/10.1016/j.ijhydene.2016.03.006>
4. S. Nogales-Delgado, C.M. Alvez-Medina, V. Montes, J.F. González, Catalysts, **13**, 1482 (2023). <https://doi.org/10.3390/catal13121482>
5. F. Li, D. Liu, K. Sun, S. Yang, F. Peng, K. Zhang, G. Guo, Y. Si, Sustainability, **16**, 1890 (2024). <https://doi.org/10.3390/su16051890>
6. J. Riera, R. Lima, O. Knio, Int. J. Hydrogen Energy, **48**, 13731–13755 (2023). <https://doi.org/10.1016/j.ijhydene.2022.12.242>
7. Hou, J., Xu, C., Liu, J., Wen, Z., Sustainability, **17**, 6181 (2025). <https://doi.org/10.3390/su17136181>
8. M. R. Hamed, A. Tsolakis, C. S. Lau, Int. J. Hydrogen Energy, **39**, 12532-12540, (2014), <https://doi.org/10.1016/j.ijhydene.2014.06.017>
9. D. Ph. Minh, T. J. Siang, N. Vo, et.al., Hydrogen supply chains, (2018), <https://doi.org/10.1016/B978-0-12-811197-0.00004-X>
10. <https://www.iea.org/>
11. <https://www.irena.org/>
12. S. Almaraz, Racz V. et al., Applied Energy, **325**, 119882 (2022)

Machine Learning Prediction of Mechanical Properties for Al-Mg-Si Alloys Using a Hybrid Data Synthesis Approach

Mihail Kolev¹, Tatiana Simeonova^{12*}

¹ Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre “Acad. A. Balevski”, Bulgarian Academy of Sciences, Sofia, 1574, Bulgaria

² Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, 1113, Bulgaria

* Corresponding author: tsimeonova@imbm.bas.bg

Abstract: This study develops a machine learning framework for predicting the mechanical properties of 6xxx series Al-Mg-Si alloys (6061, 6063, 6082) across seven temper conditions. A hybrid dataset of 860 real measurement-based and 4,200 Monte Carlo augmented samples was generated from a literature-mined dataset. Random Forest (RF), Gradient Boosting (GBR), and Multilayer Perceptron (MLP) models were evaluated via 5-fold cross-validation (CV). RF achieved the best or comparable accuracy: coefficient of determination $R^2 = 0.80$ (ultimate tensile strength), 0.92 (yield strength), and 0.83 (elongation). Feature importance analysis showed that alloy type and temper encodings dominated predictions (>90% combined), while individual compositional features contributed <3% a result partly attributable to the augmentation strategy, which decoupled measured compositions from their corresponding property values. Learning curve analysis confirmed model convergence above 2,000 samples.

Keywords: Al-Mg-Si ALLOYS; MACHINE LEARNING; HYBRID DATA AUGMENTATION; MECHANICAL PROPERTIES; RANDOM FOREST; MLP NEURAL NETWORK

1. Introduction

The 6xxx series Al-Mg-Si alloys are among the most versatile aluminum alloys in automotive, construction, and general engineering applications, owing to their favorable combination of medium strength, excellent formability, good corrosion resistance, and weldability [1–3]. Alloys 6061, 6063, and 6082 represent a broad strength spectrum: 6063 is a lower-strength extrusion alloy [4], 6061 is a general-purpose structural alloy [5], and 6082 offers higher strength [6]. Their mechanical properties are governed by Mg_2Si precipitation, controlled by the temper condition [7]. Machine learning (ML) methods have shown promise for materials property prediction [8–10], but 6xxx alloys present particular challenges because alloy-to-alloy property variations are large and available data are sparse for certain conditions.

In this work, we apply three ML regression models — Random Forest, Gradient Boosting, and MLP Neural Network — to a hybrid dataset combining real measurements with Monte Carlo augmented data for predicting ultimate tensile strength (UTS), yield strength (YS), and elongation of 6061, 6063, and 6082 alloys across seven temper conditions. We evaluate model accuracy, analyze feature importance, and assess data sufficiency through learning curve analysis.

2. Materials and Methods

Composition and property data were sourced from the publicly available dataset of Pfeiffer et al. [11], which contains aluminum alloy data extracted from scientific manuscripts and US patents. Three 6xxx alloys were selected covering seven temper conditions: 6061 (T4, T6, T651), 6063 (T4, T5, T6), and 6082 (T6), consistent with their broad use in structural and extrusion applications [12,13]. The compositional features comprised 9 elements (Al, Cu, Mn, Si, Mg, Zn, Cr, Fe, Ti), with Al calculated as the balance. Figure 1 presents radar chart profiles of the normalized mechanical properties for each alloy-temper combination, highlighting the wide property envelope spanning UTS from 150 MPa (6063-T4) to 340.5 MPa (6061-T651) and YS from 90 MPa (6063-T4) to 248.0 MPa (6061-T651).

A hybrid dataset was constructed in two parts: (i) real property measurements from the corpus were each paired with 20 random composition realizations sampled from specification ranges, yielding 860 measurement-based samples; It should be noted that the 43 original measurements were unevenly distributed across conditions: 6061-T6 accounted for 33 measurements (77%), while the remaining six conditions (6082-T6, 6061-T651, 6063-T6, 6061-T4, 6063-T4, 6063-T5) each contained 1–3 measurements. In the augmentation step, each real property measurement was paired with randomly sampled compositions drawn uniformly from the alloy

specification ranges, rather than retaining the original measured composition. This approach captures the allowable compositional variability but decouples the composition–property linkage inherent in each measurement; (ii) for each of the 7 conditions, 600 additional Monte Carlo samples were generated with 3% Gaussian noise on mean property values, yielding 4,200 augmented samples (5,060 total). The feature space comprised 17 input variables: 9 elemental compositions, 3 alloy-type one-hot encodings, 4 temper one-hot encodings, and 1 ordinal temper code. Three models were trained: RF (200 trees, depth 12), GBR (200 trees, depth 6, $lr = 0.1$), and MLP (three hidden layers: 64-32-16 neurons, Rectified Linear Unit (ReLU) activation, Adam optimizer, adaptive learning rate, $\alpha = 0.001$, early stopping). Features were standardized for MLP. Performance was assessed by 5-fold CV using coefficient of determination (R^2), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE).

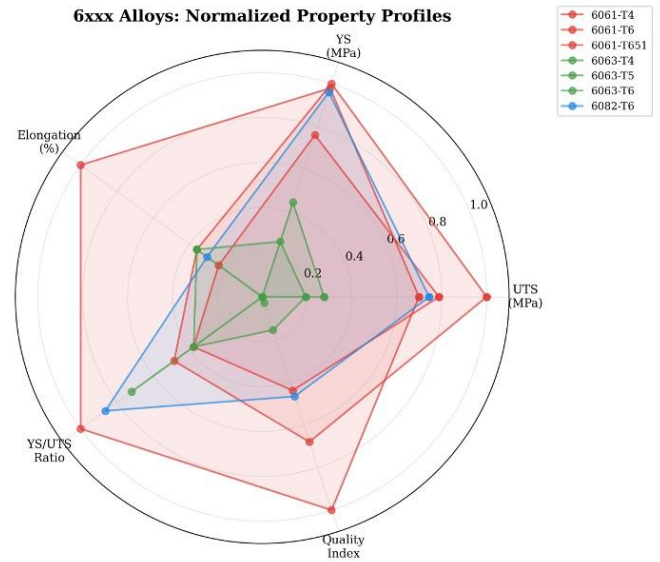


Fig. 1 Normalized radar chart profiles of mechanical properties for 6xxx alloy-temper combinations.

3. Results and Discussion

Table 1 summarizes the cross-validation metrics. RF achieved the best overall performance: $R^2 = 0.799$ (UTS), 0.922 (YS), and 0.827 (elongation), with MAE of 13.44, 8.21, and 0.51 respectively. MLP performed virtually identically for UTS ($R^2 = 0.799$) and comparably for YS ($R^2 = 0.919$). The moderate R^2 values (0.772–0.922) reflect the intrinsically wider property scatter within the 6xxx series, where UTS spans 150–340.5 MPa across alloys with

fundamentally different strengthening levels. Figure 2 shows that each model successfully captured the distinct property clusters of 6063 (low strength), 6082 (medium), and 6061 (high).

Table 1: Cross-validation performance metrics for 6xxx alloy ML models.

Model	Target	R ²	MAE	RMSE
Random Forest	UTS (MPa)	0.7987	13.44	30.86
	YS (MPa)	0.9218	8.21	16.68
	Elongation (%)	0.8272	0.51	1.28
Gradient Boosting	UTS (MPa)	0.7724	15.39	32.82
	YS (MPa)	0.9124	9.28	17.65
	Elongation (%)	0.7974	0.61	1.38
MLP Neural Net	UTS (MPa)	0.7994	14.29	30.81
	YS (MPa)	0.9187	8.90	17.01
	Elongation (%)	0.8219	0.56	1.30

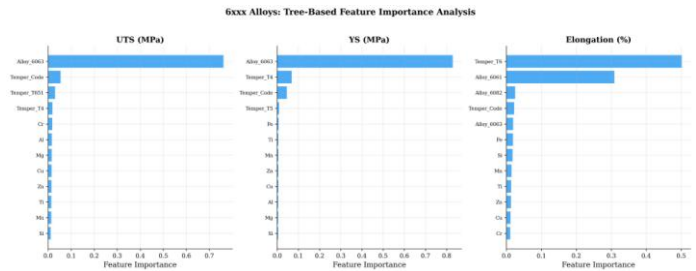


Fig. 3 Tree-based feature importance analysis for UTS, YS, and elongation prediction of 6xxx alloys.

The hierarchically clustered correlation heatmap (Fig. 4) shows strong UTS–YS correlation ($r = 0.85$), while both strength properties correlated positively with the 6061 indicator ($r = 0.67$ – 0.68) and negatively with 6063 ($r = -0.84$ to -0.90). The T651 temper showed moderate positive correlation with UTS ($r = 0.47$). Hierarchical clustering grouped compositional features separately from encoding and property variables, confirming that the two information domains are largely orthogonal in the 6xxx system.

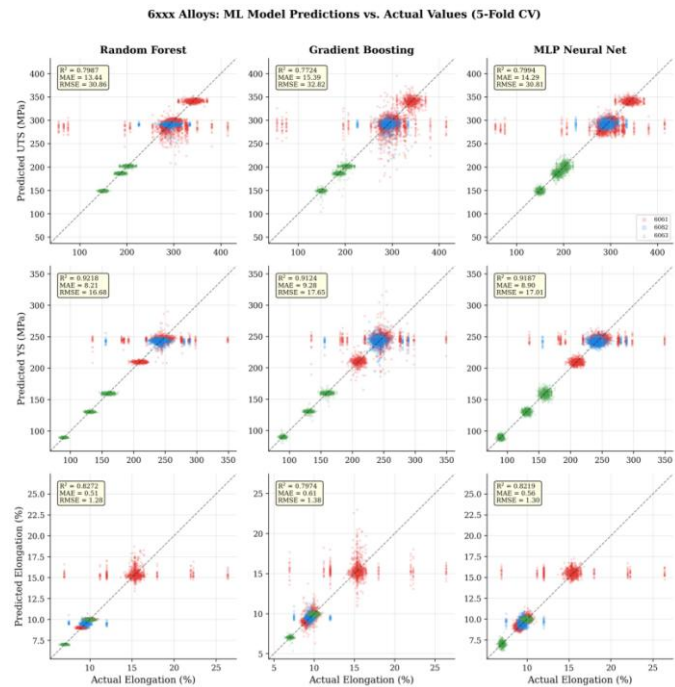


Fig. 2 Predicted vs. actual values for RF, GBR, and MLP models (5-fold CV), colored by alloy type: 6061 - red, 6082 - blue, 6063 - green.

Feature importance analysis (Fig. 3), assessed as the average of Random Forest and Gradient Boosting tree-based importances, revealed clear target-specific patterns. For UTS, the 6063 alloy indicator was the dominant feature (~76%), with the temper code contributing ~5% and the T651 indicator ~3%. For YS, the 6063 indicator was overwhelmingly dominant (~83%), reflecting the large strength gap between 6063 and the other alloys. For elongation, the T6 temper (50%) and 6061 alloy (31%) indicators dominated. Individual compositional features each contributed <3%, indicating that alloy designation and temper condition encodings dominate predictions. However, this low compositional contribution is partly a consequence of the augmentation strategy, in which property measurements were paired with randomly sampled compositions from specification ranges rather than the actual measured compositions. Because the composition–property linkage was decoupled during augmentation, the models cannot learn genuine composition–property relationships within each alloy–temper class, and the low importance of individual elements should therefore be interpreted as a methodological limitation rather than a purely physical finding.

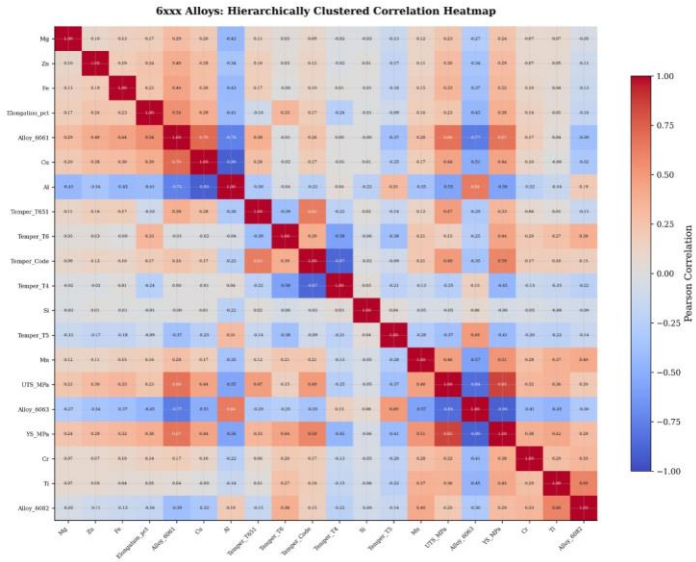


Fig. 4 Hierarchically clustered Pearson correlation heatmap of compositional, encoding, and property features

Learning curve analysis (Fig. 5), generated using simplified model configurations to reduce computational cost (RF: 100 trees, depth 10; GBR: 100 trees, depth 5; MLP: two hidden layers 64–32, 300 iterations; 3-fold CV), showed that RF achieved stable UTS prediction ($R^2 \approx 0.65$ – 0.66) above ~2,000 training samples. GBR exhibited slower convergence, while MLP matched RF at larger training sizes but showed higher variance at small sample sizes. The convergence at ~2,000 samples suggest that the hybrid augmentation strategy provides sufficient data volume for model training, although the lower R^2 values compared to Table 1 reflect the reduced model complexity used for the learning curve analysis.

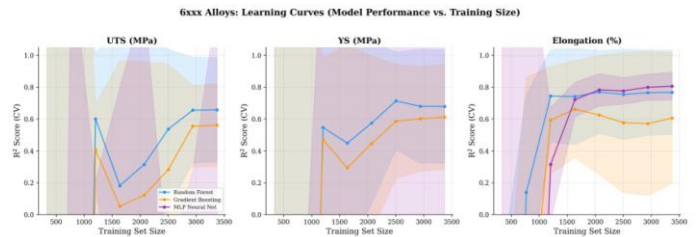


Fig. 5 Learning curves showing R^2 score vs. training set size for RF, GBR, and MLP models (simplified configurations; see text for details).

4. Conclusions

A hybrid ML framework combining real measurements with Monte Carlo augmentation was developed for predicting UTS, YS, and elongation of 6061, 6063, and 6082 Al-Mg-Si alloys across seven temper conditions. RF provided the best or comparable performance across all three targets (UTS: $R^2 = 0.80$, MAE = 13.44 MPa; YS: $R^2 = 0.92$, MAE = 8.21 MPa; elongation: $R^2 = 0.83$, MAE = 0.51 percentage points). Alloy type and temper condition encodings dominated predictions (>90% combined importance), while compositional features contributed <3% each; the low compositional contribution is partly attributable to the augmentation strategy, in which random compositions from specification ranges were paired with property measurements, thereby decoupling the composition–property linkage. Learning curve analysis confirmed convergence above ~2,000 samples. The moderate R^2 values reflect the wide property envelope of the 6xxx series. The framework demonstrates that corpus-mined data with hybrid augmentation provides a viable route for rapid property screening of engineering aluminum alloys, although future work should explore augmentation strategies that preserve composition–property correlations within each alloy-temper class.

5. Funding

This research was funded by the Bulgarian National Science Fund, Project **KII-06-H97/10** “Fabrication and Investigation of Antifriction Hybrid Nanocomposites Based on Aluminum Alloys Using an Integrated Approach Combining Experimental Methods and Machine Learning”.

6. References

1. Chauhan, K.P.S.; FUTURE INSTITUTE OF ENGINEERING AND TECHNOLOGY, BAREILLY (U.P.) Influence of Heat Treatment on the Mechanical Properties of Aluminium Alloys (6xxx Series): A Literature Review. *Int. J. Eng. Res. Technol.* (Ahmedabad) **2017**, *V6*, doi:10.17577/ijertv6is030301.
2. Gao, Y.-H.; Zhang, X.-X.; Zhou, J.-Z.; Xu, P.; Xin, Z.-J.; Gao, J.-H.; Shi, Y.-H.; Lü, Y.; Zhao, Y.-F.; Li, J.-Y. Engineering Heterogeneous Microstructures for Enhanced Strength and Ductility in Air-Cooled Al-Mg-Si Alloys. *Trans. Nonferrous Met. Soc. China* **2025**, *35*, 1017–1031, doi:10.1016/s1003-6326(24)66731-2.
3. Hagen, A.B.; Wenner, S.; Bjørge, R.; Wan, D.; Marioara, C.; Holmestad, R.; Ringdalen, I.G. Local Mechanical Properties and Precipitation Inhomogeneity in Large-Grained Al-Mg-Si Alloys. *SSRN Electron. J.* **2022**, doi:10.2139/ssrn.4216356.
4. Effect of Copper/Alumina Hybrid Reinforcement on the Microstructure and Mechanical Properties of Stir Cast Aluminum Alloy AA6063;
5. Wang, H.; Zheng, H.; Hu, M.; Ma, Z.; Liu, H. Synergistic Effect of Al₂O₃-Decorated Reduced Graphene Oxide on Microstructure and Mechanical Properties of 6061 Aluminium Alloy. *Sci. Rep.* **2024**, *14*, 16213, doi:10.1038/s41598-024-67004-x.
6. Jiang, W.; Zhu, J.; Li, G.; Guan, F.; Yu, Y.; Fan, Z. Enhanced Mechanical Properties of 6082 Aluminum Alloy via SiC Addition Combined with Squeeze Casting. *J. Mater. Sci. Technol.* **2021**, *88*, 119–131, doi:10.1016/j.jmst.2021.01.077.
7. Qian, X.; Parson, N.; Chen, X.-G. Effect of Post-Homogenisation Cooling Rate and Mn Addition on Mg₂Si Precipitation and Hot Workability of AA6060 Alloys. *Can. Metall. Q.* **2020**, *59*, 189–200, doi:10.1080/00084433.2020.1719332.
8. Shawon, A.R.; Ghosh, R.; Islam, M.A. Analysis of Thermal Conductivity of Aluminum Alloys by Compositions and Tempering Process Using Machine Learning. *Sci. Rep.* **2025**, *15*, 33352, doi:10.1038/s41598-025-15868-y.
9. Li, J.; Zhang, Y.; Cao, X.; Zeng, Q.; Zhuang, Y.; Qian, X.; Chen, H. Accelerated Discovery of High-Strength Aluminum Alloys by Machine Learning. *Commun. Mater.* **2020**, *1*, doi:10.1038/s43246-020-00074-2.

10. J. Soofi, Y.; Rahman, M.A.; Gu, Y.; Liu, J. A Feasibility Study of Machine Learning-Assisted Alloy Design Using Wrought Aluminum Alloys as an Example. *Comput. Mater. Sci.* **2022**, *215*, 111783, doi:10.1016/j.commatsci.2022.111783.
11. Pfeiffer, O.P.; Liu, H.; Montanelli, L.; Latypov, M.I.; Sen, F.G.; Hegadekatte, V.; Olivetti, E.A.; Homer, E.R. Aluminum Alloy Compositions and Properties Extracted from a Corpus of Scientific Manuscripts and US Patents 2021.
12. Silva, M.S.; Barbosa, C.; Acseleard, O.; Pereira, L.C. Effect of Chemical Composition Variation on Microstructure and Mechanical Properties of a 6060 Aluminum Alloy. *J. Mater. Eng. Perform.* **2004**, *13*, 129–134, doi:10.1361/10599490418307.
13. Trindade, W.G.; Padovezzi, R.O.; Pinto, E.P.G.; Marques, G.A.; Amorese, R.A.; Silva, M.C.; Damasio, T.S.; Andrade, G.O. de; Luca, R. de; Nascimento, P.H.T. do Influence of Alloying Elements on the Mechanical Properties and Electrical Conductivity of 6000 Series Aluminum Alloy. A Review. *CONTRIBUCIONES A LAS CIENCIAS SOCIALES* **2025**, *18*, e18763, doi:10.55905/revconv.18n.6-193.

Uncertainty analysis of man B&W 6S70ME-C diesel engine based on measured operating parameters in each cylinder

Mrzljak Vedran¹, Prpić-Oršić Jasna¹, Andelić Nikola¹, Poljak Igor²

¹Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia

²Department of maritime sciences, University of Zadar, Mihovila Pavlinovića 1, 23000 Zadar, Croatia

E-mail: vedran.mrzljak@riteh.uniri.hr, jasna.prpic.orsic@riteh.uniri.hr, nikola.andjelic@riteh.uniri.hr, ipoljak1@unizd.hr

Abstract: In this paper, an uncertainty analysis is performed related to the marine MAN B&W 6S70ME-C diesel engine. Uncertainty analysis is based on six different engine operating parameters (Maximum pressure, Compression pressure, Mean indicated pressure, Exhaust Gas Outlet Temperature, Cooling Fresh Water Outlet Temperature, and Piston Cooling Oil Outlet Temperature) measured in each engine cylinder. Various engine loads are observed. Exhaust Gas Outlet Temperature uncertainties are the highest in comparison to uncertainties of all other considered operating parameters. The highest Exhaust Gas Outlet Temperature uncertainty is detected at engine load of 90% and is equal to $\pm 2.421\%$, while considering all observed engine loads, Exhaust Gas Outlet Temperature uncertainty is equal to $\pm 4.296\%$. Overall uncertainty of the analysis performed in this paper (which considers all observed operating parameters at all engine loads) is equal to $\pm 4.837\%$, which also falls within the range of the recommended uncertainty limit ($\pm 5\%$).

KEYWORDS: UNCERTAINTY ANALYSIS, MARINE DIESEL ENGINE, OPERATING PARAMETERS, ENGINE CYLINDER

1. Introduction

In the marine propulsion sector, internal combustion diesel engines are the dominant mechanical power producers [1]. In addition to pure diesel engines, dual fuel engines increase their share in this sector each day due to low combustion gas emissions [2, 3]. Along with diesel or dual fuel internal combustion engines, in marine propulsion can be used various other propulsors, but its share in this sector is much lower in comparison to internal combustion engines [4, 5].

Due to its dominance, in the literature can be found various analyzes related to the marine internal combustion engines. A notable part of the literature is related to processes and procedures which reduce combustion gas emissions from such internal combustion engines [6-8]. Also, many different numerical models are developed for the performance analysis of various marine internal combustion engines [9-11]. Therefore, it can be concluded that due to its dominance in the marine propulsion sector, internal combustion engines are an important topic in the scientific and professional literature.

In this paper, an uncertainty analysis of marine MAN B&W 6S70ME-C diesel engine is performed, presented, and discussed. Uncertainty analysis is based on six different engine operating parameters measured in each engine cylinder. For each considered operating parameter, uncertainty analysis is performed at each engine load and at all engine loads observing all cylinders. Finally, uncertainty analysis is performed for all considered operating parameters at all engine loads. Uncertainty analysis performed in this paper provides information related to which considered operating parameter has the highest uncertainties and did overall uncertainty (for each parameter and for all parameters) fall in the range of recommended uncertainty ($\pm 5\%$).

2. Description of the analyzed engine and considered operating parameters in each cylinder

Marine low-speed two-stroke diesel engine analyzed in this paper is MAN B&W 6S70ME-C. This diesel engine is one of two identical engines used for the commercial LNG (Liquefied Natural Gas) carrier drive, where each of two identical parallel-running engines directly drives its own propulsion propeller (main engines) [12]. Along with the main diesel engines, the mentioned LNG carrier has four auxiliary diesel generator engines for electricity production [13]. MAN B&W 6S70ME-C main engine cross section is found in the producer specifications [14] and presented in Fig. 1, while the main engine particulars are obtained from the LNG carrier internal documentation [15] and presented in Table 1.

As can be seen from Table 1, the analyzed engine has six in-line cylinders. In this paper, uncertainty analysis is performed on the basis of measured operating parameters in each of six engine cylinders. Considered operating parameters are: Maximum pressure,

Compression pressure, Mean indicated pressure, Exhaust Gas Outlet Temperature, Cooling Fresh Water Outlet Temperature, and Piston Cooling Oil Outlet Temperature. All mentioned operating parameters are obtained during the producer test-bed measurements, which results are shown in [16]. Mentioned operating parameters used in the uncertainty analysis are measured in seven engine loads (load of 25%, 50%, 75%, 85%, 90%, 100%, and 110%). Exact used measurement procedure and measuring equipment are explained and presented also in [16].

It should be highlighted that uncertainty analysis is performed observing all cylinders for each considered operating parameter at each engine load, for each operating parameter at all engine loads, and finally, for all considered operating parameters at all engine loads (overall analysis uncertainty).

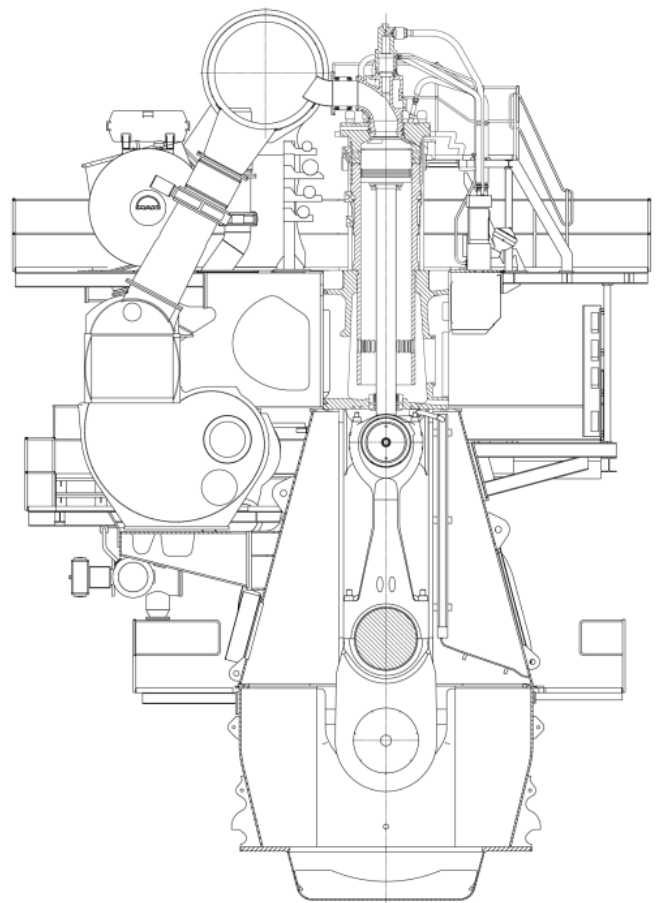


Fig. 1. MAN B&W 6S70ME-C engine cross section

Table 1. MAN B&W 6S70ME-C engine main particulars

Number of cylinders	6
Cylinders arrangement	In-line
Process type	Two-stroke
Cylinder bore	700 mm
Piston stroke	2800 mm
Fuel	Diesel very-low sulfur oil
Fuel Lower Heating Value (LHV)	41.98 MJ/kg
Fuel injection type	Direct injection
Power output at Maximum Continuous Rating (MCR)	17550 kW
Engine speed (at MCR)	85 rpm
Mean effective pressure (at MCR)	18.9 bar

3. Uncertainty analysis equations

Equations used for the uncertainty analysis are defined by Kline and McClintock's approach [17, 18]. Uncertainty analysis is based on six measured operating parameters in each cylinder of the analyzed marine internal combustion engine at seven engine loads (Maximum pressure, Compression pressure, Mean indicated pressure, Exhaust Gas Outlet Temperature, Cooling Fresh Water Outlet Temperature, and Piston Cooling Oil Outlet Temperature).

The arithmetic mean (A_{mean}) is calculated as:

$$A_{\text{mean}} = \frac{\sum_{i=1}^m Z_i}{m}, \quad (1)$$

where Z_i is the parameter considered and m is a number of engine cylinders. Standard deviation (σ) is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^m (Z_i - A_{\text{mean}})^2}{m-1}}. \quad (2)$$

Considered parameter uncertainty ($UN_{\text{parameter}}$) is defined as:

$$UN_{\text{parameter}} = \frac{\sigma}{\sqrt{m}}. \quad (3)$$

Considered parameter percentage of uncertainty ($UN_{\text{parameter}}(\%)$) is:

$$UN_{\text{parameter}}(\%) = \frac{UN_{\text{parameter}}}{A_{\text{mean}}} \cdot 100. \quad (4)$$

Overall uncertainty (UN_{overall}) is defined as:

$$UN_{\text{overall}} = \sqrt{\sum_{i=1}^n [UN_{\text{parameter}}(\%)]^2}, \quad (5)$$

where in the case analyzed in this paper n is the number of engine loads (for each considered parameter) or the number of all considered parameters (overall analysis uncertainty).

4. Considered operating parameters at various MAN B&W 6S70ME-C engine loads

Marine diesel engine operating parameters used in the uncertainty analysis are measured in seven engine loads (load of 25%, 50%, 75%, 85%, 90%, 100%, and 110%). The considered operating parameters are obtained during the producer test-bed measurements, presented and explained in [16].

In this paper, the exact measurement results of all considered operating parameters are shown at two MAN B&W 6S70ME-C engine loads – load of 50% (Table 2) and load of 100% (Table 3).

From Table 2 and Table 3 can be seen that an increase in engine load increases all considered pressures and temperatures in each engine cylinder. Moreover, considering temperatures only between engine cylinders at each load, it can be clearly seen that the change

in Exhaust Gas Outlet Temperature is much higher than the change in Cooling Fresh Water Outlet Temperature and Piston Cooling Oil Outlet Temperature, which must result in higher Exhaust Gas Outlet Temperature uncertainty (in comparison to the other two temperatures).

Table 2. Measured operating parameters at MAN B&W 6S70ME-C engine load of 50%

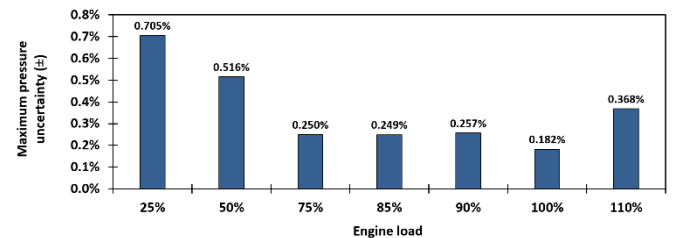
Cylinder	1	2	3	4	5	6
Maximum pressure (bar)	110.1	108.6	107.9	108.1	111.5	109.7
Compression pressure (bar)	84.4	83.4	81.3	83.6	83.4	81.3
Mean indicated pressure (bar)	12.75	12.69	12.41	12.63	12.78	12.90
Exhaust Gas Outlet Temperature (°C)	270.0	265.0	250.0	277.0	280.0	280.0
Cooling Fresh Water Outlet Temperature (°C)	78.0	78.0	78.0	78.0	79.0	79.0
Piston Cooling Oil Outlet Temperature (°C)	50.0	50.0	50.0	50.0	50.0	50.0

Table 3. Measured operating parameters at MAN B&W 6S70ME-C engine load of 100%

Cylinder	1	2	3	4	5	6
Maximum pressure (bar)	150.9	150.5	150.0	149.5	151.2	151.1
Compression pressure (bar)	133.0	134.3	132.5	134.9	132.9	133.1
Mean indicated pressure (bar)	20.01	19.95	20.05	19.87	19.68	20.20
Exhaust Gas Outlet Temperature (°C)	325.0	320.0	314.0	325.0	335.0	332.0
Cooling Fresh Water Outlet Temperature (°C)	82.0	81.0	82.0	82.0	82.0	82.0
Piston Cooling Oil Outlet Temperature (°C)	52.0	52.0	52.0	53.0	52.0	52.0

5. Results and discussion

Maximum pressure uncertainty at each observed engine load is presented in Fig. 2. Maximum pressure uncertainties are the highest at two the lowest observed engine loads (loads of 25% and 50%) and equal $\pm 0.705\%$ and $\pm 0.516\%$, respectively. The lowest maximum pressure uncertainty is detected at engine load of 100% and is equal to $\pm 0.182\%$.

**Fig. 2.** Maximum pressure uncertainty at each observed engine load

Considering compression pressure uncertainties, Fig. 3, it can be easily concluded that the highest and the lowest uncertainties are obtained at the same engine loads as the maximum pressure uncertainties. Therefore, the highest compression pressure uncertainties ($\pm 0.636\%$ and $\pm 0.637\%$) are obtained at engine loads of 25% and 50%, respectively, while the lowest compression

pressure uncertainty of $\pm 0.286\%$ is obtained at engine load of 100%.

The highest and the lowest uncertainties related to the mean indicated pressure did not occur at the same engine loads as obtained for the maximum pressure and compression pressure uncertainties, Fig. 4. The highest uncertainty related to the mean indicated pressure (equal to $\pm 0.534\%$) occurs at the engine load of 50%, while the lowest mean indicated pressure uncertainty of $\pm 0.229\%$ occurs at the engine load of 110%.

According to the recommendations from the literature [17, 19], the acceptable uncertainty limit is $\pm 5\%$, regardless of the observed measured parameter. For all uncertainties related to the pressures at each engine load (Maximum pressure – Fig. 2, Compression pressure – Fig. 3 and Mean indicated pressure – Fig. 4), maximum values are notably lower than the highlighted limit.

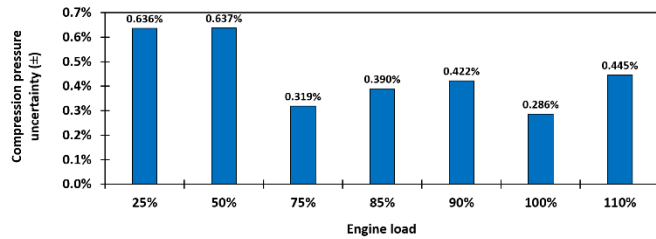


Fig. 3. Compression pressure uncertainty at each observed engine load

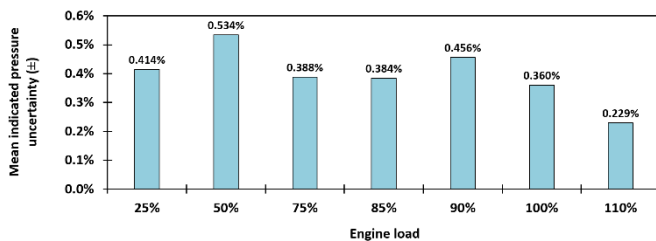


Fig. 4. Mean indicated pressure uncertainty at each observed engine load

Exhaust Gas Outlet Temperature uncertainties at each observed engine load are presented in Fig. 5. The highest Exhaust Gas Outlet Temperature uncertainty is obtained at engine load of 90% ($\pm 2.421\%$), while the lowest Exhaust Gas Outlet Temperature uncertainty is detected at engine load of 100% ($\pm 0.964\%$).

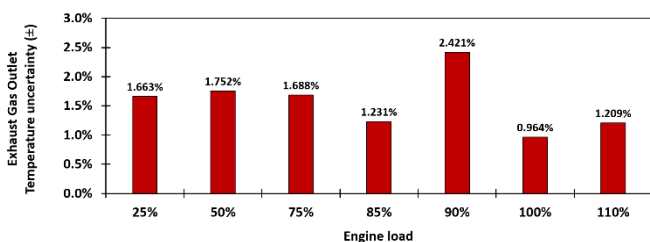


Fig. 5. Exhaust Gas Outlet Temperature uncertainty at each observed engine load

Cooling Fresh Water Outlet Temperature uncertainties at each engine load can be seen in Fig. 6. The highest Cooling Fresh Water Outlet Temperature uncertainty is detected at engine load of 110% (equal to $\pm 0.403\%$), while the lowest Cooling Fresh Water Outlet Temperature uncertainty is obtained at engine load of 100% (equal to $\pm 0.204\%$). In comparison to Exhaust Gas Outlet Temperature uncertainties, Cooling Fresh Water Outlet Temperature uncertainties are much lower at each engine load, Fig. 5 and Fig. 6.

The highest Piston Cooling Oil Outlet Temperature uncertainty is obtained at engine load of 85% and is equal to $\pm 0.408\%$, Fig. 7. However, the lowest Piston Cooling Oil Outlet Temperature uncertainty, equal to zero, is detected at engine load of 50%. At

engine load of 50%, Piston Cooling Oil Outlet Temperature uncertainty is equal to zero because measurements in all six engine cylinders resulted in the same temperature, which is clearly visible in Table 2.

In comparison to Exhaust Gas Outlet Temperature uncertainties, Piston Cooling Oil Outlet Temperature uncertainties are much lower at each engine load, Fig. 5 and Fig. 7. This confirms the statement highlighted before – due to much higher Exhaust Gas Outlet Temperature change between engine cylinders at each observed load, Exhaust Gas Outlet Temperature uncertainties are notably higher in comparison to Cooling Fresh Water Outlet Temperature and Piston Cooling Oil Outlet Temperature uncertainties.

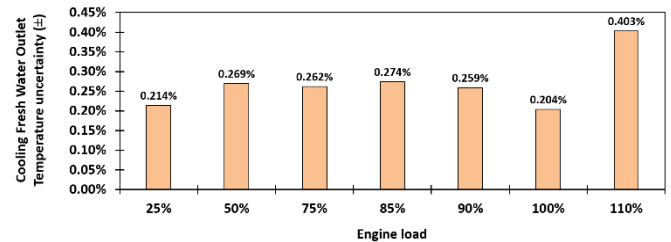


Fig. 6. Cooling Fresh Water Outlet Temperature uncertainty at each observed engine load

Finally, also all uncertainties related to the temperatures considered in this analysis at each engine load (Exhaust Gas Outlet Temperature – Fig. 5, Cooling Fresh Water Outlet Temperature – Fig. 6 and Piston Cooling Oil Outlet Temperature – Fig. 7) are notably lower than the recommended uncertainty limit of $\pm 5\%$.

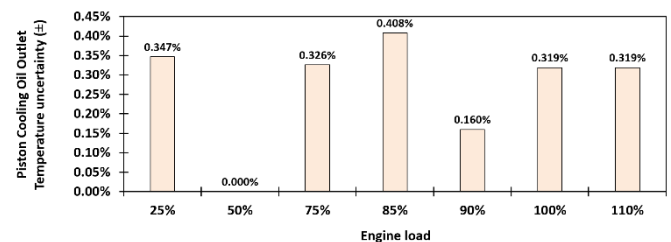


Fig. 7. Piston Cooling Oil Outlet Temperature uncertainty at each observed engine load

Overall uncertainty of considered operating parameters in this analysis at all observed engine loads is presented in Fig. 8.

From Fig. 8 is easy to detect that the highest overall uncertainty (considering all observed engine loads), equal to $\pm 4.296\%$, has Exhaust Gas Outlet Temperature, while the lowest overall uncertainty of $\pm 0.731\%$ has Cooling Fresh Water Outlet Temperature. Fig. 8 additionally confirms that overall uncertainties related to the Cooling Fresh Water Outlet Temperature and Piston Cooling Oil Outlet Temperature are notably lower in comparison to Exhaust Gas Outlet Temperature uncertainties at all engine loads.

Overall uncertainties related to all three observed pressures at all engine loads (Maximum pressure, Compression pressure, and Mean indicated pressure) are around $\pm 1\%$. Moreover, uncertainties of all six operating parameters observed in this paper at all engine loads are lower than the uncertainty limit of $\pm 5\%$.

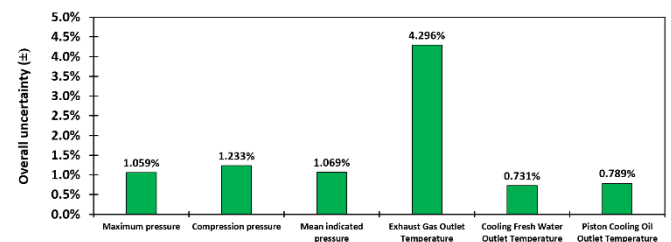


Fig. 8. Overall uncertainty of all considered parameters at all observed engine loads

Overall uncertainty of the analysis performed in this paper (which considers all observed operating parameters at all engine loads), and which is calculated by using Eq. 5, is equal to $\pm 4.837\%$, what also falls within the range of the recommended uncertainty limit ($\pm 5\%$).

6. Conclusions

This paper presents an uncertainty analysis related to the marine MAN B&W 6S70ME-C diesel engine. Performed analysis is based on six different engine operating parameters (Maximum pressure, Compression pressure, Mean indicated pressure, Exhaust Gas Outlet Temperature, Cooling Fresh Water Outlet Temperature, and Piston Cooling Oil Outlet Temperature) measured in each engine cylinder. Various engine loads are observed. For each considered operating parameter, uncertainty analysis is performed at each engine load and at all engine loads observing all cylinders. At the end, uncertainty analysis is performed for all considered operating parameters at all engine loads. The most important conclusions of the performed analysis are:

- Uncertainties related to all pressure operating parameters (Maximum pressure, Compression pressure, and Mean indicated pressure) are lower than $\pm 1\%$ considering each engine load and are around $\pm 1\%$ considering all engine loads. Uncertainties of all pressure operating parameters are notably lower than the recommended uncertainty limit ($\pm 5\%$).
- Exhaust Gas Outlet Temperature uncertainties are the highest in comparison to uncertainties of all other considered operating parameters. The highest Exhaust Gas Outlet Temperature uncertainty is detected at engine load of 90% and is equal to $\pm 2.421\%$, while considering all observed engine loads, Exhaust Gas Outlet Temperature uncertainty is equal to $\pm 4.296\%$. Still, also Exhaust Gas Outlet Temperature uncertainties are lower than the recommended uncertainty limit of $\pm 5\%$.
- Cooling Fresh Water Outlet Temperature uncertainties as well as Piston Cooling Oil Outlet Temperature uncertainties are the lowest of all considered operating parameter uncertainties (at each engine load as well as observing all engine loads).
- If the observed operating parameter has the same measured values in all cylinders at any engine load, its uncertainty is equal to zero (as can be observed in this analysis for Piston Cooling Oil Outlet Temperature uncertainty at engine load of 50%).
- Overall uncertainty of the analysis performed in this paper (which considers all observed operating parameters at all engine loads) is equal to $\pm 4.837\%$, which also falls within the range of the recommended uncertainty limit ($\pm 5\%$).

7. Acknowledgment

This work was supported by the Croatian Science Foundation under the project number HRZZ-IP-2022-10-2821 and by the University of Rijeka scientific grants uniri-iz-25-6, uniri-iz-25-220 and uniri-iz-25-10 (Funded by the European Union – NextGenerationEU).

8. References

- [1] Bilousov, I., Bulgakov, M., & Savchuk, V. (2020). Modern marine internal combustion engines. Berlin/Heidelberg, Germany: Springer International Publishing.
- [2] Nemati, A., Ong, J. C., Pang, K. M., Mayer, S., & Walther, J. H. (2022). A numerical study of the influence of pilot fuel injection timing on combustion and emission formation under two-stroke dual-fuel marine engine-like conditions. *Fuel*, 312, 122651. (doi:10.1016/j.fuel.2021.122651)
- [3] Yu, H., Wang, W., Sheng, D., Li, H., & Duan, S. (2022). Performance of combustion process on marine low speed two-stroke dual fuel engine at different fuel conditions: Full diesel/diesel ignited natural gas. *Fuel*, 310, 122370. (doi:10.1016/j.fuel.2021.122370)
- [4] Fernández, I. A., Gómez, M. R., Gómez, J. R., & Insua, Á. B. (2017). Review of propulsion systems on LNG carriers. *Renewable and Sustainable Energy Reviews*, 67, 1395-1411. (doi:10.1016/j.rser.2016.09.095)
- [5] Jelić, M., Mrzljak, V., Radica, G., & Račić, N. (2025). An alternative and hybrid propulsion for merchant ships: current state and perspective. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 47(1), 10241-10273. (doi:10.1080/15567036.2021.1963354)
- [6] Lion, S., Vlaskos, I., & Taccani, R. (2020). A review of emissions reduction technologies for low and medium speed marine Diesel engines and their potential for waste heat recovery. *Energy Conversion and Management*, 207, 112553. (doi:10.1016/j.enconman.2020.112553)
- [7] Ni, P., Wang, X., & Li, H. (2020). A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines. *Fuel*, 279, 118477. (doi:10.1016/j.fuel.2020.118477)
- [8] Senčić, T., Mrzljak, V., Blecich, P., & Bonefačić, I. (2019). 2D CFD simulation of water injection strategies in a large marine engine. *Journal of Marine Science and Engineering*, 7(9), 296. (doi:10.3390/jmse7090296)
- [9] Mrzljak, V. (2015). Quasi-dimensional model for numerical simulations of marine two-stroke diesel engine (Doctoral dissertation, Doctoral Thesis, Rijeka, University of Rijeka).
- [10] Feng, Y., Wang, H., Gao, R., & Zhu, Y. (2019). A zero-dimensional mixing controlled combustion model for real time performance simulation of marine two-stroke diesel engines. *Energies*, 12(10), 2000. (doi:10.3390/en12102000)
- [11] Muše, A., Jurić, Z., Račić, N., & Radica, G. (2020). Modelling, performance improvement and emission reduction of large two-stroke diesel engine using multi-zone combustion model. *Journal of thermal analysis and calorimetry*, 141(1), 337-350. (doi:10.1007/s10973-020-09321-7)
- [12] Baressi Šegota, S., Poljak, I., Andelić, N., & Mrzljak, V. (2025). On Predicting Marine Engine Measurements with Synthetic Data in Scarce Dataset. *Journal of Marine Science and Engineering*. (doi:10.3390/jmse13071289)
- [13] Poljak, I., Mrzljak, V., Andelić, N., & Šegota, S. B. (2025). Cylinders problematic operation detection in two parallel running 6S70ME-C diesel engines at low loads. *Energy*, 341, 139405. (doi:10.1016/j.energy.2025.139405)
- [14] <https://www.man-es.com> (accessed 12.01.2026.)
- [15] LNG carrier Machinery Systems Operating Manual. Internal ship documentation. March 2009.
- [16] Instruction Book for Hyundai-MAN B&W 50-98 ME/ME-C diesel engines, Hyundai heavy industries co., ltd., engine & Machinery Division, Ulsan, Korea, 2007, internal ship documentation.
- [17] Adib, A. R., Rahman, M. M., Hassan, T., Ahmed, M., & Al Rifat, A. (2024). Novel biofuel blends for diesel engines: optimizing engine performance and emissions with C. cohnii microalgae biodiesel and algae-derived renewable diesel blends. *Energy Conversion and Management: X*, 23, 100688. (doi:10.1016/j.ecmx.2024.100688)
- [18] Mohammed, A. S., Ancha, V. R., At Naw, S. M., Desta, M., & Bhandari, R. (2025). Analysis of Cylinder Pressure and Heat Release Rate Variation in Diesel Engine Fueled with Croton Macrostachyus (CMS) Seed Oil Biodiesel as an Alternative Fuel. *Energies*, 18(6), 1449. (doi:10.3390/en18061449)
- [19] Wang, R., Chen, H., & Guan, C. (2021). A Bayesian inference-based approach for performance prognostics towards uncertainty quantification and its applications on the marine diesel engine. *ISA transactions*, 118, 159-173. (doi:10.1016/j.isatra.2021.02.024)

Ways to reduce atmospheric air pollution from transport in the city of Kutaisi through an artificial intelligence – driven method

Natia Kamkamidze, Lamara Gobejishvili, Nino Tsutskiridze, Natia Khazaradze
Akaki Tsereteli State University, Kutaisi, Georgia
natia.kamkamidze@atsu.edu.ge , lamara.gobejishvili@atsu.edu.ge , nino.tsutskiridze@atsu.edu.ge ,
natia.khazaradze1@atsu.edu.ge

Abstract: The article discusses the ecological state of atmospheric air in the city of Kutaisi and ways to reduce pollution from one of the main factors - transport, through the method of optimizing the urban road traffic system. This method integrates environmental responsibility with the goal of ensuring efficient, safe, and accessible mobility. It will also help urban planners and environmentalists, through an artificial intelligence-driven method, to reduce the negative environmental impact of transport and maintain the efficiency of transport systems.

KEYWORDS: ATMOSPHERIC POLLUTION; CONCENTRATION; PM2.5, PM10; URBAN TRAFFIC; ARTIFICIAL INTELLIGENCE.

1. Introduction

Georgia's geographical location determines its role in transit in the Caucasus. Currently, transit infrastructure in the country is developing rapidly: high-speed highways are being constructed, and as a result, traffic flow and transportation volumes are expected to increase in the future if environmental protection measures are not implemented.

In addition to air pollution, a significant problem for large cities is the steady increase in noise levels caused by intensive urban traffic. High noise levels result from heavy traffic, technical malfunctions of some vehicles, narrow streets, the unsatisfactory condition of boulevards and road surfaces, the absence of protective green zones between pedestrian paths and roadways, violations of traffic rules, the use of loud vehicle horns in prohibited areas, and poor street planning and design. As a result of the processes listed above, emissions of pollutants and noise levels in urban areas will increase, leading to ecosystem deterioration and adverse effects on human health.

It is from this point onward that we have studied air pollution in the city of Kutaisi and the contemporary approach to mitigating this issue.

Data from the National Environmental Agency were reviewed. In 2024, atmospheric air pollution monitoring in Kutaisi was conducted at an automatic station located on Asatiani Street. Concentrations of the following harmful substances were measured: particulate matter (PM10 and PM2.5), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), ozone (O₃), and carbon monoxide (CO).

- The concentrations of sulfur dioxide (SO₂), based on both 1-hour and 24-hour averaging periods, did not exceed the respective limit values.
- The average annual concentration of particulate matter (PM₁₀) was 30 µg/m³, which did not exceed the maximum permissible norm. The average monthly values of daily mean concentrations also remained within permissible limits; however, PM₁₀ concentrations based on 24-hour averaging exceeded the limit values on 25 occasions during the year. Of

- these, 14 exceedances were attributed to synoptic processes, specifically the transport of air masses containing desert dust particles from the southeast over the territory of Georgia.
- The average annual concentration of particulate matter (PM_{2.5}) was 14 µg/m³, which did not exceed the respective limit value.
- The average annual concentration of nitrogen dioxide (NO₂) was 39 µg/m³ and did not exceed the maximum permissible concentration; 1-hour average concentrations also remained below the respective limit value throughout the year.
- The maximum daily 8-hour average concentrations of ozone (O₃) did not exceed the respective limit values throughout the year.
- The 8-hour daily average concentrations of carbon monoxide (CO) did not exceed the respective limit value.

2. Methodological and theoretical framework

In 2024, based on data obtained from indicative measurements conducted in the city of Kutaisi, exceedances of the annual average concentration limit for nitrogen dioxide (NO₂) were recorded at two out of four monitoring locations. In particular, concentrations reached 63.32 µg/m³ (1.6 MPC) near R. Shengelia Stadium, while the value recorded on David Agmashenebeli Avenue (40.03 µg/m³) slightly exceeded the permissible limit.

Results show that the average annual concentrations of benzene were within the permissible limits at all monitoring sites. In addition, air samples were collected using an aspirator to determine lead content. The results indicate that in 2024, the average annual concentration of lead in the ambient air of the city of Kutaisi did not exceed the established limit value (Table 1).

According to data from the National Environmental Agency for 2024–25, the average annual concentrations of nitrogen dioxide and particulate matter were exceeded in several instances, primarily due to street repair works, industrial activities, and heavy traffic.

Table 1: Results of Four Stages of Indicative Measurements in the City of Kutaisi

Address	Stages	Nitrogen dioxide, µg/m ³				Ozone, µg/m ³				Benzene, µg/m ³			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
Chechelashvili Street		21.63	17.26	16.99	21.95					0.9	0.8	0.9	1.8
Kharazovi's Garden		11.19	8.41	4.67	14.04					1.8	1.7	1.8	3.1
Near R. Shengelia Stadium		74.24	62.49	60.50	56.04								
David Agmashenebeli Avenue		41.92	41.09	41.07	36.02								
Near Bagrati Cathedral						125.45	117.1	89.78	62.07				

The present paper addresses traffic-related pollution using a sustainable transport approach that balances environmental

responsibility with efficient, safe, and accessible mobility. The primary goal is to minimize the negative environmental impact of

transport while maintaining the effectiveness of transport systems through innovative strategies.

Traditional approaches are limited in their ability to assess traffic flow and the urban environment effectively. To enhance urban mobility and optimize traffic flow, artificial intelligence (AI)-driven methods are increasingly needed. This paper presents the Traffic Optimization Framework (LLM-RL-TOF).

Urban transport faces challenges from both environmental issues and traffic congestion [1]. To meet the growing demand for efficiency and reliability in urban transport networks, experts are exploring innovative traffic management strategies [2]. Traditional rule-based traffic management systems (TMS), which rely on pre-programmed signal timings, often struggle to adapt to dynamic road conditions in high-density metropolitan areas [3]. In contrast, AI-driven traffic optimization offers a promising solution, using real-time data to make intelligent decisions that improve traffic flow while minimizing environmental impact.

Modern traffic management increasingly relies on Internet of Things (IoT) sensors, including inductive loops and drone monitoring systems. These sensors provide precise data on vehicle movements, congestion, and environmental conditions, enabling real-time traffic management decisions [5]. However, a major challenge lies in effectively organizing and utilizing this vast flow of data [6]. Large language models (LLMs) are particularly well-suited to this task, as they excel at pattern recognition, forecasting, and generating insights in complex, dynamic environments.

AI-driven dynamic traffic management can assist urban planners in optimizing vehicle flow while reducing environmental impact [7]. Large language models (LLMs) can be integrated into traffic control systems via the Internet, offering novel approaches to planning and decision-making [8]. Beyond text processing, LLMs are capable of analyzing complex datasets, making them well-suited for future applications in system control. Their potential to enhance urban traffic management is significant, as LLMs' cognitive capabilities can improve efficiency, traffic flow, and overall quality of life [9]. By using artificial intelligence, data-driven traffic management becomes a practical and effective solution [10].

Reinforcement learning (RL) has been extensively studied for traffic signal control, with models designed to manage signal timing in real time based on traffic conditions [11]. As a subset of machine learning (ML), RL evaluates multiple outcomes to determine the optimal actions for interacting with the environment [12]. By automatically managing signals, congestion, and delays, RL optimizes traffic flow [13]. When combined with large language models (LLMs), real-time traffic data can further enhance performance: LLMs analyze traffic patterns, predict congestion, and provide actionable information that RL agents use to improve traffic flow. Continuous system performance feedback allows RL agents to make better decisions, reducing waiting times and increasing overall traffic throughput [14].

Experimental evaluations show that the **LLM-RL-TOF** approach outperforms advanced baseline models, including GRU-BRNN, UTMOM, and p-H-WDFOA, across key transportation metrics [15]. In particular, it increased intersection throughput by 17.5%, reduced the queue length accumulation index by 22.3%, and decreased average vehicle delay by 18.6%. These results highlight the method's efficiency, positive environmental impact, and reliability in policy implementation. As a result, the LLM-RL-TOF model has been selected for deployment in future smart city transportation networks, as it enhances pedestrian safety, improves emergency response efficiency, and supports sustainability objectives.

3. Conclusion

The present study examines atmospheric air pollution in the city of Kutaisi and proposes strategies to mitigate transport-related pollution through real-time urban traffic system

optimization, guiding urban planners and environmental protection specialists.

4. References

- [1] M. Miftah, D.I. Desrianti, N. Septiani, A.Y. Fauzi, C. Williams. Big data analytics for smart cities: optimizing urban traffic management using real-time data processing. *J. Comput. Sci. Technol. Appl.*, 2 (1) (2025), pp. 14-23. [Google Scholar](#)
- [2] I. Moumen, J. Abouchabaka, N. Rafalia. Enhancing urban mobility: integration of IoT road traffic data and artificial intelligence in smart city environment. *Indones. J. Electr. Eng. Comput. Sci.*, 32 (2) (2023), pp. 985-993. [View at publisherCrossrefView in ScopusGoogle Scholar](#)
- [3] H. Xu, A. Berres, S.B. Yoganath, H. Sorensen, P.J. Nugent, J. Severino, J. Sanyal. Smart mobility in the cloud: enabling real-time situational awareness and cyber-physical control through a digital twin for traffic. *IEEE Trans. Intell. Transp. Syst.*, 24 (3) (2023), pp. 3145-3156. [View at publisherCrossrefView in ScopusGoogle Scholar](#)
- [4] Balasubramanian, A. AI-Driven Optimization of Urban Mobility: Integrating Autonomous Vehicles with Real-Time Traffic and Infrastructure Analytics. *traffic*, 5(5). [Google Scholar](#)
- [5] A.A. Taiwo, C.C. Nzeanorue, S.A. Olanrewaju, Q.O. Ajiboye, A. A. Idowu, S. Hakeem, R.A. Olusola. Intelligent transportation system leveraging Internet of things (IoT) technology for optimized traffic flow and smart urban mobility management. *World J. Adv. Res. Rev.*, 22 (3) (2024), pp. 1509-1517. [Google Scholar](#)
- [6] R. Kumar, N. Kori, V.K. Chaurasiya. Real-time data sharing, path planning and route optimization in urban traffic management. *Multimed. Tools Appl.*, 82 (23) (2023), pp. 36343-36361. [View at publisherCrossrefView in ScopusGoogle Scholar](#)
- [7] M. Anedda, M. Fadda, R. Girau, G. Pau, D. Giusto. A social smart city for public and private mobility: a real case study. *Comput. Netw.*, 220 (2023), Article 109464. [View PDFView articleView in ScopusGoogle Scholar](#)
- [8] C. Gheorghie, A. Soica. Revolutionizing urban mobility: a systematic review of AI, IoT, and predictive analytics in adaptive traffic control systems for road networks. *Electronics* (20799292), 14 (4) (2025). [Google Scholar](#)
- [9] G. Chen, J. wan Zhang. Intelligent transportation systems: machine learning approaches for urban mobility in smart cities. *Sustain. Cities Soc.*, 107 (2024), Article 105369. [View PDFView articleView in ScopusGoogle Scholar](#)
- [10] S. Dikshit, A. Atiq, M. Shahid, V. Dwivedi, A. Thusu. The use of artificial intelligence to optimize the routing of vehicles and reduce traffic congestion in urban areas. *EAI Endorsed Trans. Energy Web*, 10 (2023), pp. 1-13. [View in ScopusGoogle Scholar](#)
- [11] E. Faliagka, E. Christopoulou, D. Ringas, T. Politi, N. Kostis, D. Leonardos, N. Voros. Trends in digital twin framework architectures for smart cities: a case study in smart mobility. *Sensors*, 24 (5) (2024), p. 1665. [View at publisherCrossrefView in ScopusGoogle Scholar](#)
- [12] Dai, S., Pu, M., Liu, C., Ning, X., Wang, Q., Makantasis, K., & Cheng, L. Towards Energy-Efficient and Low-Carbon Transportation Systems Via Llm-Assisted Multi-Agent Reinforcement Learning. Available at SSRN 5207038. [Google Scholar](#)
- [13] L. Da, K. Liou, T. Chen, X. Zhou, X. Luo, Y. Yang, H. Wei. Open-ti: open traffic intelligence with augmented language model. *Int. J. Mach. Learn. Cybern.*, 15 (10) (2024), pp. 4761-4786. [View at publisherCrossrefView in ScopusGoogle Scholar](#)
- [14] S. Choi, Y. Lim. Optimizing traffic signal control using LLM-Driven reward weight adjustment in reinforcement learning. *J. Inf. Process. Syst.*, 21 (1) (2025), pp. 43-51. [View in ScopusGoogle Scholar](#)
- [15] Arvind R. Singh, Muhammad Wasim Abbas Ashraf, Rajkumar Singh Rathore, Bin Li M.S. Sujatha. Real-time traffic flow optimization using large language models and reinforcement learning for smart urban mobility. <https://doi.org/10.1016/j.asoc.2025.113917>. Get rights and content

Investigation of Positioning Accuracy Improvement Methods for Sigfox IoT Devices through WiFi MAC Address Analysis

Masaya Watanabe¹, Takuya Nanjo¹, Tomoo Sigehuzi², Satoru Tada¹, Masayuki Yamauchi¹,
Takeshi Nishiyone³, Hironori Wakaoka³, Shuji Oji³, Naoki Kabemoto⁴, Hiroki Mori⁴, Takeshi Tanaka¹ and Katia Vutova⁵
Hiroshima Institute of Technology, Hiroshima, Japan¹
National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan²
Chudenko Corporation, Hiroshima, Japan³
Interface Corporation, Hiroshima, Japan⁴
Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria⁵
tanaka@cc.it-hiroshima.ac.jp

Abstract: This study presents and validates a method for achieving positioning accuracy comparable to standalone GPS (approximately 10 m) using a proprietary Sigfox WiFi positioning system that transmits only two MAC addresses per message. Due to Sigfox's severe payload limitations, conventional positioning attempts often fail or yield significant errors. Our approach introduces continuous scanning on the device to dynamically collect up to four MAC addresses, paired with meticulous backend analysis and filtering of MAC address quality using a custom Here API Validation Tool. The proposed method effectively addresses these limitations, demonstrating a 100% location acquisition rate and a median positional error of 19 meters, making it highly effective for both stationary and dynamic mobile tracking.

Keywords: SIGFOX, WIFI POSITIONING, MAC ADDRESS, HERE API, LPWA, IOT, ESP32-S3

1. Introduction

Location information is crucial across various fields, including surveying, autonomous driving, construction, and disaster response. GPS positioning, a common method for location estimation, typically incurs an error of approximately 10–30 m[1]. With the widespread adoption of IoT devices, the demand for low-cost, low-power positioning methods that utilize Sigfox, a low-power wide area network, has increased[2].

Sigfox's official Atlas WiFi service enables positioning by obtaining the MAC addresses of nearby WiFi access points. However, within the proprietary mechanism developed in this study, the number of MAC addresses that can be transmitted in a single message is strictly limited to two due to Sigfox's payload constraint of 12 bytes. Attempting to perform positioning by directly sending this limited MAC address information to the Here Positioning API often results in complete failures or significant errors (ranging from tens to hundreds of meters).

To address these challenges, this study proposes and validates a method that achieves accuracy comparable to standalone GPS positioning (approximately 10 m) using a proprietary Sigfox WiFi positioning system that transmits only two MAC addresses per message. This is achieved through meticulous scanning of the WiFi environment using NetSpot, along with quality analysis and selection of MAC addresses via a custom-built Here API Validation Tool designed for this verification.

2. GPS Positioning (Baseline accuracy verification)

A. IoT Device Configuration

We first developed an IoT device equipped with a Sigfox network module and a GPS module. The configuration combines an Arduino Uno Rev3[3] with a Sigfox shield for Arduino V2S[4] and a GPS module[5]. Detailed construction methods and the modules utilized are outlined in the literature[6].



Fig. 1 IoT device with Sigfox network and GPS modules.

B. GPS Positioning Results (Accuracy: Approximately 10 m)

Latitude (multiplied by 1 M) and longitude (multiplied by 1 M) data acquired from the IoT device are transmitted via email through the Sigfox cloud.

An example of the received data is given as follows:

```
{
  "device" : "771E2D",
  "time" : 1771975311,
  "seqNumber" : 954,
  "data" : "020c7a2807e640d0",
  "slt" : 34372136,
  "slg" : 132530384
}
```

When the acquired location information was plotted on Google Maps, an error of approximately 10 m was observed between the GPS positioning (red dot) and the actual physical location (blue dot). In general, GPS positioning errors range from 10 to 30 m due to factors such as ionospheric delay and multipath effects, which align with the findings of this experiment. Therefore, this study establishes a GPS precision of approximately 10 m as the target accuracy for the Sigfox WiFi positioning system.



Fig. 2 IoT GPS device displayed on Google Maps.

3. Positioning using Sigfox: Mechanisms and Challenges

This section discusses the mechanisms of positioning using the Sigfox network, its accuracy, and the inherent challenges.

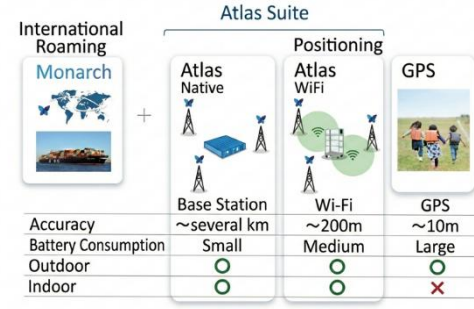


Fig. 5 Comparison of Sigfox Atlas Native and WiFi.

A. Atlas Native Positioning (Accuracy: Several Kilometers)

Atlas Native is a location measurement service that communicates with Sigfox base stations to provide geographical coordinates (latitude and longitude) and an estimated error range. This information is relayed via callbacks or the standard Sigfox API based on factors such as signal strength from transmitted messages. Although it is extremely low-power and does not require additional modules like GPS, its accuracy is limited to several kilometers, allowing only for rough area estimations. In this experiment, the indicated area spanned 90 km east-west and 110 km north-south.

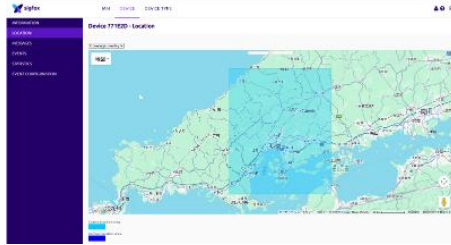


Fig. 4 Mechanism of Sigfox Atlas location estimation.

B. Atlas WiFi and Custom Sigfox WiFi Positioning (Here API Integration)

Sigfox's official Atlas WiFi service enables low-power acquisition of location information both indoors and outdoors by utilizing surrounding WiFi access points (BSSID/MAC addresses), provided the area has Sigfox coverage. It offers latitude, longitude, and an expected accuracy range based on MAC addresses, facilitating location identification even in environments where GPS signals are unavailable, such as indoors or in urban canyons.

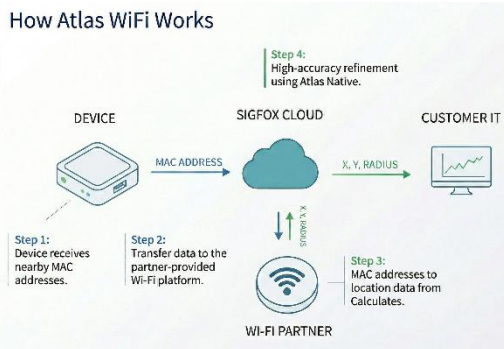


Fig. 5 Mechanism of Sigfox Atlas Wi-Fi.

Instead of relying on the existing Atlas WiFi service, this research developed and validated a proprietary mechanism[7] that directly stores MAC addresses acquired from the device into the Sigfox message payload and queries the Here Positioning API through a custom backend server (e.g., AWS). Due to Sigfox communication specifications, the maximum payload for a single message is strictly limited to 12 bytes, allowing for the inclusion of only two MAC addresses (six bytes each). This limitation presents significant challenges:

- **Positioning Failure:** The Here API often cannot calculate a location based on only two MAC addresses, resulting in no coordinate data. An analysis of historical experimental data involving 5,431 unique transmissions revealed that approximately 75.3% of all transmissions failed to acquire even a single valid MAC address (resulting in no data), highlighting the extreme difficulty of data acquisition in sparsely populated areas.
- **Large Errors:** Even when a location is successfully identified, the accuracy can vary significantly, ranging from tens to hundreds of meters when relying on only two data points.
- **Effects of Inappropriate APs:** If mobile access points (APs), such as smartphone tethering devices, or APs with registered locations that differ from their actual physical locations are included in the transmission, the center of gravity for location estimation can be severely distorted.

The following visualization presents experimental data obtained using the conventional single-scan method (maximum of two MACs per location, no MAC filtering). As shown, the estimated coordinate points are widely dispersed across a vast area, visually confirming that practical positioning accuracy has not yet been achieved.

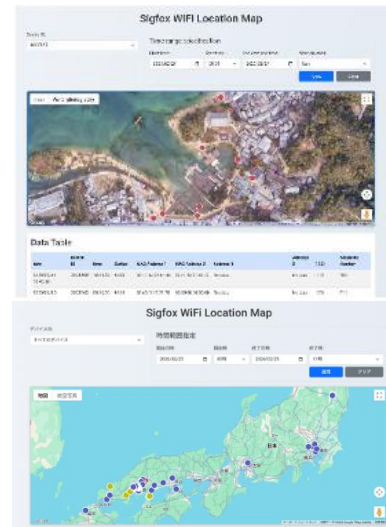


Fig. 6 Data scattering by conventional methods (max two MACs per location, no MAC filter)

C. Summary of Challenges

The previous analysis clearly shows that achieving practical accuracy (approximately 10 m, similar to GPS) in custom Sigfox WiFi positioning, while using a minimal number of MAC addresses (two), requires a mechanism to evaluate and prefilter the quality of MAC addresses before transmission.

4. Accuracy improvement method via WiFi MAC address analysis

A. Verification of Continuous Scanning via Walking (Device-side Enhancements)

In this verification, communication and positioning experiments were conducted using a dedicated edge device (shown in Fig. 7) that incorporates an ESP32-S3 chip for WiFi scanning, alongside the aforementioned GPS module.



Fig. 7 ESP32-S3 edge device.

Objective: To address payload constraints, the “Continuous Scan” approach, which acquires a maximum of four MAC addresses through overlapping scans in two separate transmissions, was tested for its effectiveness in improving positioning accuracy within a 110-m sectional environment.

Method: Data was collected in a 110-m section (11 points at 10-m intervals) under consistent conditions that simulated stopping every 10 m. Two methods were compared based on the minimum error reported by the Here API: “Single Scan (transmitting a maximum of two MACs per location)” and “Continuous Scan (scanning twice per location to transmit a maximum of four MACs).”



Fig. 6 110-m section comparison experiment environment

Summary of Results: In the Single Scan method (two MACs transmitted), the Here API lacked sufficient information to accurately determine the location, resulting in a failure to acquire data at eight of 11 points. At the remaining three points where positioning was successful, the average error was 26.5 m, with a median error of 25.3 m. By contrast, the Continuous Scan method (maximum of four MACs transmitted) successfully determined locations at all 11 points, achieving a 100% acquisition rate. Furthermore, the location information error improved, with an average of 25.8 m and a median of 19.2 m. These results indicate that an accuracy level comparable to standalone GPS can be achieved, and that the dynamic collection of multiple MACs in two stages is an effective strategy for significantly enhancing both the “positioning success rate” and “accuracy” within Sigfox’s severe payload constraints.

Figure 9 illustrates the measurement results for the 110-m section at 10-m intervals. True coordinates are indicated by blue pins, single scan results are shown in orange, and continuous scan results are in red, accompanied by their respective accuracy radii. The single scan (orange) exhibited failures at numerous points, resulting in scattered data, whereas the continuous scan (red) is consistently plotted near the true coordinates (blue) at all points, visually demonstrating its superior tracing capabilities as a trajectory.



Fig. 9 Plot of actual coordinates and positioning results in the 110-m section (single vs. continuous).

Table 1: presents the actual measured errors for each positioning method across the 110-m section (11 points in total). Entries marked with “-” in the Single Scan column denote points where positioning was not possible, as the Here API did not return coordinate data due to insufficient information.

Point Name	Single Scan Error (m)	Continuous Scan Error (m)	Accuracy Improvement (m) / Notes
Point 1	-	67.9	Acquisition Improved
Point 2	-	73.6	Acquisition Improved
Point 3	-	5.5	Acquisition Improved
Point 4	15.3	17.9	-2.6
Point 5	25.3	27.2	-1.9
Point 6	39.0	27.8	11.2
Point 7	-	11.0	Acquisition Improved
Point 8	-	23.8	Acquisition Improved
Point 9	-	4.4	Acquisition Improved
Point 10	-	5.5	Acquisition Improved
Point 11	-	19.2	Acquisition Improved
Average	26.5	25.8	-
Median	25.3	19.2	-

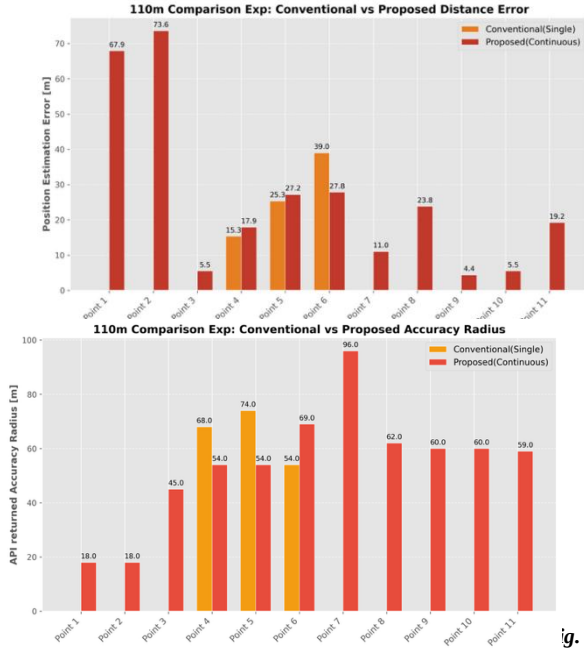


fig. 10

Comparison of error and accuracy radius under the positioning method

Through the implementation of the aforementioned methodology, which relies on operational ingenuity at the Sigfox device end (Continuous Scanning combined with rough received signal strength indicator (RSSI) filtering), the acquisition rate significantly improved, resulting in a positioning accuracy refined to approximately 19 m.

B. Verification of Effectiveness during Continuous Walking (3 and 6 km/h)

Objective: To assess the feasibility of achieving highly accurate positioning by dynamically collecting and merging four MAC addresses while walking continuously at a constant speed.

Method: Positioning data was gathered within the same 110-m segment while moving at “Low-speed Walking (approximately 3 km/h)” and “High-speed Walking (approximately 6 km/h).” Two sequential messages, each transmitting two MAC addresses, were merged into a single group (with a maximum of four MACs at the backend). The estimated coordinates and accuracy radius were then calculated using the Here API.

Results and Discussion: Table 2 lists the positioning results for each group during continuous walking. When walking at a low speed of approximately 3 km/h, all three groups achieved successful positioning. Notably, Group 1 demonstrated a high precision, namely, a radius of 18 m, which is comparable to standalone GPS positioning. However, a significant issue was noted: when comparing the estimated coordinates (latitude and longitude) to the actual starting point of the walk, Group 1 exhibited a spatial offset exceeding 50 m. This discrepancy was not due to measurement errors from the device; rather, it indicated that the physical locations of the MAC addresses (access points) used by the Here Positioning API did not align with their true real-world positions. Thus, whereas the API reported a location with “high confidence” (an 18-m accuracy radius), inherent biases or deviations in its reference database remained. By contrast, during high-speed walking at approximately 6 km/h, the accuracy radius for Group 1 increased significantly to 89 m. At this speed, equivalent to 100 m per min (approximately 1.67 m/s), the subject covered the entire 110-m section in just 66 s. Given that the subject had already advanced nearly 100 m during the time spent transmitting multiple messages via Sigfox (including scanning intervals), achieving a location “within an 89-m radius” using dynamically acquired MAC addresses represents a sufficiently high and practically effective accuracy considering the speed of movement.

Table 2: Positioning results for each group during continuous walking.

Walking Speed	Group	Transmission Count	Estimated Lat	Estimated Lng	Accuracy Radius(m)
Approx. 3 km/h	Slow ①	4 MACs	34.38839	132.49108	18
Approx. 3 km/h	Slow ②	4 MACs	34.38852	132.49209	65
Approx. 3 km/h	Slow ③	4 MACs	34.38868	132.49221	68
Approx. 6 km/h	Fast ①	4 MACs	34.38869	132.49235	89

Figure 11 plots the positioning data recorded at each walking speed while continuously scanning along the 110-m route. (The blue line represents the actual 110-m path; green pins indicate Slow Walking; purple pins denote the positioning results and accuracy radius for Fast Walking). The visual representation confirms that data acquisition remains consistently successful even during motion.



Fig. 11 Positioning results plot during continuous walking (3 and 6 km/h)

These results validate that the method of merging multiple scans operates effectively while in motion, achieving a reasonable positioning accuracy (ranging from tens of meters to approximately 10 m) relative to walking speed.

To address coordinate fluctuations (discrepancies in accuracy between groups) caused by walking, to achieve a more advanced and consistent improvement (ensuring errors remain under 10 m), and to cope with mobile APs (e.g., smartphone tethering), detailed data accumulation and thorough analysis on the backend (e.g., AWS) are essential. Therefore, to capture nuanced WiFi data that the device alone cannot interpret and to utilize this for constructing whitelists, the custom Here API Validation Tool was developed.

C. Detailed Investigation of the WiFi Environment using NetSpot

To enhance the accuracy of the Here Positioning API, NetSpot was employed to conduct thorough scans of the WiFi environment in the target area. This process effectively gathers the MAC addresses, SSIDs, and RSSI profiles of all nearby access points.

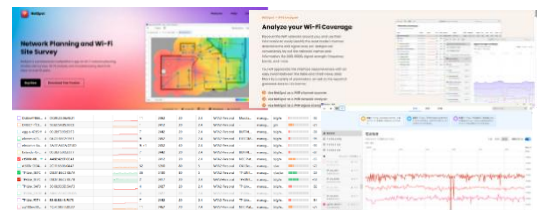


Fig. 12 NetSpot WiFi environment map, heatmap, SSID list, and time-series graph

From the data collected from NetSpot, such as the quantitative distribution of APs detected at each location, the localized signal

strength patterns, and the temporal stability of APs, the essential baseline data was established for the subsequent analytical phases.

D. Development of the Here API Validation Tool (WiFi Positioning Validator)

To support whitelist registration and advanced accuracy-enhancement measures in the upcoming backend (e.g., AWS), a robust validation tool (WiFi Positioning Validator) was autonomously developed. This tool automatically queries the Here Positioning API with the MAC address sets obtained from NetSpot and calculates the positional error relative to the actual coordinates. The tool includes the following key features:

- Queries the API with various combinations of MAC addresses to determine the coordinate error compared to the ground truth.
- Visualizes the “Contribution Parameter” for each MAC address, indicating how much each AP affects tracking accuracy.
- Analyzes systemic errors in orientation (directional bias vectors).
- Compiles error statistics from various waypoints into comparative analyses.

Through this validation tool, a thorough accuracy audit was conducted. The complete MAC address repository from the NetSpot data, mapped at the same 11 waypoints used in the Continuous Scan experiment, was input into the live Here API. The interface schematics and detailed analytical visualizations for Waypoint 1 are presented in Figs. 13–15.

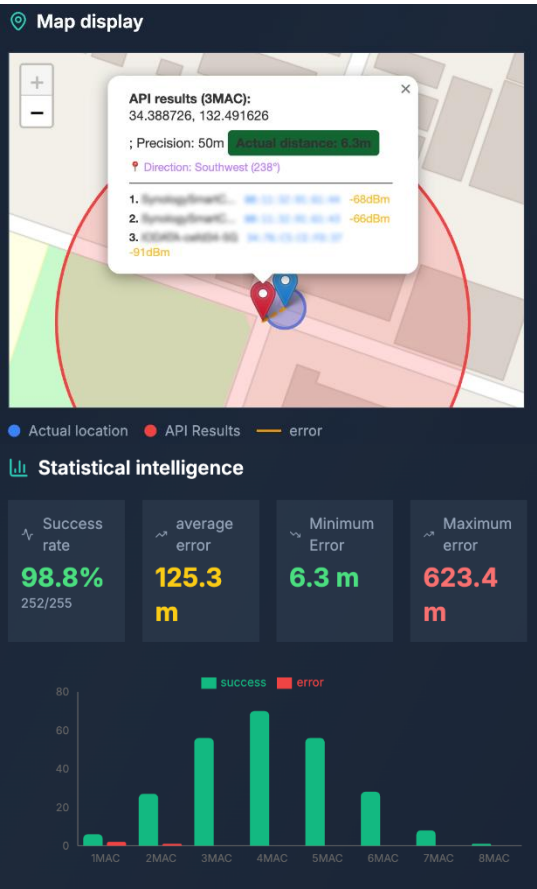


Fig. 13 Top screen and statistical data of the custom-developed Here API Validation Tool

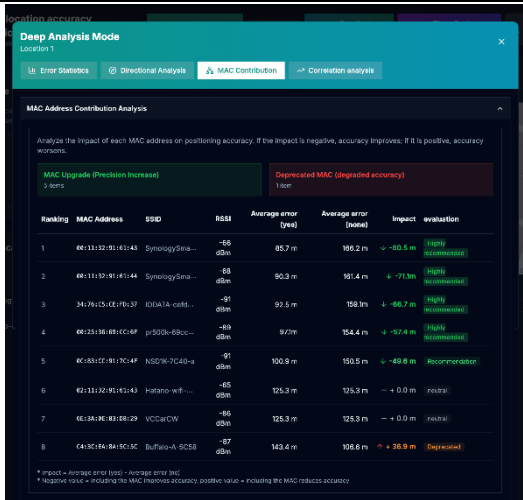


Fig. 14 Analysis of the MAC address contribution to error at Point 1

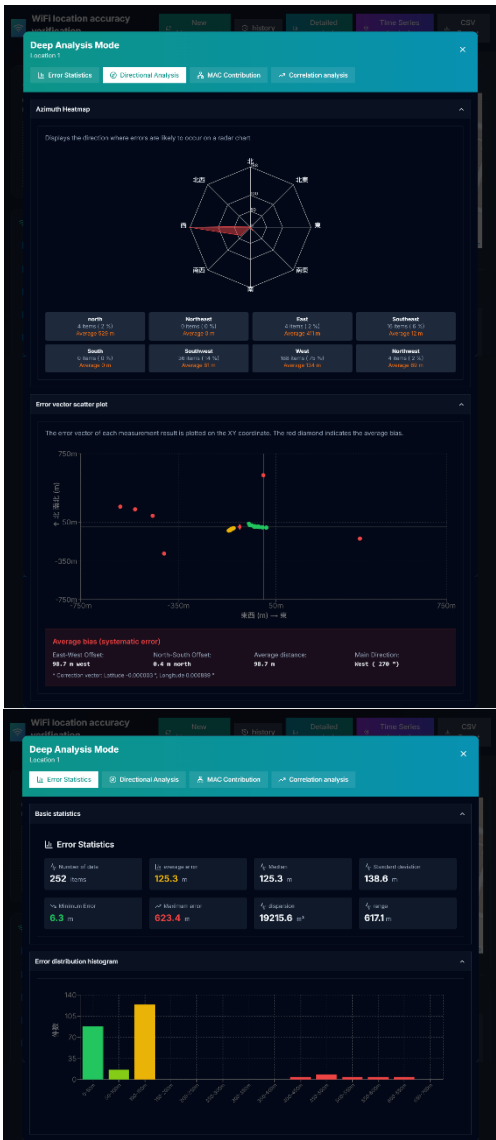


Fig. 15 Bearing analysis and detailed statistical graphs at Point 1

E. Implementation of Proactive Prefiltering on the Device (ESP32-S3)

To improve positioning accuracy at the device level, unique prefiltering and screening architectures were integrated and validated on the edge device (execution environment: ESP32-S3) prior to transmission over Sigfox.

Absolute Exclusion of LAA and Mobile OUIs

- **Mechanism:** During the ESP32-S3 WiFi scanning protocol, randomly generated MAC addresses (LAA: locally administered addresses) and OUIs (vendor codes) associated with mobile devices, which are prone to displacement via tethering, are strictly removed from the MAC cache.
- **Implementation Strategy:** Inspect the first octet of the MAC address to instantaneously identify and discard LAAs (where the second character is 2, 6, A, E). Maintain a dedicated blacklist of mobile OUIs within the ESP32 to continually eliminate MAC addresses originating from mobile terminals that match the blacklist.
- **Empirical Substantiation via the Validation Tool:** The Waypoint 1 audit, conducted with the designated validation tool, conclusively demonstrated that MAC addresses categorized as LAA have no effect on the Here API's positioning calculations (resulting in an error contribution of 0 m). In simpler terms, including these addresses in the limited Sigfox payloads (which allow two to four inputs) constitutes a complete waste of bandwidth. Therefore, a reliable local discard logic on the device side is essential.

Triage Optimization by Apex RSSI

- **Mechanism:** After passing through the filtration process, the most powerful APs, which emit the highest RSSI (signal strength), are prioritized for data transmission.
- **Implementation Evaluation:** Although the ESP32-S3 has sufficient computational bandwidth and memory (SRAM/Flash), the core protocol developed for this validation primarily focuses on applying a simple descending sort based on RSSI values to the filtered array (after LAA/OUI exclusion). Only the top-ranking APs are then used in the payload sequence.

F. Experiment 1: Correlation between MAC Address Volume and Positioning Accuracy

Objective: To quantitatively assess the extreme limits of positioning accuracy defined by the 2-unit Sigfox constraint and to identifying the necessary threshold for MAC address inclusion.

Method: The validation tool was used to incrementally increase the volume of MAC addresses injected uniformly across all 11 waypoints, carefully recording and compiling the changes in positioning error.

Summary of Results: Data collected from all 11 waypoints revealed an average error of approximately 112 m when restricted to a 2-unit injection limit, significantly below the expected GPS accuracy of approximately 10 m. Notably, increasing the MAC address payload resulted in a significant improvement in accuracy, peaking at an average error of approximately 36 m, the most stable level of accuracy observed, with the injection of four units. However, raising the throughput threshold to eight units resulted in an average error of approximately 38 m, indicating a plateau (and slight regression) in accuracy improvement. This decline can be attributed to the introduction of distant, weak signal APs (ambient noise) that distort the API's estimation process. This finding underscores that optimal preprocessing logic is not achieved by simply increasing the volume of data but by methodically isolating and querying the optimal echelon of approximately four "superior-quality" MAC networks with maximum broadcast resilience.

G. Experiment 2: Accuracy Elevation through Rigorous MAC Quality Segmentation

Objective: This study aims to evaluate the exact kinetic effects of the "Qualitative Fidelity" of injected MAC addresses on terminal positioning accuracy and to develop optimized selection criteria.

Method: Implement and assess the following three-segment taxonomy to compare raw accuracy differentials.

Segmentation Protocol	Analytical Architecture	Formulated Expectation
RSS Filtration Pivot	Exclusive utilization of top N units displaying paramount RSSI vectors	Primacy applied to hyperstable adjacent arrays
Mobile AP Eradication	Systemic excision of mobile APs classified by chronological manifestation flux models	Eradication of unstable geographical transients
Contribution Diagnostics	Algorithmic calculation of individual MAC liability parameters to ostracize detrimental arrays	Radical deprecation of systemic bias

Summary of Results: Utilizing a foundational RSS filtration baseline (top eight units) combined with rigorous mobile AP excision led to a remarkable increase in accuracy, closely aligning with the 10-m radius target. In addition, applying the "Contribution Diagnostics" protocol from the validation tool to the Waypoint 1 datasets revealed a concerning finding: the integration of specific isolated APs (e.g., C4:3C:EA:...) increased the average coordinate error by a significant 37 m. This serious issue is identified with high certainty as a "corrosive rogue AP," incorrectly logged within the overarching database, and is directly responsible for the "50-m+ locational displacement" documented during the continuous traversal phase near Waypoint 1 in Chapter 4.2. By utilizing this tool, designed specifically to detect and blacklist rogue AP vectors from the operational backend, we can effectively eliminate large-scale systemic deviations from the positioning lifecycle.

H. Experiment 3: Calibration of Systemic Error (Azimuth Bias)

Objective: To create comprehensive error vectors based on azimuth orientation derived from successive positioning outputs and to develop correction matrices that optimize maximum theoretical precision.

Method: Calculate statistical azimuth error vectors from extended multi-point positional outputs to create a dynamic algorithmic bias-correction framework. Assess its overall effectiveness by comparing spatial dispersal matrices before and after calibration.

I. Experiment 4: Spatial Trajectory Filtration Using Chronological Data Clusters

Objective: To address dynamic transit-tracking paradigms by using chronologically ordered positional clusters to eliminate outlier anomalies and enhance tracking precision trajectories.

Method: Conduct iteratively staggered positioning bursts over the Sigfox substrate, then apply trajectory constraints (such as advanced Kalman filters). Analyze whether this temporal matrix yields significantly improved trajectory stabilization compared to isolated point-estimation sequences by incorporating logical movement constraints (e.g., pedestrian velocity limits of ≤ 5 km/h) to physically mitigate erratic positional spikes.

J. Comprehensive Synthesis of Precision Enhancement Frameworks

Based on the empirical findings of this research, the essential methodologies required to overcome the significant Sigfox 2-MAC payload limitations and achieve accuracy levels comparable to GPS paradigms (sub-10-m limits) are outlined as follows:

1. **Device-level Architecture Triage (Continuous Scan Implementation):** Implement staggered, two-stage sequential scanning clusters combined with macroscopic RSSI truncation at static waypoints to significantly increase MAC throughput (up to four apex-tier inputs), thereby eliminating the high positioning attrition rate seen in single-scan applications and stabilizing coordinate isolation medians at approximately 19 m.
2. **Propulsive Dynamic Scan Integration:** Coupling messages to transmit up to four MAC arrays consistently maintains exceptionally sharp localized accuracy (with minimal extremes at approximately 18 m), matching static orientations, even during movement at speeds of up to 3 km/h.
3. **Backend Algorithmic Tier Segmentation:** Isolate erratic mobile arrays from the device using cloud-based (AWS) whitelisting mechanisms informed by comprehensive WiFi contextual analysis (Here API Validation Tool benchmarks).
4. **Calibration Protocol of Systemic Discrepancies:** Dynamically reduce macro-errors through the azimuth-oriented bias correction framework.
5. **Chronological Filtration Models:** Suppress outlier spikes using dynamic trajectory velocity matrix constraints.

Recently published studies demonstrate that machine learning strategies are improving the accuracy of localized indoor WiFi coordinate estimation to a mean absolute error of approximately 1 m[8]. The advanced filtration techniques and comprehensive modeling approaches discussed here are essential steps toward the next level of location estimation technology.

Integration Potential with the Atlas WiFi Private DB Initiative

In addition to proprietary network applications, a significant opportunity emerges when rigorously verified high-reliability APs are registered in the formal administrative registry of the Sigfox Atlas WiFi Private DB initiative. This could lead to significant improvements in both the overall success rate and accuracy of their official public platform infrastructure.

5. Conclusion

This research addressed the persistent challenges in positioning accuracy caused by the limitations of payload architecture (restricted to two MAC addresses) in custom Sigfox-based WiFi localization systems. The “Continuous Scan” algorithm was introduced as a corrective protocol for devices stationed at fixed waypoints every 10 m. By overlapping multiple transmissions, this protocol enables the dynamic use of up to four MAC addresses, which effectively eliminates the significant failure rate associated with single-scan attempts (which exhibited an approximately 70% failure margin under test conditions) resulting in precise coordinate isolation at each waypoint and stabilizing the overall positional median at approximately 19 m. In addition, empirical tests involving continuous walking at speeds of approximately 3 km/h confirmed that chaining as many as four MAC addresses consistently yields practical and efficient accuracy in dynamic mobile tracking scenarios. This validates the robust functional capability of the system. Critically, data accumulation combined with macro-analytical processing on a centralized backend is vital for achieving greater accuracy levels (maintaining within 10-m thresholds). To this end, we propose a strong MAC address segmentation strategy driven by extensive WiFi environmental analysis using NetSpot, in conjunction with our custom-built Here API Validation Tool. By incorporating the empirical filtering logic validated by this toolset, such as aggressive RSS filtering, elimination of mobile AP profiles, recalibration of systemic biases,

and longitudinal tracking models, into the backend network implementations (e.g., AWS whitelists) and aligning it with the edge device’s continuous scanning infrastructure, we aim to deliver highly stabilized coordinate projection operations that match or exceed the performance of traditional standalone GPS methodologies.

6. References

- [1] B. W. Remondi, “Global positioning system carrier phase: Description and use,” *Bulletin Géodésique*, vol. 59, no. 4, (1985) pp. 361-377.
- [2] U. Raza, P. Kulkarni and M. Sooriyabandara, “Low power wide area networks: An overview,” *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, (2017), pp. 855-873
- [3] <https://docs.arduino.cc/hardware/uno-rev3> (March 1, 2026)
- [4] <https://unabiz.github.io/unashield/hardware.html> (March 1, 2026)
- [5] <http://akizukidenshi.com/catalog/g/gK-09991/> (March 1, 2026)
- [6] T. Tanaka, N. Okamitsu, and K. Nishino, IoT device with Global Positioning System using Sigfox, ThingSpeak, and Anaconda platform, *E+E*, vol. 55, (2020)pp. 94-98.
- [7] M. Watanabe, S. Ohji, T. Ishikawa, Y. Ueda, S. Tada, R. Masumoto, M. Yamauchi, K. Kakugawa, T. Tanaka, and K. Vutova, “Location estimation using Wi-Fi media access control address and device miniaturization”, *Industry 4.0*, vol. 10, no. 2, (2025) pp. 43-46.
- [8] H. Esmaeili Gorjan and V. P. Gil Jiménez, “Improving indoor WiFi localization by using machine learning techniques,” *Sensors*, vol. 24, no. 19, (2024) p. 6293.

Reconnoitering implementation barriers of industrial symbiosis through social and economic kpi's: a comparative analysis approach

Blisard Zani¹, Almudena Muñoz Puche²

University of Tirana, St. "Arben Broci" 1001, Albania¹

Centro Tecnológico del Mueble Y la Madera (CETEM), C. de Perales, S/N, 30510, Spain²

blisard.zani@unitir.edu.al; a.munoz@cetem.es

Abstract: Industrial Symbiosis (IS) is currently seen as one of the most avantgarde concepts embracing circularity and business cooperation in almost all economic sectors. Industrial Symbiosis processes are novel concepts compared to traditional business models with profit based and business oriented. This paper aims to present key findings and insights from Poland and Albania, both in early stages of IS implementation, as a study within LIAISE COST Action framework. Since the industrialization process for both countries have had similar patterns from their centralized past, they face nowadays similar challenges and barriers. Using a comparative quantitative approach, the findings highlight shared obstacles, including high investments costs, limited awareness of IS benefits, low trust among firms, insufficient coordination mechanisms, and constrained access to finance for collaborative investments. This paper also suggests the importance of tailored policies for each country, as well as the importance of support from public institutions.

Keywords: CIRCULAR ECONOMY, INDUSTRIAL SYMBIOSIS, SOCIO – ECONOMIC BARRIERS

1. Introduction

Traditional linear economic models have grown critical concerns related to overall and long-term impact on environmental and social sustainability. The growth of Industry 4.0 and 5.0 has imposed obligatory shifting from traditional linear model to circular economic concepts [23]. Making the 'circular transition' requires understanding the whole new business processes, as well as adopting novel methods to increase profitability [11]. In order to further advance into circularity, the role of industrial symbiosis implementation has emerged as a pivotal point. Within this logic framework, the circular economic system is becoming 'the ideal option' fitting all the requirements, in order to enhance waste reduction and resources prevention [22].

Industrial Symbiosis processes are new and avantgarde concepts compared to traditional business models with profit based and business oriented. Poland and Albania, traditionally come from a past linked to the centralized economy, totally oriented by the state control and organization, that has not allowed the process of industrialization to be normalized as in Western European countries and other advanced economies [10, 13, 20, 27]. After late '80s, Poland and Albania started their economic transition shifting from state-controlled economy to a market-oriented one. However, their path toward transition has not been the same. Due to their differences in size of economy, country area, population and technologic development, Poland passed the transition period way faster compared to Albania [3, 9]. In Albania, still nowadays, the country has negligible and insignificant amount of industrial contribution to the economy, with a very low percentage of industries contributing into Gross Domestic Product (GDP). From the difference's perspective, and from the past similar economic models, this has been one of the reasons while we chose to see the Industrial Symbiosis perspective in these two countries.

This paper aims to present the current situation of Industrial Symbiosis (IS) implementation in Albanian and Poland, exploring familiarity and perceptions about it. Moreover, the authors explore primary data collected by dedicated questionnaires in Poland and Albania, estimating the main economic barriers and obstacles hindering industrial symbiosis implementation. From more than 100 responses in both countries, quantitative data with Likert scale are being used to measure the main socio – economic barriers of industrial symbiosis implementation in Albania and Poland. Key findings emphasize the similarity in approach related to the vast majority of barriers, yet differences are seen in several of them.

High investment costs, insufficient funding sources, minor business collaboration, as well as financial inability to adapt industrial symbiosis projects are ranked as the most influential ones for Albania and Poland, even though with slight differences. Meanwhile, the lack of human resources, geographical barriers, lack of public awareness and legislative framework barriers are

evaluated as focal points for industrial implementation from social and environmental aspects.

The paper starts with a brief introduction of the concept of industrial symbiosis, followed by a dedicated literature review section exploring the authors' viewpoint for specific barriers and obstacles hindering industrial symbiosis. Then, the methodology section explores the main approaches related to statistical data analysis, as well as comparison between two countries data. The next topic summarizes the main key findings and discussion of data. The paper closes with the conclusion and recommendations.

2. Literature review

The rise of the industrialization process and urbanization in the last decades has led to an increase in carbon dioxide emission [16]. This has increased the attention of researchers trying to find alternative ways of cooperating, to reduce carbon emissions, also contributing to the reduction and waste management. Pioneers such as Chertow and Desrochers has predefined the concept of industrial symbiosis, as an alternative viewpoint of economy as a whole, as industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products [5]. Lawal and other authors has also emphasized the importance of industrial symbiosis and its relation to sustainability and industrial ecology [16]. Industrial symbiosis has now been documented in all continents, with sporadic or standardized cases [17]. Chertow and Ehrenfeld developed a 3-stage theory for IS, beginning with the synergy of the actors involved in IS [5].

The last decade has shown an immense improvement in adapting novel approaches to circularity in Poland and Albania. The industrial sector is way more developed in Poland, compared to Albania, due to several factors impacting the process like geographical conditions, country's size, population, industrial inheritance from past, etc. Nowadays, circular economy is developing rapidly in Poland, especially in regions like Małopolska [23]. The authors have also confirmed that the public awareness is still not one of the major forces embracing circular economy in Poland. Other late studies affirms the role of technological drivers and innovation as key players in emphasizing the importance of circular economy in Poland [4, 7].

The situation of circular economy in Albania is however still in its early stages, being implemented only in few sectors like light food industry, wood industry, livestock farming, etc. Late studies have confirmed that the readiness of Albanian consumers is still in low and moderate levels, thus hindering the circular economy [8], [19], [21].

As the economic cycles are considered now more and more dynamic, the implementation of IS faces significant barriers and challenges. These obstacles are related to all phases of

implementation, starting from understanding the importance of IS, technical aspects of implementation, socio – cultural barriers, etc. The barriers and obstacles of IS are analyzed from several authors, emphasizing the role of governments and learning from case studies, thus reducing the implementation challenges [18]. Previously, Islam et. Al has also emphasized the importance of clear policies to support IS implementation [12]. Neves et. Al noticed that the diversity of industries, geographical proximity, facilitating entities and legislation, plans, and policies are shown to be the main barriers of IS implementation. From the business perspective, the organizational challenges are most significant in the journey towards IS [28]. In addition, during IS Implementation, some firms are oriented by maximizing their own profit creating bilateral agreements [1]. Moreover, the latest studies also mention the lack of technology and infrastructure readiness as one of the most important barriers on IS implementing, especially in manufacturing industry [18, 24].

Industrial symbiosis, as a powerful tool promoting circularity, is now becoming more and more documented in crucial sectors in economic activity of Poland. Various studies have now documented the implementation of industrial symbiosis cooperation in dedicated industrial parks [14]. Industrial Symbiosis is becoming present in sectors like meat waste industry, sustainable energy parks, local communities, etc. [6, 7, 15]. It is also more present in urban regions, as well as promoting local government initiatives [7].

Notwithstanding, the industrial symbiosis cases are almost inexistent in Albanian economic framework. There are several businesses operating within circular economy framework but not fully implementing industrial symbiosis principles. Moreover, there are also very few studies dedicated to industrial symbiosis in Albania, aiming to identify main barriers and obstacles of IS implementation [25, 26]. Circular economy principles are more evident as part of decarbonization initiatives from specific businesses, with focus on food industry, metal production, and construction sector [1, 2].

3. Methodology

For methodological purposes of primary data collection, two dedicated questionnaires were conducted to gather data from Poland and Albania, in order to create a comparative approach of how business managers, professionals and other stakeholders' percept the level of IS implementation barriers. The questionnaires were shared among professionals predominantly with economics backgrounds, followed by others with juridical, engineering and information technology education. The questionnaires were identical for both countries, and are compounded by three different sections:

- General indicators impacting IS implementation;
- Social barriers that hinder IS implementation;
- Economic obstacles that challenge IS implementation.

The vast majority of questions related to IS implementation barriers are based on the obstacles that have been identified by late studies and research, with information provided in the 2. Literature review, with focus on exploring the most important barriers that hinder industrial symbiosis from Economic and Social Key Performance Indicators (KPIs).

The dataset of more than 100 responses per country is being structured and adapted to better in-depth present the key findings from this study. As a precondition for primary data, some statistical tests for data significance and general descriptive statistics are provided below. Some of the questions are structured as a Likert scale estimation, to measure the perception of the importance of some factors.

3.1 Descriptive statistics of IS in Poland and Albania

Since the implementation of industrial symbiosis remains quite an avantgarde concept, there are no major datasets that have collected information dedicated to Poland or Albania. In that context, the two separate questionnaires prepared for this paper contribute to additional primary information related to IS. The questions reflect the main barriers and hinderances taken into consideration by the literature review process, enhancing the obstacles for developing countries in implementing industrial symbiosis. The questionnaires were shared anonymously with target groups for more than 9 months, collecting more than 230 responses [200 after data cleaning and outliers removing].

After the dataset were cleaned in R programming language (by removing n/a and error missing data), the two datasets for each country were merged to measure the consistency and stability of data, in order to have a preconfirmation for later use. One of the most used tests for data consistency and stability is the measurement of Cronbach's alpha. As measured, the Cronbach's alpha for the merged dataset [hereby: *IS_dataset*] was estimated to **0.82**, indicating a high-level of internal consistency in dataset. In this logic, this data can be used for further analysis.

Table 1: Cronbach's Alpha for IS dataset in Albania and Poland

Raw_alpha	std.alpha	avg_r	s/n	mean	sd	median_r
0.82	0.81	0.27	5	3.6	0.5	0.25

(Author's calculations in RStudio software)

From the first section of general questions, there are slightly different responses related to the familiarity, the types of industries with more potential on implementing Industrial Symbiosis, the main initiatives undertaken etc. The level of familiarity in Poland is relatively higher (68%), compared to the Albanian professionals and business managers that have knowledge about IS (56%). Additionally, the main industries precepted with the highest potential implementing IS in Albania are being considered the waste management sector, followed by the paper and pulp processing industry. In Poland the sector with the highest potential is being considered waste management sector, followed by the food and beverage industry.

In both countries, educational initiatives, as well subsidies for recycling are seen as the most effective ones, having high similarities in responses. Furthermore, in Albania, the corporates and big industries are seen as the main promoters, while in Poland the public institutions are seen as the most impactful ones (in Albania it is ranked as the second impactor). In Albania, more than 75% think that corporates can be the key-player, due to high potential of big companies to be involved in industry. These differences also reflect the strong institutional presence of the concept of state in the past for both Albania and Poland, which still estimate the role of government as crucial in promoting new economic initiatives.

Table 2: Differences in perception for IS general concepts in Albania/ Poland

Factor	Albania	Poland
Familiarity of IS	56%	68%
Important sectors	Waste Management Paper/ Pulp Industry	Waste Management Food and Beverages
IS promoters	Educational Initiatives Subsidies	Educational Initiatives Subsidies
Economic agents	Big Industries Public Institutions	Public Institutions Corporates

(Authors' data preparation)

4. IS barriers discussion and analysis

4.1 Social barriers for industrial symbiosis implementation

There are several obstacles that hinders industrial symbiosis implementation in daily economic activities. Even though the vast majority of businesses are being positive on having the willingness to adapt more IS principles, yet they face social and economic barriers. The main social barriers on implementing IS are listed as below:

- Local culture
- Lack of information about industrial symbiosis
- Public awareness about industrial symbiosis
- Geographical conditions/ proximity

Local Culture

The local culture is one of the most important social barriers that creates a continuous problem on not promoting the industrial symbiosis in desirable levels. The chart below presents the perception for Poland and Albania.

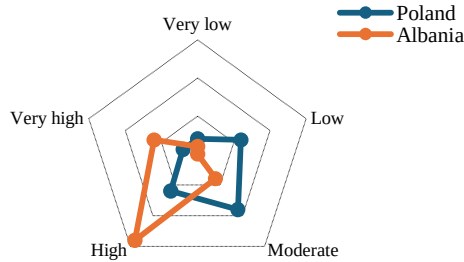


Chart 1: Local culture differences on IS for Albania and Poland

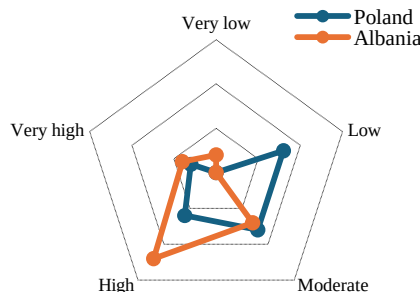
Local culture is being precepted predominantly with low to moderate impact, while in Albania, business managers and professionals see it majorly with high impact. This is the first difference between perceptions on IS. Due to lack of information (as another factor affecting implementation of IS), in Albania the local culture is seen as a more important factor.

Lack of information about IS

Following the first social barrier, the lack of information about the industrial symbiosis also tends to create obstacles for further promotion of IS. There are still differences in perception about this factor. In Albania, this is also being considered as an important factor, with most respondents ranking it as a high level, while in Poland, the lack of information is being precepted with low – moderate impact.

Chart 2: Lack of information about IS differences for Albania and Poland

Public awareness and sensitivity about environmental and



economic aspects plays also a very important role in enhancing the power of circular economic concepts and particularly industrial symbiosis. However, public awareness perception has also slightly different responses comparing Albania with Poland. In Albania, public awareness about these concepts is being considered with high and very high levels of importance, while polish professionals and business managers think that this social barrier have lower impact. Even though the level is lower compared to Albania, in

Poland this factor is still estimated with moderate to high importance.

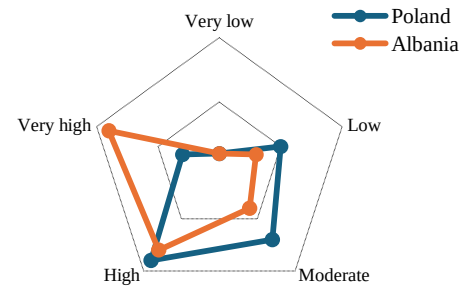


Chart 3: Social

awareness differences on IS for Albania and Poland

Geographical barriers

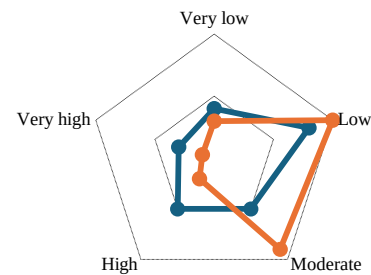


Chart 4: Geographical barriers differences for Albania and Poland

The change in the geographical features of a country can heavily influence the further development of industrial symbiosis, due to the importance of proximity of businesses to each other, in order to reduce costs of transportation and logistics. In that context, the geographical conditions of both Albania and Poland are not precepted as an important barrier to hinder IS, thus having low impact on IS implementation. The reason, however, is different for both countries. In Albania, the geographical barriers are estimated with low to moderate impact, due to small size of the country, while in Poland it is estimated to have low impact due to favorable terrain and physical conditions, with considerable plains and no mountains to hinder business cooperation.

4.1 Economic barriers for industrial symbiosis implementation

Beside the social aspects impacting industrial symbiosis, there are also economic indicators that can either enhance, or hinder the industrial symbiosis processes. There are several economic barriers [identified from literature review] that can create obstacles to IS, but the main factors identified are listed as below:

- Insufficient funding
- Cost of investments
- Minor business collaboration
- Inadequate fiscal regulations

These barriers are also precepted in similar viewpoint, yet with small differences on them.

Insufficient funding – Cost of investment

The process of adapting new business technologies and processes requires high capital investments. It is closely related to investing in new machineries, production lines, new implants, etc.

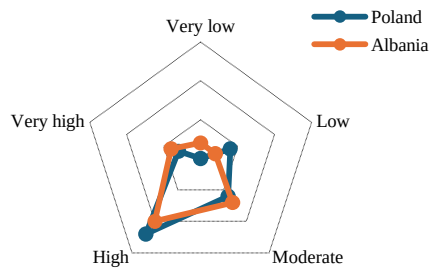


Chart 5: Insufficient funding barrier on IS implementation

Insufficient funding is seen almost identically in Poland and Albania, having high importance to impact IS. This reflects the business logic that is almost the same in both countries. Moreover, there are no responses that evaluate the funding barrier with very low or low impact.

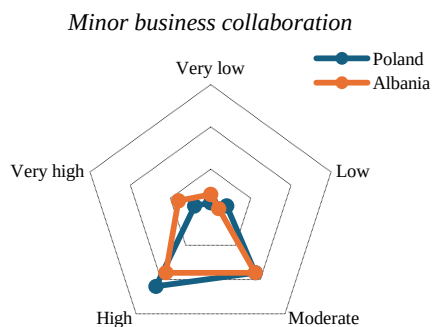


Chart 6: Business collaboration barrier in Albania and Poland

The level of business collaboration is also a barrier that is estimated almost identically in Albania and Poland, having moderate to high impact. In some cases, the minor collaboration between businesses does not derive from the unwillingness of businesses to collaborate, but due to the lack of information about other businesses offering by-products or waste that can be used as an input.

Inadequate fiscal regulations

Fiscal regulations can also influence the further industrial symbiosis implementation. Businesses dealing with IS and circular economy are expecting fiscal ease in terms of tax exemptions, subsidies, reimbursements, etc.

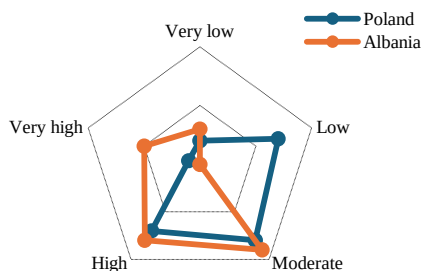


Chart 7: Inadequate fiscal regulations as barrier for IS

Fiscal regulations are precepted as a barrier with moderate to high impact in Albania, while in Poland there is no clear trend on

what professionals and businesses think about business collaboration.

4. Conclusions and recommendations

Industrial symbiosis, as a relatively new economic concept is closely related to the circular economy. The collaboration between industries and businesses in local and regional context is seen as vital in the near future to prevent waste management, carbon emission reduction and other consequences with climate and environmental impacts. However, industrial symbiosis implementation in different countries face several barriers and obstacles. For analytical purposes, this study classified barriers and socio-economic factor to make a comparison between Poland and Albania. Technological barriers to IS implementation are significant and multifaceted. Investments in industry and local culture make it difficult for industries to adopt advanced solutions. Many organizations face insufficiently developed infrastructure and limited availability of advanced recycling technologies, hindering resource exchange. Additionally, lack of public awareness and inadequate regulations further hinder industrial symbiosis in Poland and Albania, seen similarly in both countries. Poland as EU member has made significant progress on IS regulations and implementation in several industries in the agricultural sector, service industry, processing industries, etc. However, there are neglectable cases in Albania adapting industrial symbiosis concepts. Albania, as a non-EU country still faces highly important barriers related to the factors mentioned above, combined with the slow adaptation culture of circular economy and recycling. High promotion of IS via media and other channels, fiscal incentives for companies adapting processes of IS, increased capacities and technologies for IS implementation are highly recommended, to ease the implementation of industrial symbiosis.

Acknowledgment: The authors gratefully acknowledge the support of LIAISE COST Action CA22110 “Cooperation, development and cross-border transfer of Industrial Symbiosis among industry and stakeholders”, under the COST Association framework (European Cooperation in Science and Technology), funded by the Horizon Europe Framework Program of the European Union.

4. References

- [1] Alcani, M., Bebi, E., Gjeta, A., & Dorri, A. (2024). Decarbonization of the Industrial Sector in Albania. Problems and Challenges. In G. Guxho, T. Kosova Spahiu, V. Prifti, A. Gjeta, E. Xhafka, & A. Sulejmani (Eds.), *Proceedings of the Joint International Conference: 10th Textile Conference and 4th Conference on Engineering and Entrepreneurship* (pp. 234–243). Springer Nature Switzerland.
- [2] Angelis-Dimakis, A., Arampatzis, G., Alexopoulos, A., Vyrkou, A., Pantazopoulos, A., & Angelis, V. (2022). Industrial Symbiosis in the Balkan-Mediterranean Region: The Case of Solid Waste. *Environments*, 10(1), 1.
- [3] Belletti, M. (2015). The Emerging Role of the Peasant Economy at the End of the Industrial Age: Insights from Albania. *Procedia Economics and Finance*, 33, 78–89. [https://doi.org/10.1016/S2212-5671\(15\)01695-0](https://doi.org/10.1016/S2212-5671(15)01695-0)
- [4] Bogdan, A., Kledyński, Z., Lelicińska-Serafin, K., Rucińska, J., Zubrowska-Sudol, M., Jackiewicz-Rek, W., Machowska, A., Rolewicz-Kalińska, A., Manczarski, P., Walczak, J., Szczygielski, T., Wojtkowska, M., & Masłowska, D. (2020). Condition of Circular Economy in Poland. *Archives of Civil Engineering*, 37–80. <https://doi.org/10.24425/ace.2020.131820>
- [5] Chertow, M., & Ehrenfeld, J. (2012). Organizing Self-Organizing Systems - Toward a Theory of Industrial Symbiosis. *Journal of Industrial Ecology*, 13–27, Vol. 16, Issue 1 - <https://doi.org/10.1111/j.1530-9290.2011.00450.x>.
- [6] Czaplicka-Kotas, A., Kulczycka, J., & Iwaszczuk, N. (2020). Energy Clusters as a New Urban Symbiosis Concept for Increasing Renewable Energy Production—A Case Study of Zakopane City. *Sustainability*, 12(14), 5634. <https://doi.org/10.3390/su12145634>
- [7] Czerwionka, K., Kolečka, K., Kasprzyk, M., Fitobór, K., Wilińska-Lisowska, A., & Gajewska, M. (2025). Circular economy in Poland: Good practices and recommendations – case study.

- Journal of Ecological Engineering*, 26(3), 166–176. <https://doi.org/10.12911/22998993/199698>
- [8] Dionizi, B., Kalaj, E. H., & Avdullahi, A. (2025). Behavioral readiness for circular economy in Albania: A consumer perspective. *Frontiers in Sustainability*, 6, 1681357.
- [9] Domański, B. (2003). Industrial Change and Foreign Direct Investment in the Postsocialist Economy: The Case of Poland. *European Urban and Regional Studies*, 10(2), 99–118.
- [10] Gomułka, S. (2016). Poland's economic and social transformation 1989–2014 and contemporary challenges. *Central Bank Review*, 16(1), 19–23. <https://doi.org/10.1016/j.cbrev.2016.03.005>
- [11] Ingelsson, F., & Mellgren, M. (2020). From Linearity to Circularity - Enabling a Transition to Circular Business Models. Göteborg, Sweden: Chalmers University of Technology.
- [12] Islam, K., Rahman, M. F., & Islam, K. (2016). Industrial Symbiosis: A Review on Uncovering Approaches, Opportunities, Barriers and Policies. *Journal of Civil Engineering and Environmental Sciences*, 11-19, Vol. 2, Issue 1.
- [13] Kaser, M. (2001). Economic Continuities in Albania's Turbulent History. *Europe-Asia Studies*, 53(4), 627–637. <https://doi.org/10.1080/09668130120052926>
- [14] Kowalski, Z., Kulczycka, J., Makara, A., Mondello, G., & Salomone, R. (2023). Industrial Symbiosis for Sustainable Management of Meat Waste: The Case of Śmółowo Eco-Industrial Park, Poland. *International Journal of Environmental Research and Public Health*, 20(6), 5162. <https://doi.org/10.3390/ijerph20065162>
- [15] Kulczycka, J., Uberman, R., & Dziobek, E. (2020). Industrial Symbiosis for the Circular Economy Implementation in the Raw Materials Sector—The Polish Case. In R. Salomone, A. Cecchin, P. Deutz, A. Raggi, & L. Cutaia (Eds.), *Industrial Symbiosis for the Circular Economy* (pp. 73–86). Springer International Publishing. https://doi.org/10.1007/978-3-030-36660-5_5
- [16] Lawal, M., Alwi, S. R., Manan, Z. A., & Ho, W. S. (2021). Industrial symbiosis tools—A review. *Journal of Cleaner Production*, Vol. 280, Part 1 - <https://doi.org/10.1016/j.jclepro.2020.124327>.
- [17] Lombardi, D. R., Lyons, D., Shi, H., & Agarwal, A. (2014). Industrial symbiosis: testing the boundaries and advancing knowledge. *Journal of industrial ecology*, 2-7, Vol. 16, Issue 1 - <https://doi.org/10.1111/j.1530-9290.2012.00455.x>.
- [18] Lybæk, R., Christensen, T. B., & Thomsen, T. P. (2021). Enhancing policies for deployment of Industrial symbiosis – What are the obstacles, drivers and future way forward? *Journal of Cleaner Production*, Vol. 280, Part 2 - <https://doi.org/10.1016/j.jclepro.2020.124351>.
- [19] Marku, D., Minga, A., & Sosoli, I. (2024). Circular Economy Perspective and Implications for Livestock Farming in Albania. *The Open Agriculture Journal*, 18(1), e18743315312132. <https://doi.org/10.2174/0118743315312132240611074625>
- [20] Pashko, G. (1993). Obstacles to economic reform in Albania. *Europe-Asia Studies*, 45(5), 907–921. <https://doi.org/10.1080/09668139308412130>
- [21] Prendi, K., Elezi, B., & Murrja, A. (2024). Risks of Implementing Circular Economy Practices in Smes in Albania. *Interdisciplinary Journal of Research and Development*, 11(1 S1), 228. <https://doi.org/10.56345/ijrdv11n1s135>
- [22] Sanz-Torró, V., Cafalat-Marzal, C., Guaita-Martinez, J. M., & Vega, V. (2025). Assessment of European countries' national circular economy policies. *Journal of Environmental Management*, Vol. 373, ELSEVIER <https://doi.org/10.1016/j.jenvman.2024.123835>.
- [23] Smol, M., Avdiushchenko, A., Kulczycka, J., & Nowaczek, A. (2018). Public awareness of circular economy in southern Poland: Case of the Malopolska region. *Journal of Cleaner Production*, 197, 1035–1045. <https://doi.org/10.1016/j.jclepro.2018.06.100>
- [24] Sterev, N. (2019). New Industrial Business Models: From Linear To Circular Economy Approach. *Trakia Journal of Sciences*, 17(Suppl.1), 511–523. <https://doi.org/10.15547/tjs.2019.s.01.082>
- [25] Zani, B., & Lleshaj Ll. (2025) "Technical and non-technical barriers and challenges in industrial symbiosis implementation in the economic and technological context". *Workshop & Conference: Industrial Symbiosis from a business perspective: challenges and opportunities*, Izmir, Türkiye.
- [26] Zani, B., & Munoz Puche, A. (2025). Industrial symbiosis in Albania: Hinderances on the road to circularity. Paper presented at the *ICEBIT 2025 International Conference, Tirana, Albania*.
- [27] Zukowski, R. (2004). Historical path dependence, institutional persistence, and transition to market economy: The case of Poland. *International Journal of Social Economics*, 31(10), 955–973. <https://doi.org/10.1108/03068290410555417>

How Data Literacy Learning Quality Shapes Student’s Professional Readiness in Albania

Teuta Xhindi¹, Dardane Nuka¹
¹European University of Tirana, Tirana, Albania
teuta.xhindi@uet.edu.al, dardane.nuka@uet.edu.al

Abstract: Data literacy has become a core competence for employability and digital transformation in higher education. This study investigates how Albanian students perceive the quality of Data Literacy learning experiences and whether perceptions differ between public and private universities. Survey data were collected within the DELTA project (N = 250). A composite learning quality index was constructed across nine dimensions and demonstrated excellent reliability (Cronbach’s $\alpha = 0.977$). Spearman’s correlation revealed a positive association between perceived learning quality and professional usefulness ($\rho = 0.287, p < 0.001$). A Mann–Whitney U test indicated a statistically significant difference between institutional types ($U = 6478.50, p = 0.048$), with public university students reporting higher mean ranks. However, the effect size was small ($r \approx 0.13$). The findings underline the importance of structured, practice-oriented learning offers while indicating modest institutional variation in perceived quality.

KEYWORDS: DATA LITERACY; LEARNING QUALITY; INSTITUTIONAL CONTEXT; EMPLOYABILITY; HIGHER EDUCATION; ALBANIA.

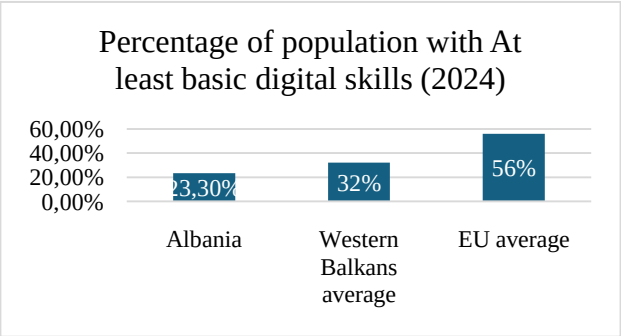
1. Introduction

The growing availability of data and the rapid diffusion of digital technologies have fundamentally transformed how organizations, institutions, and societies operate. In this context, data literacy has emerged as a critical competence enabling individuals to interpret, analyze, and ethically use data for informed decision-making. Higher education institutions play a central role in developing these competences, particularly in countries undergoing digital and economic transition, such as Albania.

Recent evidence on digital skills performance highlights the urgency of strengthening data-related competences within the Albanian higher education system. According to the Digital Economy and Society Index (DESI) indicators for the Western Balkans, digital skills remain significantly below the EU average [1]. While internet use among individuals in Albania increased from 82.5% in 2022 to 83.1% in 2023, it still remains below the EU average of 90% (DESI 2024). More critically, only 23.3% of individuals in Albania reported having at least basic digital skills in 2023, compared to 56% at the EU level.

Fig. 1 Share of Individuals with At Least Basic Digital Skills: Albania Compared to the Western Balkans and EU Average (2024). Source: Eurostat, INSTAT, DESI 2024.

Similarly, the share of individuals with above-basic digital skills



reached only 7.8% in 2023, substantially lower than the EU average of 27%.

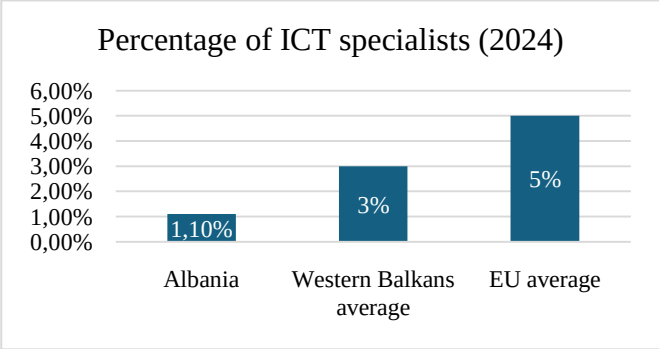
Data literacy forms part of internet user skills, which constitute one of the five key dimensions of digital skills within the DESI framework. Indicators related to digital content creation skills, closely linked to applied data competences, show that 39.6% of individuals in Albania possessed at least basic digital content creation skills in 2023, compared to 68% in the EU. Structural gaps are also visible in the labour market: ICT specialists account for

only 1.1% of total employment in Albania (2023), compared to 5% in the EU. Although the share of ICT graduates in Albania (8%) is comparable to or slightly higher than the EU average (5%), this has

not yet translated into broad-based digital competence across the population.

Fig. 2 Share of ICT Specialists in Total Employment: Albania Compared to the Western Balkans and EU Average (2024). Source: Eurostat, INSTAT, DESI 2024.

These figures suggest that Albania faces a dual challenge: increasing both the overall level of digital skills and the depth of advanced competences necessary for data-driven decision-making. In this context, strengthening Data Literacy within higher education



becomes not merely a curricular choice but a structural necessity for improving employability, innovation capacity, and economic competitiveness.

Despite increasing policy attention at European and national levels, evidence suggests that gaps persist between higher education outcomes and labour-market needs, especially with regard to applied data skills. Beyond the overall quality of learning experiences, institutional context may also shape how students perceive and benefit from Data Literacy education. Public and private universities often operate under different governance structures, resource constraints, and degrees of pedagogical flexibility, which may translate into differences in learning design and delivery.

In Albania, the higher education system is characterized by a dual structure comprising both public and private institutions, all operating under the same national regulatory framework but with varying institutional capacities. This context provides a relevant setting for examining whether students’ perceptions of Data Literacy learning quality differ across institutional types. Understanding such differences is important not only for academic research but also for policy discussions on quality assurance, curriculum reform, and equity in higher education.

Aim and objectives

- The aim of this paper is to examine how the perceived quality of Data Literacy learning experiences shapes students’ professional readiness in the Albanian higher education context.

By focusing on students' evaluations of their learning experiences, the study seeks to contribute empirical evidence to ongoing debates on curriculum quality, employability, and institutional effectiveness.

Objectives

- To analyze the relationship between perceived quality of Data Literacy learning experiences and students perceived professional usefulness of these competencies.
- To investigate whether statistically significant differences exist between students enrolled in public and private universities regarding their perceptions of Data Literacy learning quality.

Research hypothesis

Research hypothesis 1

Perceived quality of Data Literacy learning experiences is positively and significantly associated with students perceived professional readiness in the Albanian higher education context.

Research hypothesis 2

Students enrolled in public and private universities differ significantly in their perceptions of the quality of Data Literacy learning experiences.

By addressing both relational and comparative dimensions, the study offers a comprehensive perspective on how learning quality and institutional context interact in shaping students' professional readiness.

2. Literature Review

2.1 Data Literacy as a Core Competence in Higher Education

According to Ologbosere [2], data literacy represents a fundamental competence in the twenty-first century, particularly for higher education institutions seeking to foster sustainable development and enhance global competitiveness. The author defines data literacy as the ability to identify, work with, analyze, interpret, and communicate data effectively, emphasizing its critical importance in the era of big data and datafication. Ologbosere [2] further argues that integrating data literacy into educational systems, especially at the higher education level, is essential for strengthening research productivity, critical thinking, and informed decision-making processes.

Similarly, Echtenbruck, Fühles-Ubach, Naujoks, and Kaliva [3] conceptualize data literacy as a cross-disciplinary competence that must be systematically embedded within higher education and research. Through the Data Literacy Initiative (DaLI) at TH Köln, the authors develop a comprehensive competence model structured around seven overarching areas: Establish Data Culture, Provide Data, Manage Data, Analyze Data, Evaluate Data, Interpret Data, and Publish Data. By defining clear competence dimensions and progression levels, the DaLI model offers a structured framework for curriculum design, teaching, and assessment, thereby supporting the strategic institutionalization of data literacy across academic disciplines.

At the European level, the DATA-READY and EVIDALI [4] initiatives further reinforce the systemic nature of data literacy reform. These initiatives highlight that bridging the data literacy gap requires a dual focus on individual competencies and institutional

ecosystems. While DATA-READY identifies teachers as both beneficiaries and enablers of reform, pointing to inconsistencies in professional development, EVIDALI places teachers at the center of empirical investigation, examining dimensions such as data skills, decision-making capacity, professional development, and accountability. Importantly, DATA-READY emphasizes that individual competencies can only flourish within supportive institutional environments characterized by coherent policies, effective leadership, and adequate resources.

At the policy level, the European Union's DigComp 2.2 framework identifies information and data literacy as a core domain of digital competence, further reinforcing its strategic relevance for higher education transformation and reform [5].

Taken together, these perspectives indicate that data literacy is no longer an optional technical skill but a strategic institutional competence that requires structured curricular and policy-level integration.

2.2 Data Literacy and Employability

Growing empirical evidence confirms the strong relationship between digital competences and labor market outcomes. Đorđević, Milanović Zbiljić, and Radosavljević [6], through a cross-sectional regression analysis based on Eurostat data from 32 European countries, demonstrate that specific dimensions of digital competence, particularly communication and collaboration, digital content creation, and safety skills, have a statistically significant and positive impact on employment rates. Within this broader digital competence framework, information and data literacy function as foundational components that enhance individuals' ability to adapt to data-driven work environments. Their findings suggest that strengthening digital and data literacy competences contributes directly to improved employability prospects and workforce competitiveness in the contemporary digital economy.

From the perspective of students, Mahmud, Wong, Keong, and Tazijan [7] report an increasing awareness of the importance of data literacy for career success. The authors argue that data literacy not only enhances job prospects but also provides a competitive advantage, as organizations increasingly prioritize employees with data and statistical knowledge. Their findings further emphasize the importance of self-directed learning in developing data literacy skills and sustaining long-term professional competitiveness. While many students express confidence in their abilities, variations in perceived proficiency levels highlight the continued need for structured institutional support and guidance.

In the Albanian context, Kokomani [8] stresses the necessity of curriculum reform to better align education with European standards and labor market requirements. The author underscores the importance of strengthening key competences, particularly practical, entrepreneurial, digital, and social skills, as essential pillars of employability and professional success. This perspective reinforces the argument that integrating applied data competences into higher education curricula is critical for enhancing graduates' labor market relevance.

These findings suggest that data literacy operates not only as a cognitive competence but also as a measurable employability asset in contemporary labor markets.

2.3 Learning Quality and Perceived Professional Readiness

The relationship between learning quality and students perceived professional readiness has gained increasing attention in higher education research, particularly in the context of education massification and rapidly evolving labor market expectations. Enstroem and Schmaltz [9] analyze how large-scale teaching environments influence students’ work readiness and argue that pedagogical strategies must be carefully aligned with employer-defined competence requirements. They contend that sustaining educational quality in large cohorts requires purposeful efforts to enhance student engagement, personalize learning experiences, and cultivate transversal competencies.

Importantly, Enstroem and Schmaltz [9] emphasize that work readiness is strongly associated with the development of soft and transversal skills, including communication, collaboration, adaptability, and problem-solving. Although large-scale teaching presents structural challenges, the authors identify significant opportunities to strengthen perceived professional readiness through experiential learning, real-world simulations, peer interaction, and structured academia–industry feedback mechanisms. Their analysis suggests that learning quality extends beyond content transmission; it is fundamentally shaped by the degree to which curricula promote practical application, industry relevance, and skill transferability.

Complementing this perspective, Uzorka and Odebiyi [10] demonstrate that the integration of digital learning tools significantly enhances student engagement and academic achievement. Their findings indicate that Learning Management Systems, interactive simulations, and gamified instructional approaches foster interactivity, autonomy, and stronger links between theory and practice. Such technology-enhanced learning environments contribute to improved motivation and performance, factors that are closely associated with students’ confidence in their professional preparedness. However, the authors also caution that the effectiveness of digital tools depends on adequate digital literacy levels and institutional infrastructure.

Similarly, Nguyen and Oanh [11] highlight the role of cooperative learning in strengthening student engagement. Their study shows that well-structured instructional design, clear task distribution, and effective group management positively influence students’ personal development, emotional involvement, and collaborative competencies. By fostering inclusive and interactive learning environments, cooperative learning not only improves academic outcomes but also supports the development of interpersonal and collaborative skills that are essential for workplace readiness.

Therefore, perceived professional readiness can be understood as an outcome of learning environments that combine engagement, applied practice, and competence-oriented pedagogies.

3. Research Methodology

3.1 Data collection

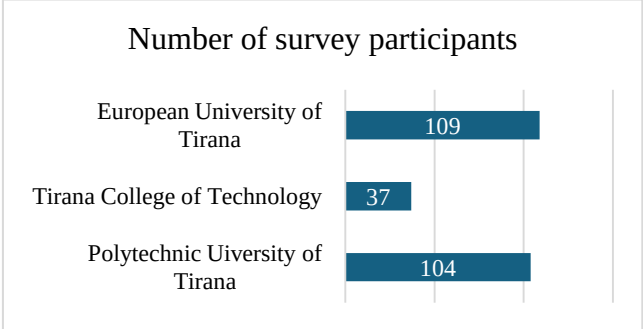
The study is based on quantitative survey data collected within the framework of the DELTA project, which aims to assess Data Literacy competencies and learning experiences in Albanian higher education. Data were gathered through a structured questionnaire administered to students who had participated in Data Literacy-related learning activities.

The final analytical sample consists of 250 valid responses distributed across three higher education institutions: 104 students from the Polytechnic University of Tirana (UPT), 37 students from Tirana College of Technology (TCT), and 109 students from the European University of Tirana (UET). The sample includes students

from both public and private universities, allowing for comparative analysis across institutional contexts.

Fig. 3 Number of Survey Participants by institution (DELTA Project Sample). Source: Authors’ calculations based on DELTA project survey data (N = 250).

Participation was voluntary, and the sampling approach can be characterized as convenience sampling. Only complete responses



for the variables of interest were retained for statistical analysis. While this approach enabled efficient data collection within the DELTA project framework, it represents a limitation in terms of the generalizability of findings beyond the participating institutions.

3.2 Variables construction

The empirical analysis is based on the construction of two main variables: Perceived Learning Quality and Perceived Professional Usefulness.

Perceived Learning Quality

Perceived Learning Quality was operationalized as a composite variable constructed from eight items assessing different dimensions of the Data Literacy learning experience. The items included: Relevance of topics selected, Adequacy of learning mode, Appropriateness of trainers’/mentors’ knowledge and facilitation skills, Quality of learning materials, Extent to which students feel prepared to apply what they have learned, Balance between theory and practical elements, Extent to which students were able to bring in their own expertise, Adequacy of overall learning offer duration. Each item was measured on a 7-point Likert scale (1 = very low, 7 = very high).

To assess the internal consistency of the scale, a reliability analysis was conducted. The eight-item learning quality scale demonstrated excellent internal consistency (Cronbach’s $\alpha = 0.977$). Corrected item–total correlations ranged from 0.867 to 0.935, substantially exceeding the recommended minimum threshold of 0.30. This indicates that each item is strongly associated with the overall scale score (excluding the respective item). The Cronbach’s alpha if item deleted values ranged between 0.972 and 0.975, all slightly lower than the overall alpha coefficient, suggesting that removing any item would not increase the reliability of the scale.

Given the high internal consistency and the conceptual complementarity of the items, all items were retained. A composite Learning Quality score was computed as the arithmetic mean of the eight items, ensuring that the final variable remained on the original 7-point scale and could be interpreted as an overall evaluation of perceived learning quality.

Perceived Professional Usefulness

Perceived Professional Usefulness was measured using a single-item variable assessing the perceived usefulness of Data Literacy competencies for students’ current and future professional life. Responses were recorded on a 5-point Likert scale (1 = not at all useful, 5 = very strong). As a single-item measure, no reliability analysis was required.

Table 1 presents the descriptive statistics for the two main variables: *Evaluation of Learning Offers* (measured on a 1–7 Likert-type scale) and *Perceived Professional Usefulness* (measured on a 1–5 Likert-type scale), based on 250 observations.

Table 1: Descriptive statistics for the two main variables. Source: Authors own calculation

Statistic	Evaluation of Learning Offers	Professional Usefulness
Mean	5.02	3.82
Standard Deviation	1.65	0.97
Minimum	1.56	1
25th Percentile	3.59	3
Median	5.56	4
75th Percentile	6.44	5
Maximum	7	5

The mean score for *Evaluation of Learning Offers* ($M = 5.02$, $SD = 1.65$) indicates generally positive perceptions of learning quality. The median (5.56) and upper quartile (6.44) suggest that a substantial proportion of students provided high evaluations.

Similarly, *Professional Usefulness* shows a relatively high mean ($M = 3.82$, $SD = 0.97$), with a median of 4, indicating that most students perceive Data Literacy learning as professionally relevant. The lower standard deviation compared to the first variable suggests more homogeneous responses regarding professional usefulness.

Institutional Type

Students were classified according to the type of higher education institution attended, distinguishing between public and private universities. The Polytechnic University of Tirana (UPT) was classified as a public institution, whereas Tirana College of Technology (TCT) and the European University of Tirana (UET) were classified as private institutions. This categorical variable was used to examine potential differences in perceived learning quality across institutional contexts.

3.3 Statistical analysis

Given that the variables were measured using Likert-type scales and the assumption of normality was formally tested, non-parametric statistical techniques were employed. Specifically, the Shapiro–Wilk test indicated statistically significant deviations from normality for both *Evaluation of Learning Offers* ($W = 0.901$, $p = 9.20 \times 10^{-12}$) and *Professional Usefulness* ($W = 0.866$, $p = 5.61 \times 10^{-14}$). These results led to the rejection of the null hypothesis of normal distribution.

Considering the ordinal nature of the measurement scales and the violation of the normality assumption, non-parametric methods

were deemed more appropriate. Consequently, Spearman's rank-order correlation was used to examine the association between perceived learning quality and perceived professional usefulness, and the Mann–Whitney U test was employed to assess differences between institutional groups. Statistical significance was evaluated at the 5% level.

4. Results

Association between Learning Quality and Professional Usefulness

Spearman's rank-order correlation revealed a statistically significant positive association between perceived learning quality and perceived professional usefulness ($\rho = 0.287$, $p = 4.2 \times 10^{-6}$).

The magnitude of the coefficient suggests a small-to-moderate association rather than a strong one. This indicates that students who report higher evaluations of learning quality also tend to perceive Data Literacy competencies as more professionally useful. However, the correlation size implies that learning quality explains only part of the variation in perceived professional usefulness. Importantly, the result reflects an association and does not imply a causal relationship.

Institutional differences in Perceived Learning Quality

The Mann–Whitney U test revealed a statistically significant difference in perceived learning quality between students enrolled in public and private universities ($U = 6478.50$, $Z = -1.978$, $p = 0.048$). Students from public universities (Mean Rank = 136.21) reported slightly higher evaluations compared to students from private universities (Mean Rank = 117.87).

To evaluate the practical significance of this difference, the effect size (r) was calculated using:

$$r = \frac{Z}{\sqrt{N}}$$

For $N = 250$:

$$r = \frac{-1.978}{\sqrt{250}} = \frac{-1.978}{15.81} \approx -0.125$$

According to conventional benchmarks (0.10 = small, 0.30 = medium, 0.50 = large), this represents a small effect size.

Therefore, although the difference is statistically significant ($p = 0.048$, borderline at the 5% threshold), its practical magnitude is limited. The findings suggest modest institutional variation rather than substantial structural differences.

5. Discussion

The findings confirm that perceived learning quality is positively associated with students' perceptions of the professional usefulness of Data Literacy competencies. While the relationship is statistically significant, its magnitude is moderate rather than strong. This indicates that learning quality plays an important, but not exclusive, role in shaping students' professional perceptions. Other contextual, individual, or labor-market-related factors likely contribute to these perceptions.

The excellent internal consistency of the learning quality scale demonstrates that students' evaluations across pedagogical dimensions form a coherent construct. This supports the validity of the composite index used in the analysis.

Regarding institutional differences, although students from public universities reported slightly higher evaluations of learning quality, the small effect size suggests that differences between institutional types are limited in practical terms. This may reflect increasing convergence in teaching standards, shared accreditation frameworks, and similar curricular requirements across public and private higher education institutions in Albania.

Rather than indicating institutional disparity, the results point to broadly comparable learning environments, with only modest variation in perceived quality.

6. Conclusions

This study provides empirical evidence on the relationship between perceived learning quality and perceived professional usefulness of Data Literacy competencies in Albanian higher education.

The results indicate that higher perceived learning quality is associated with stronger perceptions of professional relevance. However, the magnitude of the association suggests that learning quality represents one important factor among several influencing students' professional perceptions.

Institutional differences were statistically significant but small in magnitude, indicating limited practical variation between public and private universities.

Overall, the findings highlight the importance of structured, relevant, and practice-oriented Data Literacy learning offers. Strengthening pedagogical coherence and applicability may contribute to enhancing students perceived professional readiness, while acknowledging that broader contextual factors also shape employability perceptions.

7. References

[1] Regional Cooperation Council, Western Balkans Digital Economy and Society Index 2024 Report (Regional Cooperation Council, Sarajevo, 2025). Available at: <https://www.rcc.int/pubs/211/western-balkans-digital-economy-and-society-index-2024-report>

[2] O.A. Ologbosere, IASSIST Q. **47** (2023). <https://doi.org/10.29173/iq1082>

[3] M.M. Echtenbruck, S. Fühles-Ubach, B. Naujoks, E. Kaliva, A data literacy competence model for higher education and research, Technical report, TH Köln (2025). <https://doi.org/10.48550/arXiv.2504.15690>

[4] DATA-READY, Bridging the data literacy gap in European education: Insights from DATA-READY and EVIDALI (2025). Available at: <https://data-ready.eu/bridging-the-data-literacy-gap-in-european-education-insights-from-data-ready-and-evidali/>

[5] European Commission, Joint Research Centre, DigComp 2.2: The digital competence framework for citizens (Publications Office of the European Union, 2022). <https://doi.org/10.2760/115376>

[6] B. Đorđević, S. Milanović Zbiljić, M. Radosavljević, *Economies* **13**, 196 (2025). <https://doi.org/10.3390/economies13070196>

[7] M.M. Mahmud, S.F. Wong, Y.W. Keong, F. Tazijan, *Int. J. Res. Innov. Soc. Sci.* **9**, 150–160 (2025). <https://doi.org/10.47772/IJRIS.2025.9020013>

[8] E. Kokomani, *Interdiscip. J. Res. Dev.* **12**, 287–298 (2025). <https://doi.org/10.56345/ijrdv12n331>

[9] R. Enstroem, R. Schmaltz, *J. Work-Appl. Manag.* **16**, 184–199 (2024). <https://doi.org/10.1108/JWAM-10-2023-0100>

[10] A. Uzorka, O. Odebiyi, *J. Digit. Learn. Distance Educ.* **4**, 1436–1445 (2025). <https://doi.org/10.56778/jdlde.v4i1.511>

[11] T.N.T. Nguyen, D.T.K. Oanh, *Cogent Educ.* **12**, 2513414 (2025). <https://doi.org/10.1080/2331186X.2025.2513414>

Contemporary challenges to quality management in the context of the competitiveness of industrial enterprises

Ivan Genov

Technical University of Sofia, Branch Plovdiv, Bulgaria

E-mail: i.genov@std.tu-plovdiv.bg

Abstract: Quality management is an often-overlooked business factor that represents a strategic pillar for industrial enterprises that aim to strengthen their competitiveness in the national and global markets. This paper examines the contemporary challenges faced by quality management systems in industrial settings, considering digital transformation and integration with Industry 4.0. Key impediments and opportunities are identified, and recommendations for enhancing quality practices are proposed.

KEYWORDS: QUALITY MANAGEMENT, COMPETITIVENESS, INDUSTRIAL ENTERPRISES, INDUSTRY 4.0, DIGITALIZATION, STRATEGIC DEVELOPMENT

1. Introduction

The rapid changes in the national and global markets, as well as the external and internal factors of the economy, form the features that ensure the competitiveness of enterprises [3].

The general definition for an industrial enterprise describes it as a large-scale business focused on manufacturing goods or providing industry-related services, characterized by machines and devices, technology, mass production and transition from manual labor to factory systems [13].

The key characteristics of industrial enterprises describe them as focused on the manufacturing aspect of the economy, typically large by scale, with significant influence on the country's gross domestic product (GDP). They operate by utilizing machines, designed mostly for mass production, and are organized by a traditional, top-down structure, defining clear levels of authority, ensuring a strict chain of decision making, communication and control [13]. These business entities are critically important for national and regional economic prosperity, involving operations like resource conversion (coal, gas, oil) or high-tech production and are refined by their production scale, impact and often a distinct structure with specialized labor. This also involves sophisticated management, supply chain optimization, global collaboration, as well as aim for a boost of competitiveness through strategic planning and investments [15].

Flexible quality management systems (QMS) allow companies to adapt quickly to changing market demands and technological shifts. The core principles of ISO 9001 (Fig. 1) and recent developments in QMS also play a role in the vitality of the industrial enterprises, but the general understanding for a company's quality is often limited to simple inspections and aim for reduction of the rejected pieces during the production cycle.



Figure 1. The 7 principles of ISO 9001 [2]

Apart from the cost reduction aspect, quality management drives competitiveness through customer satisfaction and loyalty, market differentiation, product superiority, efficiency and innovation.

Quality management tools (e.g. Root Cause Analysis) improve product and service performance, reliability and durability, creating a strong competitive edge [5,11].

Industrial enterprises operate in an increasingly competitive global environment where the ability to deliver superior quality products and services constitutes a fundamental determinant of performance and market position [15].

In modern contexts, digital transformation and Industry 4.0 affect competitiveness drivers such as productivity, product quality and innovation through coordination with the quality management within the organization [2,10,14].

2. Impact of quality management in economic processes

2.1. Quality management systems and international standards

QMS represents an organized set of policies, procedures and processes aimed at continuously improving the quality of products and services, satisfying customer requirements and stimulating the efficiency of organizational processes. The most widely applied international standard for QMS, in its current revision, is ISO 9001:2015. It is based on the *Plan-Do-Check-Act* (PDCA) cycle and defines the requirements for QMS and the principles that must be followed by any organization, regardless of its size or economic sector. This standard emphasizes customer focus, leadership, a process approach and continuous improvement (Fig. 2), which are key to sustainable development and economic competitiveness [2].

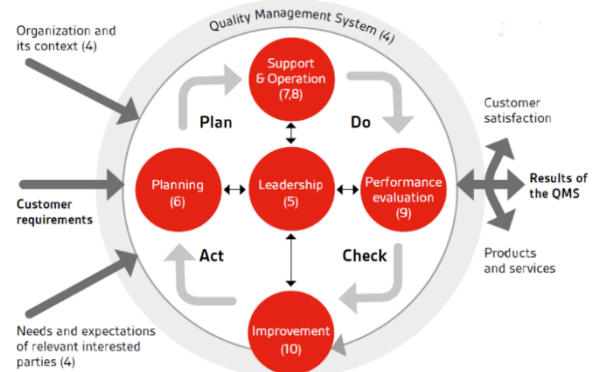


Figure 2. Structure of ISO 9001 and the PDCA (continuous improvement) approach [2]

2.2. Quality management in the context of digital transformation

With the development of new technologies and industrial automation, quality management cannot be considered only as a mechanical set of documented procedures and inspections. This allows quality to be integrated with modern digital practices and the Industry 4.0 paradigm. This leads to the concept of Quality 4.0, which is a digitalization of traditional QMS by implementing tools such as Internet of things (IoT) for real-time quality tracking, machine learning, big data analysis for predicting quality deviations, and automated process control mechanisms [15].

Digital QMS (Fig.3) allow for more precise measurements, better control of production processes and faster response to market changes [15].

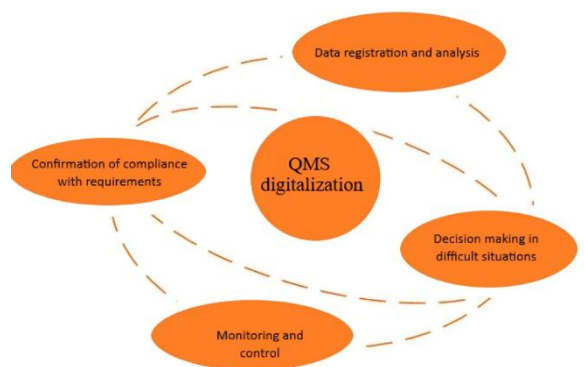


Figure 3. The Digital QMS [15]

The integration between QMS and Industry 4.0 supports the creation of adaptive and flexible processes, which are important for competitiveness in conditions of unstable markets and intense technological dynamics [1].

2.3. Organizational and strategic preconditions

For a QMS to be effective and contribute to competitiveness, it needs to be supported by an organizational strategy and involvement of the top management. Systematic and sustainable quality management results often depend on:

2.3.1. Commitment of the top management to set quality objectives that are in line with the strategic goals and interests of the enterprise. According to ISO 9001, leadership is a key factor in providing resources, communicating and taking strategic decisions, which in themselves contribute to competitive advantage [4,6].

2.3.2. Training and development of personnel, which ensures that employees understand their roles in the context of the QMS and can contribute to continuous improvement [2].

2.3.3. Internal organization and cultural development including the adoption of the principles of continuous improvement and customer focus [1].

2.4. Economic preconditions

2.4.1. European programs to support innovation, digitalization and quality

Bulgarian industrial enterprises operate within the framework of European Union policies that are related to continuous improvement, digitalization, implementation of modern technologies and improving the standards of products and services.

2.4.1.1. The “Competitiveness and Innovation in Enterprises” Program provides grants for the introduction of technologies in the field of Industry 4.0 and digitalization of enterprises, which also supports the modernization of quality processes and increased productivity. This support is part of the European Union’s (EU) policy to accelerate the technological transformation of the industrial base and improve the competitiveness of companies from the Bulgarian manufacturing sector [8].

This operational program also supports the development of quality laboratory services and conformity assessment bodies, which are a key element of the quality management infrastructure, including certification, metrology and assessment services, which companies adapt to comply with increased market requirements [9].

These tools help companies not only to modernize their technologies, but also to develop quality systems that are more adaptable, traceable and compatible with European standards – a factor that strengthens their competitive presence in foreign markets.

2.4.2. Competitiveness and digital transition policies

The European Commission clearly places competitiveness, digitalization and innovation at the heart of its economic strategy for the 2024-2029 period that includes stimulating investment in AI and digital technologies and reducing the administrative burden for

small and medium enterprises (SMEs) for access to growth measures within the operational program [8].

2.4.3. Institutional factors for quality

2.4.3.1. Regulations and standards:

External regulatory requirements, including European directives and standards (such as ISO, CE marking and other harmonised rules) set specific quality management requirements that companies must meet in order to participate freely in the single market. This creates an institutional framework that incentivises businesses to invest in QMS and certification [9].

2.4.3.2. Innovation funding:

Competitiveness programmes provide funds for the deployment of technologies, digital systems and tools that help automate and track quality through Industry 4.0 approaches [9].

2.4.3.3. Market competitiveness:

Support for exports, marketing campaigns and participation in international exhibitions increases the quality of products. Companies meet higher market standards and expand their competitive advantages on foreign markets [14].

2.4.4. Influence over Bulgarian industrial enterprises

Bulgarian enterprises, especially SMEs, operate in an economic environment where the implementation of Industry 4.0 technologies and digital solutions is considered part of the strategy for increasing quality and competitiveness, including through access to European funding programs (e.g. procedures under the CPIP 2021–2027). This supports their technological improvement and adaptation to the requirements of international markets.

3. Opportunities for strategic implementation of QMS

3.1. Adoption of QMS in SMEs

A fundamental step for Bulgarian industrial enterprises seeking enhanced competitiveness is the adoption of formal QMS, mostly based on ISO 9001. It is perceived not only as a compliance tool, but also as a strategic mechanism for improving competitiveness, especially when applied in an integrated manner with the management objectives of the enterprise [16].

In the context of Bulgarian economics, an empirical study among manufacturers in the manufacturing sector shows that managers evaluate QMS as a factor for competitiveness by reducing defects, optimizing costs and increasing market presence, including in foreign markets. As part of the strategic implementation, enterprises should involve leadership and top management in setting strategic quality objectives, integrate different functions (production, quality control, logistics) under a common monitoring and accountability system and use QMS data to support strategic management decisions [17].

3.2. Integration with Industry 4.0 – Approaches to Quality 4.0

In today's industrial environment, traditional quality management is evolving towards Quality 4.0 — an approach that combines the principles of classic QMS with digital technologies and real-time data. Quality 4.0 is not just the digitalization of procedures, but a conceptual framework that unites people, processes and technologies to achieve higher value, transparent analysis and sustainable improvement. Table 1 represents key research deficiencies and future directions for advancing the Quality 4.0 approach, with focus on integrating Industry 4.0 technologies [12].

Table 1. Key Research deficiencies and Future research directions for Quality 4.0 [12].

№	Research Area	Gaps	Future Research Directions
1	Human factors and workforce	Insufficient focus on workforce skills and engagement	Investigate strategies for employee training, engagement and role transformation
2	Lean Practices Integration	Lack of focus on managing change during adoption.	Explore methods to overcome resistance and facilitate organizational

			transformation.
3	Change Management	Lack of focus on managing change during adoption.	Explore methods to overcome resistance and facilitate organizational transformation.
4	Real-Time Decision-Making & Automation	Insufficient exploration of real-time decision-making.	Research AI, IoT, and real-time analytics for enhanced process optimization.
5	Standardization	Absence of standardized frameworks for Quality 4.0 adoption.	Create universal frameworks for consistent Quality 4.0 implementation.
6	Cross-Industry Applications	Limited cross-industry research.	Conduct cross-sector studies to understand best practices for Quality 4.0 adoption.
7	AI, IoT, Big Data Integration	Underexplored integration of digital technologies.	Investigate AI, IoT, and Big Data for quality control and operational efficiency.
8	Sustainability	Limited research on sustainability in Quality 4.0.	Explore the role of Quality 4.0 in promoting sustainability in business practices.
9	Supply Chain Integration	Lack of focus on Quality 4.0's role in supply chain management.	Research the impact of Quality 4.0 on supply chain optimization and resilience.
10	Predictive Analytics	Limited use of predictive analytics in quality improvement.	Develop predictive models to prevent quality issues and improve processes.
11	Cybersecurity	Unexplored cybersecurity risks in Quality 4.0.	Research strategies for securing Quality 4.0 systems and data from cyber threats.
12	Customer-Centricity	Insufficient focus on customer-oriented strategies.	Explore how Quality 4.0 technologies can enhance customer satisfaction and engagement.
13	Data Interoperability	Challenges in seamless data interoperability.	Investigate solutions for improved data sharing and system integration.
14	Performance Metrics	Lack of comprehensive performance metrics for Quality 4.0.	Develop new metrics to assess the impact of Quality 4.0.

Quality 4.0 includes [5]:

- Using IoT, sensors and automated measurements to monitor quality in real time;
- Applying big data and analytical platforms for predictive control and optimization of production processes;
- Building a digital culture and training that allow employees to work effectively with new tools and data;

Research shows that Quality 4.0 can significantly speed up deviation response processes, reduce delays and improve the quality

of products and services, which brings competitive advantages to companies that adopt it adequately [12].

3.3. Organizational and Human Factors in Quality Transformation

The implementation and successful operation of QMS and Quality 4.0 require not only technologies, but also organizational culture, competencies and leadership commitment.

Key social and management factors include:

3.3.1. Leadership and strategic vision

Effective leadership is key to creating an environment that supports innovation, quality and flexibility. The level of commitment from top management determines the adoption, resources and integration of QMS into the strategic goals of the company [15].

3.3.2. Training and competencies

The transition to digital and integrated quality practices requires specific skills - from data and analytics to process management - that are not always available in the traditional workforce. This creates a need for continuous training and development of human capital [16].

3.3.3. Culture of continuous improvement and collaboration

Organizations that manage to achieve successful transformation build a culture of transparency, cross-departmental collaboration and knowledge sharing. This is particularly important for the application of interdisciplinary digital tools and analyses in quality.

3.4. Overcoming Barriers and Enhancing Competitiveness

For Bulgarian enterprises, barriers to integrating modern quality management approaches often include a lack of digital readiness, financial constraints and insufficient strategic planning. Studies show that among industrial companies in Bulgaria, initiatives to implement Industry 4.0 technologies to improve quality and competitiveness are being adopted by an increasing number of organizations, but there is a significant lag compared to the EU average, which requires targeted investment and training efforts [7].

To overcome the obstacles, enterprises can:

- Develop a strategic digital transformation plan integrating elements of Quality 4.0;
- Build an information infrastructure to support data exchange and analysis;
- Stimulate internal leadership and training to increase digital and quality competence.

4. Results and discussion

The literature indicates that a well-functioning QMS correlates positively with competitive outcomes such as customer satisfaction, process efficiency and market performance. ISO 9001 certification has been shown to drive enhanced competitiveness and improved company image, which are particularly important for Bulgarian firms operating in transitional economies.

However, certain challenges persist. Many enterprises still treat QMS primarily as a certification exercise rather than a strategic initiative, which limits the system's potential impact on competitiveness. Additionally, digitalization adoption rates vary across sectors, with barriers including financial constraints, technological readiness, and workforce skills gaps [17].

The integration of quality management with digital strategies is gaining attention in academic and industrial circles as a path toward sustainable competitiveness, requiring new competencies and organizational flexibility [18].

5. Conclusion

Quality management is an essential driver of competitiveness for Bulgarian industrial enterprises. Effective implementation of QMS according to international standards such as ISO 9001 - coupled with a strategic orientation toward continuous improvement and integration with digital transformation - enhances operational performance, product quality and market responsiveness. Embracing quality management as a core strategic objective, rather

than a mere compliance requirement, supports long-term competitiveness and organizational resilience.

Future research should further investigate the impact of emerging quality paradigms on competitive outcomes, and empirical studies should explore sector-specific dynamics in Bulgarian industry to enable tailored strategies.

6. References

1. Chiarini A., An C., (2023) Integrating ISO 9001 and Industry 4.0. An implementation guideline and PDCA model for manufacturing sector
2. Chukalov K., Sabi S., (2023) Quality management system - ISO 9001 in the context of Industry 4.0, International scientific journal "Industry 4.0".
3. Filipishyna, Liliya & Patuk, Serhii & Klenin, Oleg. (2025). STRATEGIC MANAGEMENT OF INNOVATIVE DEVELOPMENT OF AN INDUSTRIAL ENTERPRISE. Baltic Journal of Economic Studies. 11. 269-275. 10.30525/2256-0742/2025-11-4-269-275.
4. Georgiev, Svetoslav & Georgiev, Emil. (2015). Motivational factors for the adoption of ISO 9001 standards in Eastern Europe: the case of Bulgaria. Journal of Industrial Engineering and Management. 8. 10.3926/jiem.1355.
5. Gomaa, Attia. (2025). Quality Management Excellence in the Era of Industry 4.0 (Quality 4.0): A Comprehensive Review, Gap Analysis, and Strategic Framework. 2. 18-40. 10.5281/zenodo.16787620.
6. <https://bds-bg.org/bg/> - opened on 19.12.2025
7. <https://opcompetitiveness.bg/> - opened on 19.12.2025
8. <https://pkip.egov.bg/wps/portal/program-pkip/procedures/open> - opened on 19.12.2025
9. <https://reform-support.ec.europa.eu/what-we-do/> - opened on 19.12.2025
10. <https://www.reagent.co.uk/blog/what-are-the-7-principles-of-iso-9001/>
11. <https://www.tuv-nord.com/bg/bg/services/system-certification/> - opened on 19.12.2025
12. Liu, HC., Liu, R., Gu, X. et al. (2023) From total quality management to Quality 4.0: A systematic literature review and future research agenda. Front. Eng. Manag. 10, 191–205. <https://doi.org/10.1007/s42524-022-0243-z>
13. Panteleeva, I. (2021) "The nature of the industrial enterprise," Production–operation management. The chosen aspects. Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu. doi: 10.18559/978-83-8211-059-3/01.
14. Pysarenko, Volodymyr & Kriuchko, Lesia & Ostapenko, Tetiana & Kubetska, Olga. (2025). Marketing Strategy Development in the Management of Industrial Enterprise Competitiveness. Economics Ecology Socium. 9. 96-108. 10.61954/2616-7107/2025.9.2-7.
15. Ranjith Kumar, R., Ganesh, L. S., & Rajendran, C. (2022). Quality 4.0—a review of and framework for quality management in the digital era. International Journal of Quality & Reliability Management, 39(6), 1385-1411. <https://doi.org/10.1108/IJQRM-05-2021-0150>
16. Sepeta, Vira. (2021). EVALUATION OF THE LEVEL OF THE COMPETITIVENESS AND LABOR POTENTIAL OF INDUSTRIAL ENTERPRISES BY MEANS OF THE INTEGRAL INDICATOR. Green, Blue and Digital Economy Journal. 2. 82-89. 10.30525/2661-5169/2021-1-12.
17. "Stefanova R., Dimova A., (2019), The Quality Management System as a Factor for the Competitiveness of the Bulgarian Pharmaceutical Manufacturers, Health Economics & Management, vol. 1"
18. Veleva N., (2020), Introduction of Industry 4.0 in Industrial Enterprises: Problems and Challenges, International scientific journal "Industry 4.0".

Innovations in industrial enterprises: the role of ai, iot, and automation in enhancing competitiveness

Slava Petkova

Technical University of Sofia branch Plovdiv, Bulgaria

E-mail: spet1788@gmail.com

Abstract: Industrial enterprises are entering a phase in which competitiveness is increasingly shaped by advanced digital technologies and the organizational capabilities that transform them into measurable outcomes. This paper analyzes how Artificial Intelligence (AI), Internet of Things (IoT), and automation influence operational excellence and how their effects are mediated by leadership, knowledge management capabilities, digitalization maturity and e-HRM systems. Based on the resource-based view and dynamic capability theory, a capability-mediated framework is proposed. Evidence from Tata Steel, Freeport-McMoRan and Siemens demonstrates that technology alone does not ensure competitiveness; value emerges when digital systems are embedded into organizational routines, governance mechanisms and workforce development processes.

Keywords: AI; IOT; AUTOMATION; INDUSTRIAL COMPETITIVENESS; DIGITAL TRANSFORMATION; KNOWLEDGE-ORIENTED LEADERSHIP; E-HRM; HR ANALYTICS; DYNAMIC CAPABILITIES

1. Introduction

Industrial enterprises are undergoing structural transformation driven by AI, IoT, and automation—technologies increasingly embedded across the industrial value chain, from engineering and manufacturing to operations, supply chains, and workforce systems [32, 23]. While earlier digital initiatives often emphasized automation or IT modernization, the current wave is characterized by AI-enabled decision systems, real-time cyber-physical connectivity, and continuous optimization through learning loops [17, 23].

From a competitiveness standpoint, firms able to sense, interpret, and act on operational data faster can reduce downtime, increase throughput, improve yield, and shorten time-to-market—advantages that accumulate into sustained performance differences when digitalization is managed as an organizational capability rather than a one-time technology investment [1, 10, 24, 33]. Evidence consistently shows that digital transformation is rarely an automatic driver of performance; instead, benefits depend on complementary organizational capabilities, governance, and digitalization management maturity [10, 24, 33].

Research in SMEs and MSMEs emphasizes that digital technologies often work through mediating mechanisms: leadership orientation, knowledge sharing quality, organizational agility, and dynamic capabilities determine whether digital adoption becomes performance improvement [10, 19, 20, 21, 33]. Extending these insights to industrial enterprises, AI/IoT/automation should be treated as strategic resources whose performance impact is contingent on organizational readiness and human systems alignment [1, 27, 33].

A further context is Bulgaria's digital transformation trajectory. Despite relatively strong connectivity, Bulgarian industrial sectors remain below EU averages in digital maturity, with limited integration of Industry 4.0 technologies and persistent capability gaps [2, 3, 7]. This reinforces the need to analyze competitiveness not only through technology adoption but through systemic capability building, ecosystem development, and change management [4, 5, 6].

This paper contributes by integrating:

- (1) operational impacts of AI/IoT/automation;
- (2) capability-based theories (resource-based view; dynamic capabilities);
- (3) leadership and HR digitalization mechanisms (KOL, e-HRM, HR analytics).

The argument is strengthened using industrial cases across steel, mining, and industrial software ecosystems [15, 8, 23].

2. Prerequisites and means for solving the problem

2.1. Conceptual framing: RBV and strategic digital assets

According to the resource-based view (RBV), sustained competitive advantage stems from resources that are valuable, rare, difficult to imitate, and non-substitutable [1]. In industrial

enterprises, AI models, IoT sensor networks, industrial data platforms, and automation systems can meet these criteria when they are deeply integrated into production routines and continuously improved through learning cycles via digitalization management and structured capability ownership [33]. Importantly, the “resource” is not only the technology artifact but also embedded know-how: data pipelines, domain-specific feature engineering, model retraining, and decision governance [8, 15].

This explains why similar technology investments can yield different outcomes across firms: performance differences emerge from the capability to convert digital tools into repeatable routines under operational complexity (e.g., mining and steelmaking environments) [15, 8].

2.2. Dynamic capabilities: sensing, seizing, and reconfiguration

Dynamic capability logic complements RBV by emphasizing a firm's ability to sense opportunities, seize them through coordinated action, and reconfigure assets as environments shift [33]. In industrial contexts, this includes iterative deployment, operational experimentation within safe boundaries, and rapid process reconfiguration based on data feedback [8]. Evidence also indicates that agility and digital process maturity act as key enablers and barriers—particularly where digital processes are fragmented, readiness is uneven, and governance is weak [21, 27, 33].

2.3. Knowledge-oriented leadership and knowledge management capabilities

Technology-driven competitiveness depends heavily on leadership systems that cultivate knowledge flow, experimentation, and high-quality knowledge sharing. Knowledge-oriented leadership (KOL) is linked to performance through mechanisms such as knowledge sharing quality, service innovation, and ambidextrous innovation—especially under technological turbulence [20, 19]. In fast-evolving environments, leaders who institutionalize learning loops and protect constructive experimentation are more likely to extract value from digital investments [10, 19].

2.4. Human systems: e-HRM, HR analytics, and adoption readiness

Industrial digitalization requires workforce readiness: skills, engagement, role clarity, and behavioral adoption. Evidence shows that e-HRM tools can improve employee engagement and HRM system effectiveness, thereby supporting organizational effectiveness [25, 31]. HR analytics contributes to organizational effectiveness by enabling evidence-based workforce decisions [34, 29]. Adoption and scaling are shaped by contextual enablers, culture, and readiness [28, 30], and readiness assessment models emphasize that industrial digitalization requires multi-dimensional

preparation (process, people, technology, governance)—not merely installing tools [27].

2.5. Bulgarian industrial context: digital transformation and resistance

Studies on Bulgarian industrial enterprises emphasize gaps in readiness, ecosystem development, and change management [2, 3, 5, 7]. Resistance to change and insufficient capabilities for reengineering projects are reported barriers that can prevent industrial digital initiatives from generating measurable performance outcomes [4]. This supports the capability-mediated perspective adopted in this paper.

3. Solution of the examined problem

3.1. Capability-mediated model

This paper applies an integrative synthesis: peer-reviewed evidence on leadership, digital transformation, and HR digitalization is combined with practitioner case studies on AI deployment in industrial operations. The core proposition is:

AI, IoT, and automation improve competitiveness primarily through capability pathways—digital transformation maturity, leadership orientation, knowledge management capability, and HR digitalization readiness—rather than through adoption alone [10, 24, 33].

Key mediators and enablers include:

- KOL and knowledge sharing quality [20, 19];
- Digitalization management and agile/dynamic capabilities [21, 27, 33];
- HR digitalization readiness and analytics [29, 27, 34];
- Organizational culture and contextual barriers [28, 30].

Table 1: Capability-mediated competitiveness mechanisms in industrial digital transformation

No.	Technology	Capability mediator	Competitiveness outcome
1	AI	Data governance; model retraining routines; agile execution; KOL	Higher throughput; lower downtime; better yield and cost efficiency
2	IoT	Real-time monitoring capability; cybersecurity governance; data backbone maturity	Faster detection of drift; fewer failures; improved resilience
3	Automation	Standardized workflows; reskilling and adoption management; e-HRM support	Stable quality; higher consistency; reduced cost of poor quality
4	Digital twins	Simulation + real-time data integration; decision validation routines	Reduced CapEx risk; faster change validation; capacity optimization
5	e-HRM / HR analytics	Workforce readiness; engagement; evidence-based HR decisions	Sustained adoption; faster upskilling; higher organizational effectiveness

3.2. AI, IoT, and automation as operational competitiveness levers

3.2.1. AI: predictive and prescriptive value

AI creates value through prediction (failures, yield, energy consumption) and optimization (recommended control settings, scheduling, resource allocation). Predictive maintenance is a documented use case in industrial environments [14]. At scale, AI improves decision quality by detecting patterns and anomalies in complex process data [17]. The highest value often comes from prescriptive optimization combined with iterative improvement cycles and adoption routines embedded into daily work [8, 15].

3.2.2. IoT: real-time monitoring and risk governance

IoT enables continuous data flows across equipment, processes, and environments. In smart manufacturing, sensor infrastructures support monitoring of equipment condition, process drift, energy waste, and quality deviations [16]. Industry tracking also highlights that IoT adoption is accelerating across industrial operations, reinforcing its role as a baseline enabler for efficiency and data-driven management [11]. These data streams become the backbone for analytics, optimization, and digital twins [23]. IoT connectivity also expands cyber risk exposure, meaning cybersecurity capability is necessary for protecting competitiveness and operational integrity [12].

3.2.3. Automation: quality stability and throughput consistency

Automation improves consistency, throughput, and quality by reducing process variability and human error. In automotive manufacturing, robotics and automation are widely linked to throughput and operational performance improvement [13]. Automated inspection and feedback loops support quality performance and reduce cost of poor quality [18]. Yet automation also intensifies workforce transition requirements, making reskilling and adoption management central to sustained outcomes [22, 25].

3.2.4. Ecosystems and platformization

Competitiveness increasingly depends on participation in digital business ecosystems where platforms enable coordination, co-creation, and scaling across networks [5]. This aligns with Siemens' ecosystem framing of Industrial AI as an integrated operating layer across lifecycle functions [23].

4. Results and discussion

4.1. Case evidence: what works in practice

4.1.1. Tata Steel (Kalinganagar): analytics as a capability system

Tata Steel's Kalinganagar plant illustrates analytics transformation in a high-variance steel process. Analytics models were used to improve control of a critical thermal stage in production, and the transformation required not only model development but workforce capability building, adoption management, and continuous model updating as conditions shifted [15]. The case demonstrates a core lesson: early model success can degrade when input conditions change, requiring retraining, governance, and internal ownership [15]. The plant's capability development contributed to recognition as an advanced Industry 4.0 adopter [15, 32].

4.1.2. Freeport-McMoRan (Bagdad): AI optimization combined with agile execution

Freeport-McMoRan's Bagdad mine demonstrates how AI can unlock gains by challenging entrenched assumptions and turning prediction into optimization. The case highlights cross-functional

teamwork, iterative deployment (MVP logic), and operational experimentation within safety boundaries—an organizational design aligned with dynamic capabilities and agility [8]. The competitiveness mechanism is not the algorithm alone, but the ability to embed model recommendations into daily operational routines and continuously improve the system [8]. This aligns with the principle that organizations should prioritize measurable business improvements over technology novelty, supported by pragmatic change and governance practices [9].

4.1.3. Siemens at CES 2026: Industrial AI operating system, digital twins, and copilots

Siemens' CES 2026 announcements illustrate an ecosystem-scale strategy: Industrial AI as a lifecycle-integrated operating layer spanning design, simulation, manufacturing, and supply chain coordination [23]. Digital Twin Composer is positioned as infrastructure for connecting comprehensive digital twins with simulation and real-time engineering data, enabling virtual decision-making and validation at scale [23]. Siemens also announced industrial copilots embedded across engineering and manufacturing software to reduce workflow friction and accelerate adoption [23]. This supports the argument that competitiveness is reinforced when AI is operationalized into routines and human systems, consistent with evidence on engagement and HR digitalization mechanisms [25, 29].

4.2. Bulgaria: why capability mediation matters even more

Bulgarian enterprise studies highlight that connectivity alone is insufficient for industrial digital maturity. Transformation requires ecosystem strengthening, platform development, and structured change management [2, 3, 5, 7]. Resistance to change and lack of reengineering skills are reported barriers, reinforcing the need for KOL, learning routines, and HR digitalization as adoption infrastructure [4, 19, 20, 27].

4.3. Synthesis: what actually creates competitive advantage

Across literature and cases, three recurring patterns emerge:

- Technology is necessary but insufficient: adoption alone does not guarantee competitiveness [10, 24, 33].
- Embedding beats pilots: value compounds when AI/IoT/automation are institutionalized into daily routines, with governance and iterative improvement [8, 15].
- Leadership and human systems are multipliers: KOL supports innovation under turbulence through knowledge sharing quality and KM capability [20, 19], while e-HRM and HR analytics strengthen adoption, engagement, and workforce readiness [31, 25, 29, 34].

Additionally, the regulatory environment can influence digital transformation performance, particularly for SMEs and ecosystem-level digitalization [26].

5. Conclusion

Industrial competitiveness in the AI era is not determined by technology adoption alone but by the ability to build an integrated capability system: IoT-enabled data infrastructure, AI decision intelligence, automation-based stability and precision, and continuous improvement enabled by agile execution and workforce readiness. Evidence from steel and mining shows that measurable operational gains depend on internal capability ownership, adoption routines, and iterative model improvement—not one-time deployments [15, 8]. Siemens' ecosystem strategy further indicates that Industrial AI is moving toward lifecycle-integrated architectures where digital twins and copilots embed intelligence into daily workflows [23].

The reviewed literature reinforces that knowledge-oriented leadership and knowledge management capabilities enable organizations to convert digital tools into innovation and performance under technological turbulence [19, 20]. Digitalization management and agile/dynamic capabilities mediate outcomes [21, 27, 33], while e-HRM and HR analytics provide the human systems infrastructure required for scaling and sustaining advantage [31, 25, 29, 34]. Regulatory frameworks can further shape digital transformation capacity and outcomes, especially for smaller firms [26].

In sum, industrial enterprises that treat AI/IoT/automation as a strategic capability program—not a technology project—are more likely to achieve durable competitiveness in global markets [1, 10, 33].

References

- [1] Barney J. Firm resources and sustained competitive advantage – Journal of Management, 17, 1991, 99–120.
- [2] Gigova T., Nikolova-Alexieva V., Valeva K., in: Proc. Int. Conf. Creative Business for Smart and Sustainable Growth (CREBUS), 2019 (IEEE, 2019).
- [3] Gigova T., Valeva K., Nikolova-Alexieva V., in: Proc. Int. Conf. Creative Business for Smart and Sustainable Growth (CREBUS), 2019 (IEEE, 2019).
- [4] Gigova T., Nikolova-Alexieva V., Valeva K. Resistance against changes in Bulgarian industrial enterprises – reasons and methods for overcoming – AIP Conference Proceedings, 2449, 2022, 070014.
- [5] Gigova T., Valeva K., Nikolova-Alexieva V. Development of digital business ecosystems through digital transformation of industrial enterprises – AIP Conference Proceedings, 2980, 2024, 070002.
- [6] Nikolova-Alexieva V., Valeva K., Gigova T. Eco-innovation activity of industrial enterprises in Bulgaria – AIP Conference Proceedings, 3274, 2025, 080013.
- [7] Nikolova-Alexieva V., Valeva K., Gigova T. State of the digital economy and the place of Bulgaria – AIP Conference Proceedings, 3274, 2025, 080012.
- [8] Conger R., Robinson H., et al. Inside a mining company's AI transformation – McKinsey & Company, 2020.
- [9] Deloitte. Navigating the Future of Work: Insights on AI and Automation – Deloitte, 2023.
- [10] Fahrudi A.N.L.I., et al. Strategic business research evidence on digital transformation and competitiveness mechanisms – Strategic Business Research, 2, 2026, 100036.
- [11] Gartner. Top 10 IoT Technologies – Gartner, 2023.
- [12] IFC. Cybersecurity for Smart Manufacturing: Protecting Your Investment – International Finance Corporation, 2022.
- [13] Industry Week. Toyota drives production with robotics and automation – IndustryWeek, 2023.
- [14] Ivanov I., Petrov P. Artificial intelligence for predictive maintenance applications – Applied Sciences, 10, 2020, 7446.
- [15] Kumar R., Dubashi N., Gupta R., Singh K. How a steel plant in India tapped the value of data—and won global acclaim – McKinsey & Company, 2019.
- [16] Lee J., Bagchi A. Internet of Things (IoT) in smart manufacturing – International Journal of Production Research, 57, 2019, 1–15.

- [17] McKinsey & Company. AI in Manufacturing and Operations: Patterns and value creation – McKinsey & Company, 2020.
- [18] Nestlé. Nestlé quality assurance in automated processes – Nestlé Corporate Reports, 2022.
- [19] Riaz M., Jie W., Ali Z., Sherani M., Yutong L. Do knowledge-oriented leadership and knowledge management capabilities help firms to stimulate ambidextrous innovation: moderating role of technological turbulence – *European Journal of Innovation Management*, 28, 2025, 235–270.
- [20] Sahibzada U.F., Janjua N.A., Muavia M., Aamir S. Knowledge-oriented leadership and organizational performance: mediating role of service innovation, knowledge sharing quality – *Journal of Organizational Effectiveness: People and Performance*, 11, 2024, 69–89.
- [21] Schmid D., Büechl J., Härting R.C., Beldarrain Y., Schwörer R., Naeve J. Opportunities and barriers of agility and digital processes in HR in SMEs – *Procedia Computer Science*, 246, 2024, 3605–3613.
- [22] Schwab K. The Fourth Industrial Revolution, Crown Business, 2016.
- [23] Siemens. Siemens unveils technologies to accelerate the industrial AI revolution at CES 2026 – Siemens Newsroom, 2026.
- [24] Skare M., de Obesso M., Ribeiro-Navarrete S. Digital transformation and European SMEs: a comparative study using DESI data – *International Journal of Information Management*, 68, 2023, 102594.
- [25] Stachová K., Stacho Z., Šamalík P., Sekan F. The impact of e-HRM tools on employee engagement – *Administrative Sciences*, 14, 2024, 303.
- [26] Succurro M., Donati C. The role of the regulatory framework in enhancing SMEs' digital transformation – *International Review of Law and Economics*, 83, 2025, 106263.
- [27] Tavana M., Sorooshian S., Ashrafiidehkordi R., Mina H. A readiness assessment model for human systems management digitalization in industrial organizations – *Journal of Industrial Production Engineering*, 42, 2025, 47–64.
- [28] Theotokas I.N., Lagoudis I.N., Syntychaki A., Prosilias J., et al. Factors affecting e-HRM practices: the role of organizational culture, cultural intelligence, and innovation – *Journal of Shipping and Trade*, 9, 2024, 13.
- [29] Verma S., Rana N., Meher J.R. Identifying the enablers of HR digitalization and HR analytics using ISM and MICMAC analysis – *International Journal of Organizational Analysis*, 32, 2024, 504–521.
- [30] Waheed A., Xiaoming M., Waheed S., Ahmad N., Tian-tian S. E-HRM implementation, adoption and its predictors: a case of SMEs of Pakistan – *International Journal of Information Technology Management*, 19, 2020, 162–180.
- [31] William A.A., Singh K. The assessment of e-HRM tools and their impact on HRM system effectiveness and organizational effectiveness – *Electronic Journal of Information Systems in Developing Countries*, 89, 2023, e12267.
- [32] World Economic Forum. The Future of Jobs Report 2021 – World Economic Forum, 2021.
- [33] Zaman S.A.A., Vilkas M., Zaman S.I., Jamil S. Digital technologies and digitalization performance: the mediating role of digitalization management – *Journal of Manufacturing Technology Management*, 36, 2025, 307–333.
- [34] Zeidan S., Itani N. HR analytics and organizational effectiveness – *International Journal of Emerging Technologies*, 11, 2020, 683–688.

The Persistence of Conflict: An Examination of Ten Critical Factors Why the Israeli–Palestinian Dispute Remains Unresolved

Maciej Huczko

Warsaw School of Economics, Warsaw, Poland

mhuczko@sgh.waw.pl

Abstract: The Middle East is a geographical and political region whose boundaries vary with analytical purpose. Depending on whether the emphasis is placed on security, politics, or economic integration, the region may be defined expansively—from Morocco to Pakistan (the “Greater Middle East,” a term popularized in the early 2000s)—or more narrowly, in line with traditional Orientalist framings, from Egypt to Iran. Although the region’s spatial scope is contested, one defining characteristic is widely recognized: chronic instability. At the center of this instability lies the Israeli–Palestinian conflict.

Since Israel’s establishment in 1948, the confrontation has evolved from an element of a broader Arab–Israeli conflict into a distinct and enduring dispute with regional and global ramifications. Although the conflict concerns a relatively small territorial space (approximately 20,000 square kilometers), it has repeatedly expanded in political significance—from local contestation to regional polarization and, ultimately, to internationalization. It remains salient across the Muslim world and continues to command sustained attention from global policymakers, who for more than seven decades have failed to broker a durable settlement.

The conflict often generates sharply polarized views and is frequently approached through simplified narratives that obscure its historical depth and institutional complexity. While its modern dynamics emerged in the twentieth century, both parties draw on longer historical, religious, and cultural claims in legitimizing competing rights. The Israeli–Palestinian conflict has also been instrumentalized by external actors, from Cold War geopolitics to post–September 11 security discourses. This article argues that the persistence of the Israeli–Palestinian dispute is best explained as a product of interacting political, structural, psychological, and international factors. By analyzing ten obstacles to peace, the paper offers a framework for understanding why repeated negotiations have failed and why conflict management has often substituted for conflict resolution.

KEYWORDS: MIDDLE EAST; ISRAEL; PALESTINE; UNITED STATES; CONFLICT RESOLUTION; INTERNATIONAL MEDIATION, ISRAELI-PALESTINIAN CONFLICT

1. Land and Identity

The end of World War II produced major transformations in borders, political alignments, and regional security environments, including in the Middle East. Since Israel’s establishment in May 1948, it has fought wars with one or more Arab neighbors, and for decades many Arab states viewed Israel as an externally enabled project that disrupted existing political and social orders through territorial appropriation. Over time, and with sustained support from third parties—most notably the United States—Israel normalized relations with several Arab states, beginning with Egypt in 1978 and extending to the United Arab Emirates and Bahrain through the 2020 Abraham Accords. A comparable normalization process has not occurred with the Palestinians.

For much of the conflict’s history, the core issues have been land and identity—two dimensions that are analytically distinct but politically inseparable. Territorial sovereignty is foundational to statehood, and therefore control of land remains central for both parties. Palestinians contend that the establishment and expansion of Israel occurred at their expense and that continued settlement growth on occupied territory entrenches dispossession and undermines the territorial basis of Palestinian statehood.



Figure 1. Palestine land loss since 1917

Source: Praxis UCC, “Human Rights Campaign: Focus on Palestine,” <https://praxisucc.ie/student-case-studies/student-projects/class-of-2022/human-rights-campaign-focus-on-palestine/>

Territorial loss also shapes identity formation. Displacement associated with Israel’s creation, subsequent wars, and settlement activity has produced a large and enduring refugee population. According to UNRWA, approximately six million Palestinian

refugees are eligible for services, many living in camps across neighboring states under conditions that perpetuate political marginalization and socioeconomic vulnerability. For many Palestinians, these experiences reinforce a collective narrative of dispossession and amplify perceptions of Israel as an occupying power.

Land and identity also converge in Jerusalem. The city is sacred to Judaism, Christianity, and Islam, and its governance and symbolic status remain among the conflict’s most contentious issues. International actors, including the United Nations, have frequently supported arrangements that protect access to holy sites and accommodate competing claims. Yet Jerusalem remains under Israeli control, and access regulations have at times been contested or restricted. For Palestinians, Jerusalem functions as a focal point of both territorial deprivation and symbolic exclusion, intensifying the conflict’s intractability.

2. Asymmetry Between the Parties

A second obstacle to conflict resolution is the persistent asymmetry between the parties in both hard and soft power. Hard power refers to material coercive capabilities—especially military strength and the willingness to employ it. Soft power, in this context, concerns legitimacy, attraction, and the ability to mobilize international support for one’s claims and strategies. The 1990–1991 Gulf War illustrates the relationship between these forms of power: Iraq possessed hard power sufficient to invade Kuwait, yet lacked the international legitimacy needed to sustain that action, enabling a U.S.-led coalition to respond with overwhelming military force and broad diplomatic backing.

Applied to the Israeli–Palestinian context, these criteria reveal profound imbalance. Israel possesses a highly capable military and is frequently ranked among the world’s strongest armed forces (Global Firepower 2017). By contrast, Palestinians lack conventional capabilities such as an air force, a navy, armored forces, or strategic weapons systems. The asymmetry has been reinforced by external assistance, particularly U.S. military aid, which has historically dwarfed the levels of aid provided to Palestinian authorities (Comparison of Military Strength of Israel and the Palestinians 2009).

This hard-power advantage enhances Israeli security, but it can also undermine Israeli soft power. The ability to impose “facts on the ground”—especially through settlement expansion—has generated significant international criticism and contributed to perceptions of

illegality or disproportionality. Palestinians, conversely, often attract international moral support precisely because their coercive capabilities are limited and their position is frequently framed as resistance to occupation rather than conventional interstate aggression. Cross-national surveys have at times indicated greater sympathy for Palestinians than for Israelis in global public opinion (Pew Research Center 2007). This imbalance is overwhelmingly visible when it comes to economy of Israel and Palestine. On the graph below presents the annual per capita income in USD in Israel, the West Bank and the Gaza Strip, depicting the difference in annual income per capita of nearly 95% compering Israel to the Gaza Strip and nearly 85% in case of the West Bank (Visualizing Palestine 2019)

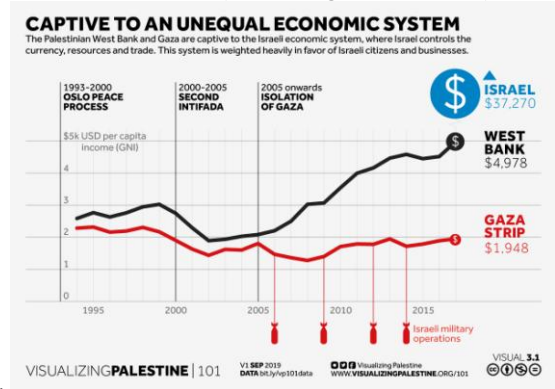


Figure 2. Captive to an Unequal Economic System
Source: Visualizing Palestine, “Captive to an Unequal Economic System”, <https://101.visualizingpalestine.org/visuals/captive-unequal-economic-system>

This data reveals a crushing difference between the parties – Isreal – a superbly developed and affluent society and on the Palestine – underdeveloped and poverty dominated region with citizens deprived of education, health care and perspectives.

3. The United States and the Conflict

No external actor has shaped the conflict more decisively than the United States. Following World War II, the United States emerged as a global power with unmatched economic and military capabilities and a willingness to intervene abroad to protect strategic interests. The Middle East has consistently ranked among Washington’s most consequential regions due to its geostrategic position, energy resources, the proliferation of weapons of mass destruction, and transnational terrorism, as well as the U.S.–Israel strategic partnership (Sasnal 2009). American support for Israel initially reflected domestic political dynamics and Cold War strategy. By 1948, U.S. policymakers increasingly perceived the Soviet Union as a long-term competitor, and Israel’s existence offered the United States a potentially reliable partner in a strategically important region. During the Cold War, the Middle East became a theater of superpower rivalry, culminating in heightened U.S. and Soviet involvement during the 1973 Yom Kippur War.

After the Cold War, U.S. priorities shifted toward broader order-building and crisis management, often relegating the Israeli–Palestinian conflict to episodic engagement. Palestinian support for Iraq during the 1990–1991 Gulf War further damaged Palestinian standing in Washington, strengthening Israel’s relative legitimacy in U.S. political discourse. After September 11, 2001, these dynamics intensified: Israel was widely framed as a counterterrorism ally and a frequent target of terrorism, while Palestinian actors were often associated—fairly or not—with terrorism in U.S. public debates. U.S. public opinion has tended to favor Israel over Palestine, including in Gallup polling (Gallup 2010). Not only Israel is favored over Palestine by the public opinion, but also this choice is presented by the politicians, the White House and the congress. Despite the fact that Israel is a well-developed and

strong economy with a modern military, it is heavily aided by the USA, placing Israel as the first recipients of US aid (Independent, 2024)

US foreign aid from 1946 to 2023

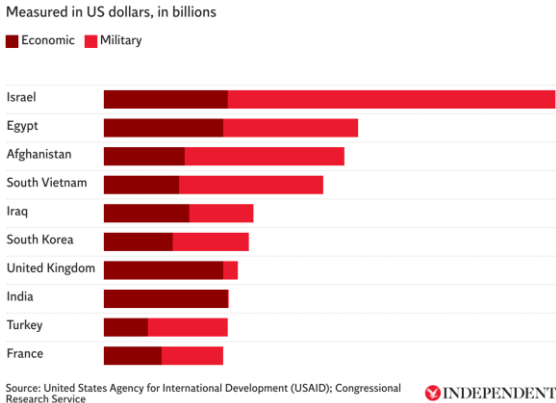


Figure 3: What weapons has the US paused sending to Israel – and what else do they supply?
Source: Independent, “What weapons has the US paused sending to Israel – and what else do they supply?”, <https://www.independent.co.uk/news/world/middle-east/israel-gaza-war-weapons-us-bombs-b2541453.html>

This aid, together with lack of US support of Palestine, creates disproportion between Israel and Palestine. It allows Israel to enter negotiations with Palestine from a power position which creates little incentives for the stronger state to show any kind of flexibility. Israel’s strength, partially derived from American support, results in lack of peace efforts on the Israel’s side.

4. Pro-Israeli and Pro-Palestinian Lobbying in the United States

Lobbying is a structural feature of U.S. politics and a significant mechanism through which organized interests influence foreign policy. Advocacy can be conducted by individuals or by institutionalized groups, and it often provides decision-makers with expertise, networks, and political support. Critics, however, describe lobbying as a legalized form of influence peddling that can privilege group interests over broader public goods. In Middle East policy, the pro-Israeli lobby is widely regarded as more influential than pro-Arab or pro-Palestinian advocacy networks. One reason is organizational coherence: while pro-Israeli lobbying tends to prioritize a relatively focused objective—strengthening U.S.–Israel ties—pro-Arab advocacy is often fragmented among state-specific or issue-specific constituencies (e.g., pro-Egyptian, pro-Saudi, pro-Turkish, pro-Palestinian), diluting messaging and political leverage. Social positioning has also mattered. In the post–September 11 environment, Arab- and Muslim-American political mobilization faced increased suspicion, while Jewish Americans generally enjoyed higher levels of institutional access and social integration. As the chart below presents, the place of both lobby groups (ethnic minorities) in the American society is much different and their agenda for US policymakers is also executed with different success. It is easier for American society and the policymakers to identify with the pro-Israeli minority.

Pro-Israeli lobby	Pro-Arab lobby
Single goal	Multi-goal
Treated as Americans	Treated as aliens
Sympathy (WWII)	No sympathy (9/11)
Fighting terrorism	Are terrorists
Well financed	Poorly financed
Prominent in society	Underrepresented

Figure 3: Pro-Israeli lobby vs. Pro-Arab lobby in the USA
Source: own work

Sustained U.S. military, diplomatic, and economic support has enabled Israel to maintain regional superiority. At the same time, such support can weaken incentives for compromise by reducing the costs of maintaining the status quo. Where a party enjoys security dominance and stable external backing, the political risks of negotiation may outweigh the benefits of concession.

5. Israeli Domestic Politics as a Challenge to Peace Process

Israel's domestic political context constitutes a major impediment to negotiated settlement. Persistent party fragmentation, polarization, and the expanded influence of nationalist and religious parties have reduced the capacity of Israeli governments to sustain credible peace initiatives. Coalition instability—driven by frequent elections and dependence on small parties—limits strategic planning and discourages far-reaching concessions (Shamir and Arian 1999).

In parallel, the strengthened role of right-wing and religious-nationalist actors has narrowed the political space for territorial compromise. These actors often frame withdrawal as both a security threat and a violation of historical or religious claims. The settlement movement has further entrenched these constraints by functioning as an institutionalized political force capable of shaping coalition bargaining and state policy (Zertal and Eldar 2007). The aspect of fueling and maintain the aura of existential threat and security has a unifying effect around hard, decisive leaders capable of defending the country and nation.

Public opinion reinforces these dynamics. Prolonged exposure to violence tends to harden attitudes, reduce trust in negotiations, and strengthen conflict-sustaining beliefs that delegitimize the adversary (Bar-Tal 2007). As a result, even when leaders endorse negotiations rhetorically, domestic incentives frequently discourage costly compromise, making peace efforts cautious, reversible, and vulnerable to political shocks.

6. Benjamin Netanyahu's Political Context

Benjamin Netanyahu's prolonged leadership has been associated with a strategic preference for managing rather than resolving the conflict. Coalition dependence on nationalist and religious parties—many opposed to Palestinian statehood—has constrained the scope for territorial concessions. As Inbar (2018) argues, Netanyahu's approach emphasized security, deterrence, and political stability over diplomatic breakthroughs.

Netanyahu's legal vulnerability has also shaped his governing strategy. Leaders facing legal and political threats often avoid high-risk initiatives that could fracture coalitions or mobilize opposition (Hassner 2020). This logic is particularly salient in a political environment where settlement expansion and hardline security positions function as bargaining currency with coalition partners.

Ideologically, Netanyahu has frequently expressed skepticism toward the two-state framework, emphasizing Israeli security control over contested territories (Huczko, 2005). Critics argue that such rhetoric contributes to the normalization of permanent control as both necessary and inevitable (Pappé 2017). Policy choices—including continued settlement expansion—have further undermined Palestinian trust, reinforcing perceptions that negotiations function as cover for territorial consolidation (Zertal and Eldar 2007). The combined effect is to institutionalize the status quo and to weaken conditions for meaningful negotiation.

7. Palestinian Political Division as an Obstacle to Peace

Internal Palestinian fragmentation has severely weakened the capacity to negotiate and implement agreements. The split between Fatah and Hamas—crystallized after Hamas's 2006 electoral victory and its 2007 takeover of Gaza—produced dual governance: the Palestinian Authority in parts of the West Bank and Hamas as the de facto authority in Gaza. This division has eroded political legitimacy and strategic coherence (Brown 2010).

Fragmentation also creates bargaining problems. Negotiations require a credible counterpart capable of making binding

commitments and enforcing compliance. Divided leadership increases the risk of “spoilers” and veto players who can undermine agreements through violence or noncompliance (Pearlman 2009). Public disillusionment has compounded these difficulties, as factional power struggles have at times overshadowed state-building objectives and weakened confidence in the peace process (Le More 2008).

External dynamics interact with these divisions. Hamas's refusal to recognize Israel and its endorsement of armed resistance provide Israel with grounds to question the feasibility of comprehensive negotiations. At the same time, the Palestinian Authority's security coordination with Israel has been criticized domestically as collaboration. This rivalry has increasingly become a contest over representation, identity, and the meaning of resistance, further reducing the likelihood of unified strategy (Milton-Edwards 2013). Lack of unity among the Palestinians can be used (and is) by the Israeli side in two ways at least. Firstly, there is no unified authority body representing Gaza and the West Bank. Therefore potential negotiations would not be bilateral but multilateral and therefore more complicated. Secondly, this Palestinian political division, serves also as an excuse and explanation for the Israelis who claim, that lack of progress in negotiations is caused by lack of serious, unified Palestinian representation. For the Israelis, sustaining such Palestinian division is useful in case of benefiting from prolonging the conflict in order to build new settlements, further destruction of Gaza and driving Palestinians from their land.

8. Trauma and Mistrust as Structural Barriers

Beyond institutional and territorial disputes, psychological and historical factors shape negotiation behavior. Collective trauma influences threat perception, identity construction, and willingness to compromise. Volkan (2001) describes “chosen traumas” as historical experiences that groups maintain as active elements of collective memory, shaping contemporary political behavior. For many Israelis, the Holocaust and repeated wars reinforce existential insecurity; for Palestinians, the Nakba of 1948 and ongoing occupation constitute a continuing trauma rather than a closed historical episode.

Intractable conflict environments generate narratives that justify one's own actions and delegitimize the opponent, sustaining mistrust and reducing openness to compromise (Bar-Tal 2007). The collapse of previous peace efforts has reinforced perceptions of bad faith. Kelman (2005) argues that trust cannot be produced solely through formal agreements; it requires mutual recognition of identity, suffering, and legitimacy.

Political psychology research further suggests that exposure to violence strengthens emotions—particularly fear and anger—that increase support for hardline policies and reduce willingness to make concessions (Halperin 2011). These processes generate a self-reinforcing cycle: violence deepens trauma; trauma strengthens mistrust; mistrust undermines negotiations. Consequently, peace initiatives focused exclusively on technical arrangements—borders, security, institutions—often fail to address the psychological foundations sustaining the conflict.

Furthermore, the model of the conflict is promoting a context in which reaching a peace deal is challenging. On one side, Israeli, there is an army, which is qualified, equipped and, as mentioned above, supported by the USA and on the other, Palestinian, the fighters are poorly equipped and far less effective. Also, the clashes are mainly in Gaza and the West Bank. As a result the human cost on both sides is incomparably uneven. As seen on the graph below, the number of casualties on both side is asymmetrical and just in the 2008-2020 period total death on the Palestinian side exceeded 5000 while the number of Israelis was 251 (McCarthy, 2021).



Figure 4: The Human Cost Of The Israeli-Palestinian Conflict

Source: Statista, The Human Cost Of The Israeli-Palestinian Conflict, <https://www.statista.com/chart/16516/israeli-palestinian-casualties-by-in-gaza-and-the-west-bank/?srsltid=AfmBOor42EcdT-SgmFfNDfnftChIeiCjZbQOXT50cv-fcDvPxSY9UMa>

Such as disproportion, especially bearing in mind that on the Palestinian side civilians vastly constitute to the human cost count, for the Palestinians, is a root of further resilience, hostility and a revenge driver. In this case, for the Palestinians, the trauma of losing the whole family is a source of hatred leading to escalation of violence.

9. The Absence of a Credible Enforcement Mechanism

Peace processes depend not only on agreement design but also on credible enforcement. In asymmetric conflicts, weak enforcement tends to privilege the stronger party, which faces limited costs for noncompliance (Pressman 2003). The Oslo process illustrates this vulnerability. While it created interim institutions and mutual recognition, it lacked robust enforcement provisions and depended heavily on bilateral trust and third-party mediation. When violations occurred—whether settlement expansion, attacks, or failures to meet obligations—there were limited mechanisms for adjudication or penalties. Pundak (2001) argues that Oslo assumed good faith while failing to develop tools for dealing with bad faith. International actors, especially the United States, typically acted as mediators rather than enforcers. Mediation without enforcement can intensify mistrust as both sides interpret inaction as bias or permissiveness. Without credible third-party guarantees, commitments remain politically fragile and easily reversible (Kelman 2005). The result is a repeated pattern of partial agreements followed by collapse, reinforcing public cynicism and empowering spoilers.

10. The Lack of a Unified International Strategy

International engagement has been extensive but often incoherent. Major actors—including especially the United States, the European Union, the United Nations, and regional powers—pursue overlapping but frequently unaligned strategies. This fragmentation reduces leverage and produces inconsistent signals that the parties can exploit (Tocci 2007). U.S. mediation has oscillated between intensive engagement and strategic neglect, limiting continuity and credibility (Quandt 2005). The European Union has emphasized legal norms and economic assistance but has often lacked political unity and enforcement capacity to translate positions into decisive influence.

The United Nations has repeatedly affirmed legal principles and Palestinian rights, yet enforcement is constrained by veto politics and great-power competition. When norms are inconsistently upheld, they risk becoming symbolic rather than regulative (Finnemore and Sikkink 1998). Regional and emerging powers further complicate coordination by pursuing distinct strategic interests, sometimes prioritizing broader rivalries over settlement. Conflicts persist when external actors fail to align incentives and pressures toward a shared end state (Zartman 2001). The process of negotiating Abraham Accords, and the Accords themselves illustrate approach of regional, Arab states towards the conflict, Palestine and Israel. The Palestinian cause, for the Arab actors, seem to be more of an obstacle for reaching business deals with Israel not a condition (Huczko, 2003).

Conclusion

The persistence of the Israeli–Palestinian conflict reflects the interaction of multiple structural, political, psychological, and international dynamics rather than a single identifiable cause. Although the dispute is frequently framed as a territorial conflict over a relatively small geographic area, the analysis presented in this article demonstrates that its endurance is rooted in a complex set of mutually reinforcing obstacles. Issues of land and identity remain foundational, shaping both the material and symbolic dimensions of the conflict and making compromise politically and emotionally costly for both societies. Yet, as presented in this article, the search for peace between Israel and Palestine encounters scores of obstacle. Land ownership, refugees and Jerusalem, the three most widely discussed, that occur to be paralyzed any negotiation initiatives are followed by other factors, which are less visible, yet equally important.

The profound asymmetry between the parties—militarily, economically, and diplomatically—affects negotiation incentives and outcomes. Israel's structural advantages, reinforced by sustained external support, particularly from the United States, reduce the urgency for concessions, while Palestinians' relative weakness increases their reliance on international sympathy and external mediation. These asymmetries are further embedded in international politics, where U.S. strategic interests, domestic lobbying dynamics, and inconsistent global coordination have contributed to a mediation framework that lacks both neutrality and effective enforcement.

Domestic political constraints on both sides also significantly impede progress. Israeli coalition politics and the growing influence of nationalist and religious actors limit the political space for territorial compromise, while Palestinian political fragmentation between competing governing authorities undermines the credibility and coherence of negotiation efforts. In addition, decades of violence, collective trauma, and entrenched mistrust have created powerful psychological barriers that cannot be resolved through institutional agreements alone.

Equally important is the absence of a credible enforcement mechanism and a unified international strategy capable of sustaining negotiated commitments. The experience of past peace initiatives—particularly the Oslo process—demonstrates that mediation without enforcement and coordination often produces fragile agreements vulnerable to collapse. Without consistent external pressure, credible guarantees, and coordinated international engagement, the incentives necessary to move the parties toward a durable settlement remain insufficient.

Taken together, these factors explain why repeated diplomatic initiatives have struggled to produce lasting progress. The Israeli–Palestinian conflict persists not simply because of unresolved territorial claims, but because the broader political, institutional, and psychological environment continues to sustain conflict management rather than conflict resolution. Understanding these interacting barriers is therefore essential for evaluating past failures and for designing future peace efforts that address not only the immediate political disputes but also the deeper structural conditions that perpetuate the conflict.

Bibliography and Netography:

- Bar-Tal, Daniel. 2007. "Sociopsychological Foundations of Intractable Conflicts." *American Behavioral Scientist* 50: 1430–1453.
- Brown, Nathan J. 2010. "The Hamas–Fatah Conflict: Shallow but Wide." *Middle East Journal* 64: 215–234.
- Comparison of Military Strength of Israel and the Palestinians. 2009. [Title as provided in manuscript; publication details not specified].
- Finnemore, Martha, and Kathryn Sikkink. 1998. "International Norm Dynamics and Political Change." *International Organization* 52: 887–917.
- Gallup. 2010. "Support for Israel in U.S. at 63%, Near Record High." [Title as provided in manuscript; publication details not specified].
- Global Firepower. 2017. *Global Firepower Ranking*. [Title as provided in manuscript; publication details not specified].
- Halperin, Eran. 2011. "Emotional Barriers to Peace: Emotions and Public Opinion of Jewish Israelis about the Peace Process." *Peace and Conflict* 17: 22–45.
- Hassner, Ron E. 2020. "Leaders under Pressure: Political Survival and Foreign Policy Risk." *International Security* 44: 7–45.
- Huczko Maciej, "The Abraham Accords and Their Legacy. A Fresh Approach to a Solution for the Middle East Conflict – from Trump to Biden.", *Cywilizacja i Polityka* 2023, nr 21: 92-107
- Huczko Maciej, "One-state solution, Two-state solution or no solution?" *The realpolitik paradigm of the Israeli-Palestinian conflict.*, *Cywilizacja i Polityka*, 202 nr 22: 58-80
- Inbar, Efraim. 2018. *Israel's National Security: Issues and Challenges since the Yom Kippur War*. London: Routledge.
- Kelman, Herbert C. 2005. "Interactive Problem Solving in the Israeli–Palestinian Case." *Peace and Conflict Studies* 12: 1–28.
- Le More, Anne. 2008. *International Assistance to the Palestinians after Oslo*. London: Routledge.
- McCarthy Niall, "The Human Cost Of The Israeli-Palestinian Conflict", *Statistica*, <https://www.statista.com/chart/16516/israeli-palestinian-casualties-by-in-gaza-and-the-west-bank/?srsltid=AfmBOor42EcdT-SgmFfNDfnftChIeiCjZbQOXT50cv-fcDvPXdSY9UMA> (03.03.2026)
- Milton-Edwards, Beverley. 2013. *Hamas: The Islamic Resistance Movement*. Cambridge: Polity Press.
- Pappé, Ilan. 2017. *The Idea of Israel: A History of Power and Knowledge*. London: Verso.
- Pearlman, Wendy. 2009. "Spoiling Inside and Out: Internal Political Contestation and the Middle East Peace Process." *International Security* 33: 79–109.
- Peleg, Ilan. 2010. "Israeli Right-Wing Politics and the Prospects for Peace." *Journal of Peace Research* 47: 395–407.
- Pew Research Center. 2007. "Views of the Middle East Conflict." [Title as provided in manuscript; publication details not specified].
- Praxis UCC. 2022. "Human Rights Campaign: Focus on Palestine." Accessed via <https://praxisucc.ie/student-case-studies/student-projects/class-of-2022/human-rights-campaign-focus-on-palestine/>
- Pressman, Jeremy. 2003. "Visions in Collision: What Happened at Camp David and Taba?" *International Security* 28: 5–43.
- Pundak, Ron. 2001. "From Oslo to Taba: What Went Wrong?" *Survival* 43: 31–45.
- Quandt, William B. 2005. *Peace Process: American Diplomacy and the Arab–Israeli Conflict since 1967*. Washington, DC: Brookings Institution Press.
- Sasnal, Patryk. 2009. *Politka Stanów Zjednoczonych wobec aktorów w konflikcie arabsko-izraelskim. Między Bushem a Obamą*, PISM, Warszawa 2009
- Shamir, Michal, and Asher Arian. 1999. "Collective Identity and Electoral Competition in Israel." *American Political Science Review* 93: 265–277.
- Tocci, Nathalie. 2007. *The EU and Conflict Resolution: Promoting Peace in the Backyard*. London: Routledge.
- Visualizing Palestine, "Captive to an Unequal Economic System", <https://101.visualizingpalestine.org/visuals/captive-unequal-economic-system> (25.25.2026)
- Volkan, Vamik D. 2001. "Transgenerational Transmissions and Chosen Traumas: An Aspect of Large-Group Identity." *Group Analysis* 34: 79–97.
- Watling Tom, Independent, "What weapons has the US paused sending to Israel – and what else do they supply?", <https://www.independent.co.uk/news/world/middle-east/israel-gaza-war-weapons-us-bombs-b2541453.html> (24.02.2026)
- Zartman, I. William. 2001. "The Timing of Peace Initiatives: Hurting Stalemates and Ripe Moments." *The Global Review of Ethnopolitics* 1: 8–18.
- Zertal, Idith, and Akiva Eldar. 2007. *Lords of the Land: The War over Israel's Settlements in the Occupied Territories*. New York: Nation Books.

Improving the Living Environment in Evacuation Shelters Using Light-Emitting Diode Lanterns and Partitions

Mana Oobashira¹, Mayumi Tanaka¹, Keiko Ishihara², Satoru Tada³, Masayuki Yamauchi³, Koji Kakugawa³, Takeshi Tanaka³, and Katia Vutova⁴

Hiroshima Prefectural Hiroshima Minami High School, Hiroshima, Japan¹

Hiroshima International University, Kure, Japan²

Hiroshima Institute of Technology, Hiroshima, Japan³

Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria⁴
tanaka@cc.it-hiroshima.ac.jp

Abstract: This study examines the effects of light-emitting diode (LED) lanterns and partition colors on the psychological condition of individuals in evacuation shelters. A previous questionnaire survey involving 193 participants evaluated emotional responses to four LED colors (yellow, green, blue, and red). Yellow light was most frequently perceived as calming and comfortable, whereas red light was strongly associated with tension and anxiety. Building on these emotional findings, we investigated environmental factors through an experiment involving blue, pink, and green partitions. The participants stayed inside each partition for 25 min, and their vital signs, including body temperature, pulse rate, and blood pressure, were measured every 5 min. The results indicate that blue partitions produced the most stable physiological responses, including lower systolic blood pressure and steady pulse rates, reflecting parasympathetic nervous system activation. In contrast, the pink and green partitions increased pulse rates and led to greater fluctuations, indicating higher stress. These findings demonstrate that appropriate lighting and partition colors can promote psychological stability and improve shelter environments. This study also highlights the importance of simple, low-cost environmental design strategies for stress reduction during prolonged evacuations.

KEYWORDS: EVACUATION SHELTERS, LIGHT-EMITTING DIODE LANTERN COLOR, PARTITION COLOR, PSYCHOLOGICAL STRESS, AUTONOMIC NERVOUS SYSTEM, ENVIRONMENTAL DESIGN

1. Introduction

As third-year high school students aspiring to pursue careers in nursing, we are concerned about the increasing frequency and severity of natural disasters, particularly earthquakes and heavy rainfall, which have caused substantial damage to communities in recent years. According to the Ministry of Land, Infrastructure, Transport and Tourism's "2020 White Paper on Land, Infrastructure, Transport and Tourism"[1], the probability of a major Nankai Trough earthquake occurring within the next 30 years is estimated to be approximately 80%. This probability has gradually increased since official assessments began in 2013. Given this situation, anticipating the potential occurrence of large-scale disasters and enhancing disaster preparedness and awareness at an early stage are considered essential. To explore practical actions that can be undertaken at present, volunteer activities were conducted in March of this year in disaster-affected regions, including Sendai, Miyagi Prefecture, and the Noto Peninsula in Ishikawa Prefecture. During these activities, evacuation facilities that were actively used were visited and systematically observed.

2. Background

(1) Participation in the Miyagi Fieldwork

Participation in the Sendai Disaster-Prevention Future Forum, held at the Sendai International Center on March 8, 2025, where we provided valuable insight into disaster preparedness. This year marked the 10th anniversary of the Great East Japan Earthquake. To link experiences and lessons derived from past disasters to future prevention efforts, the event featured lectures on disaster prevention, mitigation, and first aid, along with presentations, booth exhibitions, and workshops. During the first aid lecture, participants learned techniques for immobilizing injured areas using magazines, umbrellas, and string, as well as methods for constructing a simple stretcher from a blanket to reduce mortality caused by traumatic shock during disasters. Participation in the "Sendai Framework for Disaster Risk Reduction/5 Years Until the SDGs Target Year" session enabled engagement with five organizational representatives and university students, followed by discussions on disaster prevention and mitigation. These discussions highlighted the importance of preserving disaster memory and the difficulty of increasing awareness among individuals who have not directly experienced disasters.

In addition to these presentations, the event included a tour of Arahama Elementary School, which now serves as a museum dedicated to conveying the magnitude and severity of disasters.

Inside the building, the tsunami had left empty cans lodged in the ceiling of a first-floor classroom used by students, a space where such objects would not normally be trapped. The window frames bent by the tsunami, as shown in Figure 2, further demonstrate the destructive force of the disaster. These observations made disasters feel more immediate and increased the awareness that similar events could occur in our region.



Fig. 1 Arahama Elementary School



Fig. 2 Exterior wall of Arahama Elementary School

(2) Participation in the Oku-Noto Support Tour

Field observations conducted during the Oku-Noto Support Tour from March 28 to 31, 2025, provided direct experience in disaster recovery activities. In the Noto Peninsula, which was severely affected by the earthquake, participation in debris removal and community meal services (Figure 3) revealed that despite a year passing since the disaster, recovery remained stalled due to a shortage of volunteers and the extensive scale of damage (Figure 4). Restoration of lifeline services had also progressed slowly. Through

conversations with affected residents, we learned about the severe living conditions following the disaster, including the absence of heating, lack of electricity, and limited access to drinking water due to water supply disruptions. These conditions were further worsened during the January snowfall. We also stayed overnight in a temporary tent inside a supermarket used as an evacuation shelter. The space lacked heating, and despite the use of sleeping bags and blankets, it remained cold and uncomfortable, while noise from nearby occupants disrupted sleep.

At that time, we realized that prolonged exposure to such conditions would have a significant impact on both physical and psychological health, and we recognized the need to develop strategies to improve the living environment.



Fig. 3 Cooking okonomiyaki for the soup kitchen.



Fig. 4 Removal of soil and debris from inside a house.

(3) Issues Revealed Through Volunteering

Life in evacuation shelters significantly differs from daily life. In addition to major changes in the living environment, disaster survivors experience the loss of loved ones, homes, and employment, leading to anxiety and stress. These conditions are likely to have adverse health effects. Nurses are expected to improve the living environment in shelters and support evacuees in maintaining their health. Based on these observations, we focused on the shelter environment and disaster-prevention supplies to identify strategies for reducing psychological stress. We observed that partitions and tents used in shelters are available in various colors. During the Oku-Noto Support Tour, staying in a tent revealed physical and psychological stress from noise, such as neighboring snoring and conversation, as well as inadequate protection against cold weather. These experiences also revealed that living in a shared environment can be a significant source of stress during evacuation.

Light-emitting diode (LED) lighting color significantly influences psychological and physiological responses, especially in emergency environments such as evacuation shelters. A questionnaire survey involving 193 participants evaluated the effects of four LED colors (yellow, green, blue, and red) using handmade plastic (polyethylene terephthalate) bottle lanterns. The results demonstrated clear differences in emotional responses to light color. Yellow light was most frequently selected as the most calming and comfortable, indicating that warm tones promote relaxation and a sense of security. Green light was also highly rated and associated with nature, freshness, and visual comfort. In contrast, blue light produced mixed reactions; while some

participants reported calmness, others perceived it as cold or tense. The red light was identified as the most stressful, increasing both tension and anxiety. These findings indicate that appropriate LED color selection is essential for creating comfortable lighting environments. For practical application, yellow lighting is recommended for nighttime use, green for orientation and exit guidance, blue for task-oriented areas, and red for emergency warnings. Therefore, careful color design may improve visibility and psychological well-being in disaster situations.

In addition, heartwarming illustrations[2] (Figure 5) have been applied to white LED lanterns to promote emotional comfort among disaster-affected individuals.



Fig. 5 Lantern with a picture painted on the side.

Therefore, this study investigates the psychological effects of evacuation shelter partition colors and identifies those most suitable for promoting psychological stability among evacuees.

3. Research Objective

This study investigates whether different partition colors in evacuation shelters produce varying physical and psychological effects. Based on these results, this study aims to identify partition colors that minimize stress among evacuees.

4. Research Method

(1) Research Content

First, to examine the psychological effects of partition colors, participants stayed inside each colored partition for 25 min, and their vital signs were measured at designated times. Vital signs were assessed to observe changes in autonomic nervous system activity as indicators of psychological responses to partition color. The autonomic nervous system comprises sympathetic and parasympathetic components distributed throughout the body. Dominance of either system affects physiological functions and causes fluctuation of measured values. When the sympathetic nervous system is dominant, catecholamines are released, resulting in increases in body temperature, heart rate, blood pressure, and skin temperature. In contrast, when the parasympathetic nervous system becomes dominant, body temperature, heart rate, blood pressure, and skin temperature decrease. Increased stress is generally associated with an increase in body temperature, pulse rate, and blood pressure, whereas relaxation is associated with a reduction in these parameters[3,4,5].

During the experiment, partitions were placed around the desk to ensure that the selected color remained within the participants' field of view. Participants read inside each partition, and vital signs were measured every 5 min to observe fluctuations over 25 min. The experiment was conducted using three partition colors on separate days. Because partition colors can be broadly classified as warm, cool, and neutral, blue, pink, and green colors were selected. The following conditions were considered during the experiment.

1. To enable comparison, the experiment was conducted with two participants.
2. In evacuation shelters, partitions are used to separate families;

therefore, this situation was simulated in the experiment. Furthermore, given that the dominance of either the parasympathetic or sympathetic nervous system generally affects the body for approximately 20 min, the participants were stationed within the partitions for a 25-minute reading period.

3. Reading was selected because the restoration of lifeline services is often slow, making the use of electronic devices difficult. Therefore, reading was considered a simple and practical form of entertainment in such environments.



Fig. 6 Partition installation



Fig. 7 Experiment in progress

(2) Condition Setting

The experiment was conducted in a classroom to maintain stable temperature, humidity, and airflow. Initially, a gymnasium used as an evacuation shelter was considered. However, due to the mid-July timing and the physical condition of the student researchers, the classroom was selected as it better satisfies these requirements.

(3) Experimental Materials and Equipment

Blue, pink, and green partitions; an electronic blood pressure monitor; a pulse oximeter; a thermometer; a desk; a chair; a tape measure; and books.

5. Results

(1) Results for Participant A

Table 1: Changes in Vital Signs Under the Blue Partition (26.1°C and 50% Humidity)

Curtain Color ●Blue	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	35.9	65	99	59
5 min after the start	36.4	66	96	55

10 min after the start	36.6	69	93	51
15 min after the start	36.3	68	99	49
20 min after the start	36.9	67	85	56
25 min after the start	35.9	65	85	56

Participant A's impression: No notable changes were reported from the beginning to the end, and a calm state was maintained throughout.

Table 2: Changes in Vital Signs Under the Pink Partition (26.8°C and 50% Humidity)

Curtain Color ●Pink	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	36.6	81	98	67
5 min after the start	36.1	79	98	64
10 min after the start	35.9	74	96	55
15 min after the start	36.3	72	92	59
20 min after the start	36.8	80	94	47
25 min after the start	36.5	83	90	50

Participant A's impression: A calm state was maintained during the first 5–10 min; however, tension increased at the end.

Table 3: Changes in Vital Signs Under the Green Partition (25.1°C and 52% Humidity)

Participant A's impression: There was no particular change from the start to the end, and he remained calm throughout.

Curtain Color ●Green	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	36.5	87	96	64
5 min after the start	36.4	76	93	51
10 min after the start	36.1	83	91	62
15 min after the start	37	82	97	60
20 min after the start	36.9	76	94	57
25 min after the start	36.9	91	87	58

(2) Results for Participant B

Table 4: Changes in Vital Signs Under the Blue Partition (26.1°C and 50% Humidity)

Curtain Color ●Blue	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	36.3	79	98	60
5 min after the start	36.7	68	104	62
10 min after the start	36.6	69	97	65
15 min after the start	36.7	65	95	62
20 min after the start	36.7	71	102	63
25 min after the start	36.5	79	94	68

Participant B's impression: A calm state was maintained throughout the experiment, with no notable psychological changes reported.

Table 5: Changes in Vital Signs Under the Pink Partition (26.7°C and 50 Humidity)

Curtain Color ●Pink	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	36.7	75	115	71
5 min after the start	36.8	74	102	61
10 min after the start	36.8	74	101	64
15 min after the start	36.5	80	109	64
20 min after the start	36.9	74	102	62
25 min after the start	36.6	85	115	67

Participant B's impression: Approximately 15 min after the start, the surrounding noise became bothersome, and a desire for the experiment to end quickly was reported.

Participant B's impression: After 20 min, the surrounding noise became bothersome, and the bell increased anxiety. The concern that the experiment had not ended led to restlessness.

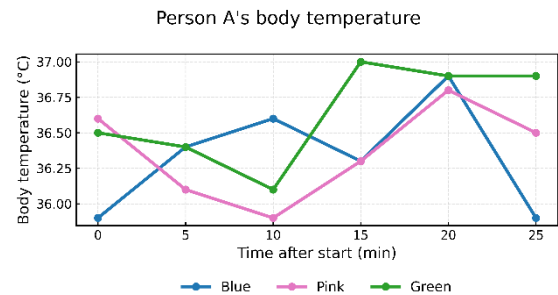
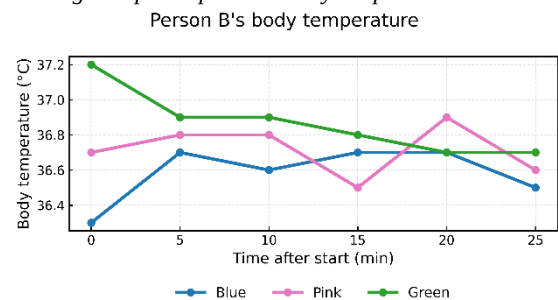
(3) Changes in Body Temperature, Pulse Rate, and Blood Pressure

Table 6: Changes in Vital Signs Under the Green Partition (25.8°C and 53% Humidity)

Curtain Color ●Green	Body Temperature (°C)	Pulse Rate (beats/min)	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)
Immediately before the start	37.2	79	100	57
5 min after the start	36.9	73	103	66
10 min after the start	36.9	82	108	64
15 min after the start	36.8	79	99	63
20 min after the start	36.7	92	103	60
25 min after the start	36.7	88	113	70

1. Body Temperature

The body temperature of participant A decreased when the partition was pink, whereas that of participant B decreased when the partitions were pink and green. With the other partition colors, body temperatures increased between the beginning and the end of the experiment.

**Fig. 8** Changes in participant A's body temperature.**Fig. 9** Changes in participant B's body temperature.

2. Pulse Rate

Figures 9 and 10 show that the pulse rates of participants A and B experienced minimal changes under the blue partition; however, they increased under the pink or green partitions.

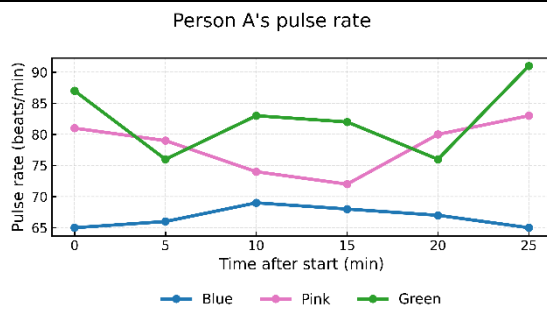


Fig. 10 Changes in participant A's pulse rate.

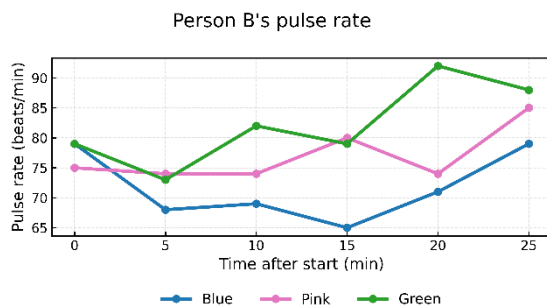


Fig. 11 Changes in participant B's pulse rate.

Figures 10 and 11 show the change in the pulse rate immediately before the start and 25 min after the start.

*Values in parentheses indicate the magnitude of change, with the value immediately before the start set as 0 and compared with the value after 25 min.

Participant A

Blue: 65 beats/min → 64 beats/min (−1 beat/min)
 Pink: 81 beats/min → 83 beats/min (+2 beats/min)
 Green: 87 beats/min → 91 beats/min (+4 beats/min)

Participant B

Blue: 79 beats/min → 79 beats/min (0 beats/min)
 Pink: 75 beats/min → 85 beats/min (+10 beats/min)
 Green: 79 beats/min → 88 beats/min (+9 beats/min)

3. Blood Pressure

Figures 12 and 13 show that the systolic blood pressure of both participants A and B was lowest under the blue partition.

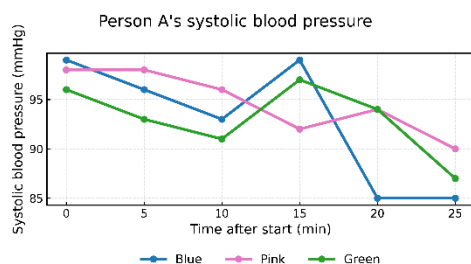


Fig. 12 Changes in participant A's systolic blood pressure

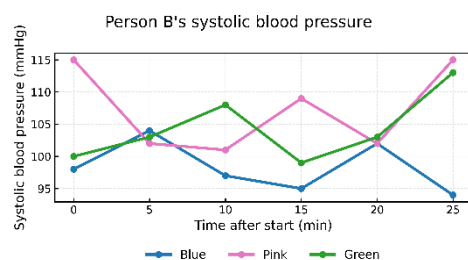


Fig. 13 Changes in Participant B's Systolic Blood Pressure

• Changes in values immediately before and 25 mins after the start are shown in Figures 12 and 13

*Values in parentheses indicate the magnitude of change, with the value immediately before the start set as 0 and compared with the value after 25 min.

Participant A

Blue: 99mmHg → 85mmHg (−14mmHg)
 Pink: 98mmHg → 90mmHg (−8mmHg)
 Green: 96mmHg → 87mmHg (−9mmHg)

Participant B

Blue: 98mmHg → 94mmHg (−4mmHg)
 Pink: 115mmHg → 115mmHg (0)
 Green: 100mmHg → 113mmHg (+13mmHg)

6. Discussion

The autonomic nervous system, a component of the peripheral nervous system that regulates the internal organs, comprises two divisions with opposing functions.

The sympathetic nervous system prepares organs and tissues for increased physical activity and is particularly active during physical exercise, mental arousal, or anxiety. When activated, the heart rate and respiration increase, the bronchi and pupils dilate, and digestion is suppressed. Blood vessels also constrict, leading to increased blood pressure and increased sweating.

In contrast, the parasympathetic nervous system is active during relaxation. Activation reduces heart rate and respiration while constricting the bronchi and pupils. Gastrointestinal motility and digestive secretion are promoted, supporting digestion and absorption.

Therefore, when the sympathetic nervous system is dominant, catecholamines are released, leading to increases in body temperature, heart rate, blood pressure, and skin temperature. In contrast, when the parasympathetic nervous system is dominant, the body temperature, heart rate, blood pressure, and skin temperature decrease.

Based on the body temperature results, both participants A and B showed decreases under the pink partition. Under the blue partition, increases were observed in both participants A and B. Under the green partition, participant A's body temperature increased, whereas that of participant B decreased. Body temperature generally decreases when the parasympathetic nervous system is dominant; thus, the results indicate that parasympathetic activity was enhanced under the pink partition. However, the increase under the blue partition, which has been associated with parasympathetic dominance in other studies, may be explained by air retention within the partition, leading to increased humidity during breathing.

The pulse rate results indicated increases for both participants A and B under the pink and green partitions, indicating sympathetic dominance.

Blood pressure results show that systolic blood pressure for both A and B was lowest under the blue partition, indicating that this condition may most strongly promote parasympathetic activity.

Based on subjective impressions, participant A remained calm throughout the experiment regardless of the partition color, whereas participant B became impatient under the pink and green partitions, resulting in greater physiological fluctuations.

7. Conclusion

This study demonstrates that both LED lighting and partition colors influence the psychological condition of individuals living in evacuation shelters. An evaluation using blue, pink, and green partitions revealed that the blue partition produced the most stable physiological responses, including lower systolic blood pressure and stable pulse rates, indicating parasympathetic activity and a relaxed state. These findings indicate that appropriately selected lighting and partition colors can reduce psychological stress and improve shelter environments. Although the study was conducted on a limited scale, it highlights the potential of simple, low-cost environmental design

strategies to support evacuees' mental well-being. Further studies under realistic shelter conditions are required to establish practical guidelines for disaster preparedness and shelter management.

Acknowledgments

We extend our heartfelt gratitude to the people of Wajima City and Suzu City in Ishikawa Prefecture, SAVE THE HIROSHIMA, the students of the Hygiene and Nursing Department and Specialized Department of Hiroshima Prefectural Hiroshima Minami High School, and the students of Hiroshima Prefectural Miyajima Technical High School for their invaluable cooperation for this study.

We also thank Enago (www.enago.jp) for their English language review.

References

- [1] White Paper on Land, Infrastructure, Transport and Tourism in Japan, 2020. (in Japanese)
- [2] Onuma Hiroaki: 6F Artist, ART BORN (Hiroshima). [https://www.artborn-hiroshima.net/news/artists/%e5%a4%a7%e6%b2%bc-%e5%af%9b%e6%98%8e/\(February](https://www.artborn-hiroshima.net/news/artists/%e5%a4%a7%e6%b2%bc-%e5%af%9b%e6%98%8e/(February) 13, 2026). (in Japanese)
- [3] Hashimoto H, ed. Kango-gaku nyumon 1: Jintai no shikumi to hataraki [Introduction to nursing 1: Structure and function of the human body]. 5th ed. Tokyo: Medical Friend; 2021. p.309. (in Japanese)
- [4] Ninomiya I, Suga H, editors. Cardiovascular Physiology: Function and Pathophysiology. Tokyo: Nankodo Co., Ltd.; 1993.p. 161. (in Japanese)
- [5] Sakai T, Okada T. Kaibo Seirigaku (Anatomy and Physiology). 9th ed. Tokyo: Igaku-Shoin; 2014. (Systematic Nursing Course: Basic Field. Structure and Function of the Human Body; Vol.1), p. 23, 243. (in Japanese)

Legal regulation problems in transport logistics: challenges and prospects

Irakli Kochadze¹, Ana Mgeladze².
Georgian Technical University¹ - Tbilisi, Georgia
Ivane Javakhishvili Tbilisi State University² – Tbilisi, Georgia
E-mail: i.kochadze@gtu.ge, ani.mgeladze@yahoo.com.

Abstract: *Transport logistics plays a decisive role in supporting global trade and economic development. The effectiveness of logistics systems largely depends on the quality, coherence, and adaptability of their legal regulation. In recent decades, profound changes in supply chains, technological innovation, and sustainability requirements have revealed significant shortcomings in existing legal frameworks governing transport logistics. This article analyzes the key problems of legal regulation in transport logistics, including fragmentation of legal regimes, challenges of multimodal transport, contractual and liability issues, digitalization, environmental regulation, and enforcement mechanisms. Using doctrinal legal analysis and comparative perspectives, the study identifies systemic weaknesses and proposes directions for regulatory improvement. The findings contribute to ongoing academic and policy debates on the modernization and harmonization of transport logistics law.*

KEY WORDS TRANSPORT LOGISTICS; LEGAL REGULATION; MULTIMODAL TRANSPORT; LIABILITY DIGITALIZATION; SUSTAINABILITY

1. Introduction

Transport logistics constitutes the backbone of modern supply chains, enabling the movement of goods across domestic and international markets. The growing integration of national economies and the expansion of global trade have increased the importance of efficient and predictable logistics systems. Legal regulation is a fundamental element of such systems, as it defines the rights and obligations of logistics actors, allocates risks, and ensures safety, security, and environmental protection [3].

Despite its central role, the legal framework governing transport logistics remains fragmented and, in many respects, outdated. Many regulatory instruments were developed for traditional, mode-specific transport operations and do not adequately address contemporary logistics practices such as multimodal transport, digital platforms, and integrated supply chain management [1]. As a result, legal uncertainty and regulatory inefficiencies persist.

This article aims to examine the principal legal regulation problems in transport logistics and to assess their implications for market participants and public authorities. It further explores potential directions for legal reform and harmonization.

2. Methodological and theoretical framework

The study employs a doctrinal legal research methodology, focusing on the analysis of international conventions, national legislation, and academic literature on transport and logistics law. The doctrinal approach is complemented by comparative legal analysis, which allows for the identification of similarities and differences between regulatory frameworks across jurisdictions. This combination makes it possible to assess the coherence, consistency, and practical effectiveness of existing legal regimes, particularly in the context of cross-border and multimodal transport operations.

The theoretical framework of the research is grounded in the principles of legal certainty and economic efficiency. Legal certainty is regarded as a key prerequisite for predictable contractual relations and effective risk allocation in transport logistics, while economic efficiency emphasizes the role of legal regulation in reducing transaction costs and facilitating trade. The theoretical framework is grounded in the concept of legal certainty and economic efficiency, emphasizing the role of law in reducing transaction costs and facilitating trade [6].

3. Functions of Legal Regulation in Transport Logistics

Legal regulation in transport logistics fulfills several interconnected functions. First, it establishes market access rules, including licensing and authorization of carriers and logistics

service providers. Second, it governs contractual relations among shippers, carriers, freight forwarders, and intermediaries. Third, it determines liability for loss, damage, or delay of goods, thereby allocating risks among parties [8].

In addition, transport logistics law addresses public interests such as safety, security, environmental protection, and fair competition. Effective regulation should strike a balance between facilitating efficient transport services and safeguarding societal objectives. However, achieving this balance has proven increasingly difficult in the context of globalized logistics networks.

4. Fragmentation of legal frameworks

4.1 Diversity of National Regulations

One of the most persistent and structurally significant problems in the legal regulation of transport logistics is the diversity of national legal systems. Each state maintains its own set of transport, commercial, labor, tax, and administrative regulations, all of which directly influence the organization and execution of logistics operations. In the context of cross-border transport, this regulatory diversity results in increased compliance costs, legal uncertainty, and administrative complexity for logistics operators, carriers, and freight forwarders [10]. Market participants are often required to navigate multiple legal regimes simultaneously, which complicates planning and risk management.

Differences in technical and operational requirements, such as vehicle standards, cabotage regulations, driver working conditions, licensing systems, and mandatory insurance coverage, further complicate international logistics operations. These disparities create barriers to market access and limit operational flexibility, particularly for small and medium-sized enterprises that lack the resources to adapt to diverse regulatory environments. Moreover, the absence or limited application of mutual recognition mechanisms between states exacerbates regulatory fragmentation, undermining legal predictability and impeding the development of integrated and efficient international logistics networks.

4.2 Limitations of International Legal Instruments

International legal regulation of transport logistics is primarily based on mode-specific conventions governing road, rail, air, and maritime transport. These instruments aim to promote legal harmonization by establishing uniform rules on contractual relations, carrier obligations, and liability regimes. However, their practical effectiveness remains limited due to incomplete ratification by states and significant differences in national implementation and interpretation [1]. As a result, the intended uniformity of international transport law is often undermined at the domestic level, leading to inconsistent legal outcomes.

Furthermore, the coexistence of multiple international conventions with distinct scopes, liability standards, limitation amounts, and defenses creates substantial legal complexity, particularly in cases involving multimodal or combined transport operations. When a single logistics chain involves several transport modes, determining the applicable legal regime becomes problematic, especially if the location of loss or damage cannot be clearly identified. This fragmented legal landscape, often described as a “legal patchwork,” undermines predictability, increases the risk of disputes, and weakens legal certainty for transport and logistics actors, ultimately limiting the efficiency and reliability of international logistics systems.

5. Multimodal Transport and Regulatory Gaps

5.1 Absence of a Comprehensive Legal Regime

Multimodal transport has become a central component of modern logistics systems, allowing the coordinated use of different transport modes under a single contractual framework and contributing to greater efficiency, flexibility, and reliability in global supply chains. Through the integration of various modes of transport, logistics operators are able to optimize routes, reduce costs, and respond more effectively to operational and market demands.

Despite its growing importance, multimodal transport remains inadequately regulated at the international level, as there is no universally accepted and binding legal regime governing such operations [7]. Most legal systems continue to rely on mode-specific rules derived from existing international conventions, which creates legal uncertainty when determining the applicable liability regime, particularly in cases where the location of loss, damage, or delay cannot be clearly identified. This regulatory gap complicates claims handling and dispute resolution, increases transaction costs, and undermines legal certainty for logistics actors, thereby limiting the full potential of multimodal transport solutions.

5.2 Liability Allocation Issues

A central legal challenge in multimodal transport concerns the allocation of liability among carriers, freight forwarders, and other logistics service providers involved in a single transport operation. When loss, damage, or delay occurs, identifying the responsible party and determining the applicable legal rules is often complex, particularly in situations where the exact location or stage of transport at which the damage occurred cannot be clearly established [8].

The absence of clear and uniform liability standards across different transport modes leads to legal uncertainty and inconsistent outcomes in claims handling and dispute resolution. This uncertainty increases transactional risks and costs for market participants and weakens effective risk allocation. As a result, the lack of harmonized liability rules discourages the wider adoption of multimodal transport solutions, despite their potential economic and operational advantages.

6. Contractual Regulation and Liability

6.1 Standard Form Contracts and Inequality of Bargaining Power

Transport logistics contracts frequently rely on standard terms and conditions developed by carriers or large logistics service providers. Such standardization plays an important role in enhancing efficiency, reducing transaction costs, and facilitating the rapid conclusion of contracts in complex logistics operations. However, the widespread use of standard form contracts may also reinforce structural imbalances of bargaining power between contractual parties, particularly where smaller shippers or subcontractors are involved [1].

In practice, shippers and subcontractors often have limited opportunities to negotiate key contractual terms, including liability

limitations, exclusions of responsibility, choice of law, and jurisdiction clauses. These standardized provisions are typically imposed on a “take-it-or-leave-it” basis, which may lead to unequal risk distribution. Legal systems differ significantly in their willingness to intervene in such contractual arrangements, with some jurisdictions offering stronger protective mechanisms than others. This divergence results in uneven levels of legal protection and contributes to further fragmentation of contractual regulation in transport logistics.

6.2 Adequacy of Liability Regimes

Existing liability regimes in transport logistics differ considerably with regard to liability limits, available defenses, and the allocation of the burden of proof. These differences stem from the mode-specific nature of international conventions and their varied implementation at the national level. In many cases, the established liability limits are outdated and no longer correspond to the value of modern, high-value cargo or to the significant economic losses that may result from delay or disruption in contemporary supply chains [7].

This misalignment between legal liability standards and the economic realities of transport logistics undermines effective risk allocation and weakens the protective function of liability regimes. As a consequence, market participants may face inadequate compensation for losses, which can reduce trust in transport services and discourage investment in efficient and innovative logistics solutions.

7. Digitalization and Legal Challenges

7.1 Electronic Transport Documents

Digitalization has significantly transformed transport logistics through the increasing use of electronic contracts, electronic bills of lading, and real-time tracking and information systems. These technologies enhance transparency, speed, and efficiency within logistics operations and contribute to better coordination across supply chains. However, despite technological progress, many legal frameworks continue to prioritize or formally require paper-based transport documentation, which limits the full realization of digital benefits [9].

The lack of uniform legal recognition and acceptance of electronic transport documents creates barriers to interoperability and legal certainty, particularly in cross-border logistics operations involving multiple jurisdictions. Divergent national approaches to electronic documentation result in inconsistent legal treatment, increased administrative burdens, and reduced efficiency gains. This regulatory uncertainty discourages wider adoption of digital solutions and highlights the need for harmonized legal standards that recognize electronic transport documents as functionally equivalent to their paper counterparts.

7.2 Data Protection and Cybersecurity

Logistics operations increasingly depend on extensive data exchange involving both commercial and personal information, including shipment data, customer details, contractual records, and real-time tracking information. This growing reliance on digital technologies exposes logistics actors to significant legal, financial, and operational risks, particularly in the context of inconsistent data protection frameworks and insufficiently developed cybersecurity regulation across jurisdictions [5].

Divergent national approaches to data protection and cybersecurity compliance create uncertainty for cross-border logistics operations and increase vulnerability to data breaches, cyberattacks, and unauthorized access to sensitive information. Ensuring robust data security while simultaneously enabling efficient information sharing and interoperability between logistics stakeholders remains a key regulatory challenge, requiring coordinated legal standards and effective enforcement mechanisms.

8. Environmental Regulation and Sustainability

Transport logistics is a significant contributor to greenhouse gas emissions, air pollution, and other forms of environmental degradation, making it a key focus of contemporary environmental policy. In response to these challenges, states and regional organizations have introduced increasingly strict environmental regulations, including emission standards, carbon reduction targets, and requirements aimed at promoting energy efficiency and the use of cleaner transport technologies [4].

While such regulatory measures are essential for achieving sustainable development goals, divergent national and regional approaches create substantial compliance challenges and legal uncertainty for logistics operators, particularly those engaged in cross-border transport. Differences in environmental standards, reporting obligations, and enforcement practices may distort competition and increase operational costs. Moreover, the absence of harmonized environmental regulations can hinder long-term investment in green technologies and sustainable logistics solutions, underscoring the need for greater coordination and legal convergence in environmental regulation within the transport logistics sector.

9. Safety, Security, and Customs Regulation

Safety and security constitute core objectives of transport regulation, aimed at protecting human life, property, and the integrity of supply chains. However, significant differences in safety standards, control procedures, and enforcement practices across jurisdictions reduce the overall effectiveness of regulatory frameworks. In the context of international logistics, the duplication of inspections, security checks, and administrative procedures often leads to increased delays, higher operational costs, and reduced reliability of transport services [10].

Customs regulation remains a critical bottleneck in global supply chains, particularly in cross-border transport operations. Despite international initiatives to promote trade facilitation and streamline customs procedures, many customs regimes continue to rely on outdated legal frameworks and paper-based processes. Limited coordination and information sharing among customs authorities further exacerbate inefficiencies, impeding the smooth flow of goods and undermining the effectiveness of modern transport logistics systems.

10. Dispute Resolution and Enforcement

Disputes arising in transport logistics frequently involve multiple jurisdictions, diverse contractual arrangements, and the application of different national and international legal regimes. Such complexity is particularly evident in cross-border and multimodal transport operations, where conflicting laws and divergent procedural rules may apply simultaneously. Differences in judicial procedures, evidentiary standards, and enforcement mechanisms significantly complicate dispute resolution and undermine legal certainty for logistics actors [2].

Arbitration and other alternative dispute resolution mechanisms are often regarded as effective tools for resolving transport logistics disputes, due to their flexibility, expertise, and international enforceability. However, the effectiveness of these mechanisms largely depends on their consistent legal recognition and enforcement at the national level. Variations in domestic arbitration laws, court practices, and enforcement standards may limit the practical benefits of alternative dispute resolution, highlighting the importance of harmonized legal frameworks and effective international cooperation in this area.

11. Directions for Legal Reform

Addressing the identified problems requires a coordinated and forward-looking approach. Key reform directions include:

- Harmonization of international transport and logistics law

- Development of a comprehensive legal framework for multimodal transport
- Modernization of liability regimes
- Legal recognition of electronic documents and platforms
- Greater coordination of environmental and safety regulations

Such reforms require cooperation between states, international organizations, and industry stakeholders.

12. Conclusions

The legal regulation of transport logistics faces significant challenges arising from fragmentation, technological change, and sustainability pressures. Existing legal frameworks often fail to provide sufficient certainty, efficiency, and adaptability.

Modernizing and harmonizing transport logistics law is essential to support global trade, promote sustainable development, and ensure fair and efficient logistics markets. Continued academic research and international cooperation will play a crucial role in achieving these objectives.

13. References

- [1] Baughen, S. (2015). *Shipping Law* (6th ed.). London: Routledge.
- [2] Born, G. B. (2021). *International Commercial Arbitration* (3rd ed.). Alphen aan den Rijn: Kluwer Law International.
- [3] Branch, A. E. (2009). *Global Supply Chain Management and International Logistics*. London: Routledge.
- [4] European Commission. (2020). *Sustainable and Smart Mobility Strategy*. Brussels.
- [5] OECD. (2020). *Enhancing Cybersecurity in the Transport Sector*. Paris: OECD Publishing.
- [6] Posner, R. A. (2014). *Economic Analysis of Law* (9th ed.). New York: Wolters Kluwer.
- [7] Ramberg, J. (2011). *ICC Guide to Incoterms 2010*. Paris: ICC Publishing.
- [8] Tetley, W. (2008). *Marine Cargo Claims* (4th ed.). Montreal: International Shipping Publications.
- [9] UNCITRAL. (2017). *Model Law on Electronic Transferable Records*. New York: United Nations.
- [10] UNCTAD. (2021). *Review of Maritime Transport*. Geneva: United Nations.

Информационно осигуряване на междуинституционално взаимодействие при киберинциденти

Information Support for Interinstitutional Interaction in Cyber Incidents

Ivan Hristozov, Veselina Gagamova

Rakovski National Defence College, 82 Evlogi and Hristo Georgievi Blvd., 1504 Sofia, Bulgaria

ihristoz@rmdc.bg, v.gagamova@rmdc.bg

Abstract: Effective response to cyber incidents requires coordinated interaction and timely information exchange among multiple institutions. This paper examines the role of information support in facilitating inter-institutional cooperation during cybersecurity incident management. The study outlines the importance of structured information flows and well-defined organizational responsibilities in ensuring efficient coordination among stakeholders. The paper presents the capabilities of the technology for developing system architecture, focusing on the developing of a logical data model view using the Enterprise Architect software platform.

Keywords: CYBERSECURITY, CYBER INCIDENTS, INTER-INSTITUTIONAL COOPERATION, INFORMATION EXCHANGE, INCIDENT RESPONSE, ARCTEVTURE.

1. Въведение

С нарастващата зависимост на съвременните организации от комуникационните и информационните технологии, въпросът за ефективното управление на инциденти в областта на киберсигурността придобива все по-голямо значение. Един от ключовите елементи за успешното противодействие на подобни инциденти е изграждането на ефективна система за междуинституционално взаимодействие между различните структури и организации, които имат отношение към предотвратяването, откриването и реагирането при киберинциденти.

Цел на настоящата разработка е да се представят възможностите на технологията за изграждане на архитектура на система. Разработен е изглед на логически модел на данните с помощта на софтуерния продукт EnterpriseArchitect.

2. Междуинституционално взаимодействие при управление на инциденти в киберсигурността

Нормативната рамка, която регламентира междуинституционално взаимодействие при управление на инциденти в киберсигурността в Република България, се основава на редица стратегически и законодателни документи. Сред тях особено значение имат:

- Национална стратегия за киберсигурност на Република България „Киберустойчива България 2023“, която определя основните приоритети и насоки за развитие на националната политика по киберсигурност [1];
- Закон за киберсигурност, който регламентира националната система за управление на киберсигурността, отговорностите на институциите и изискванията към операторите на съществени услуги и доставчиците на цифрови услуги [2];
- Наредба за минималните изисквания за мрежова и информационна сигурност, която определя конкретните технически и организационни мерки за защита на мрежовите и информационните системи [3].

Тези документи формират основата на националната политика за управление на киберрисковете и осигуряват нормативната рамка за изграждане на устойчиви и надеждни системи за защита на информационната инфраструктура.

Междуинституционалното взаимодействие представлява процес на координирана дейност между различни институции, насочена към обмен на информация, синхронизиране на действията и осигуряване на своевременна реакция при възникване на инциденти в информационните системи и мрежи. В средата на софтуерното приложение Enterprise Architect описанието на връзките между оперативните възли се представя с оперативен изглед OV-2 Operational Node Connectivity Description (Фиг. 1). В рамките на тази организация на взаимодействие се определят ролите и отговорностите на участващите институции, както и механизмите за комуникация между тях.

При възникване на инцидент в комуникационните и информационните системи първоначалната реакция обикновено се осъществява на ниво организация. В повечето структури са определени конкретни длъжностни лица, които носят отговорност за наблюдението на системите и за предприемането на първоначални действия. Сред тях особено важна роля имат дежурният по киберсигурност и дежурният по комуникационни и информационни системи (КИС). Тези специалисти осъществяват непрекъснат мониторинг на състоянието на информационната инфраструктура, регистрират аномалии и потенциални заплахи и при необходимост задействат процедурите за реагиране при инциденти.

В случай, че установеният инцидент надхвърля възможностите на конкретната организация или има потенциал да засегне други структури, се активират механизмите за междуинституционално взаимодействие. Това включва уведомяване на компетентни органи, обмен на техническа информация за инцидента, както и координиране на съвместни действия за ограничаване на последствията и възстановяване на нормалната работа на системите.

3. Модел за управление и докладване на киберинциденти в рамките на организация

Организационния модел за управление и докладване на киберинциденти в рамките на дадена организация е представен на Фиг. 1. Изгледът OV-2, - описание на връзките между оперативните възли (OV-2 - Operational Node Connectivity Description) е разработен като диаграма на унифицирания езика за моделиране UML (Unified Modeling Language) със специализирания софтуер EnterpriseArchitect. Представя се взаимодействието със секторните и националните структури - екипите за реагиране при инциденти с компютърната сигурност (СЕРИКС, НЕРИКС).



Резултатите от анализа се обобщават в **окончателен доклад за инцидента**, който се изпраща към съответния Секторен Екип за Реагиране при Инциденти с Компютърната Сигурност - СЕРИКС. Секторният екип анализира постъпилата информация

Задачата на ЕРИКС е да наблюдават за инциденти, да подават ранни предупреждения и сигнали. Тези задачи са определени от закона и от стратегията.

Ръководителят свиква екипа за реагиране при инциденти с компютърната сигурност и дава указания. Екипът започва разследване.

След разследването трябва да се изготви **анализ на инцидента**. Този анализ се прави от екипа за реагиране. Изготвя се **окончателен доклад за инцидента**, който се изпраща към секторния СЕРИКС.

След това секторният екип докладва на Националния Екип за Реагиране при Инциденти с Компютърната Сигурност – НЕРИКС.

Националният екип е в Дирекция „Международна информационна сигурност“ към Министерството на електронното управление. Там се намира националният ЕРИКС и секторния ЕРИКС за администрацията.

Уведомлението за инцидент, съдържа:

- кратко описание;
- лице, подаващо уведомлението – име, фамилия, електронна поща, телефонен номер;
- лице за контакт – име, фамилия, електронна поща, телефонен номер;
- дата и час;
- тип на инцидента;
- има ли трансгранично въздействие.

Относно типа на инцидента няма предварително дефинирана класификация дали е вътрешен или международен. Това може да се уточнява допълнително.

4. Модел на организационните взаимоотношения (OV-4) и логически модел на данните (OV-7)

Организационните взаимоотношения в структурата се представят чрез оперативен изглед OV-4 (Operational View -4 Organizational Relationships Chart). Необходимо е да съществува съответствие, т.е. елементите на изгледа OV-4 да се наслагват с тези в OV-2, както и с останалите модели на архитектурата. Тя се разработва чрез прилагането на архитектурния подход и използването на архитектурна рамка за разработването на различните изгледи от архитектурата на системата [4, 6].

Моделът на организационните взаимоотношения е представен на Фиг. 2. чрез диаграма на организационните взаимоотношения (OV-4) Той е разработен като диаграма на езика за моделиране UML със специализирания софтуер Enterprise Architect.

Логическият модел на данните, необходими за информационно осигуряване на междуинституционалното

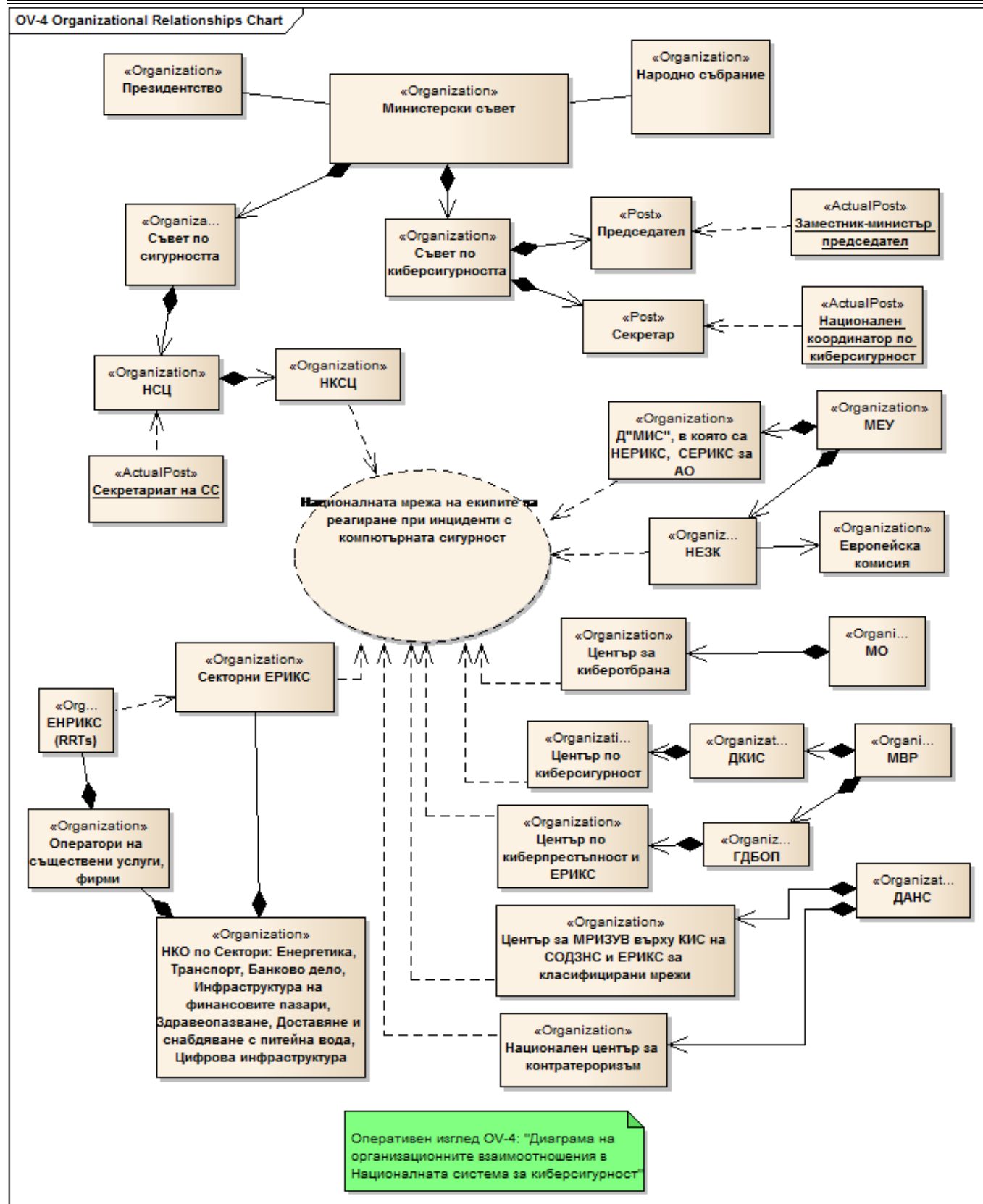
взаимодействие при киберинциденти [5] се представя в цялостната архитектура на системата за киберсигурност чрез оперативен изглед OV-7 (Operational View-7 Logical Data Model). Логическият модел на данните е представен на Фиг. 3 чрез диаграма на OV-7. Тя е разработена аналогично на езика за моделиране UML със специализирания софтуер Enterprise Architect.

Логическият модел на данните OV-7 представя модел на основните информационни обекти и документи, които се използват при управлението на киберсигурността и обработката на киберинциденти. В информационната база данни следва да бъдат включени няколко основни компонента, като: **опис на информационните активи, физическа схема и логическа схема на информационните потоци**.

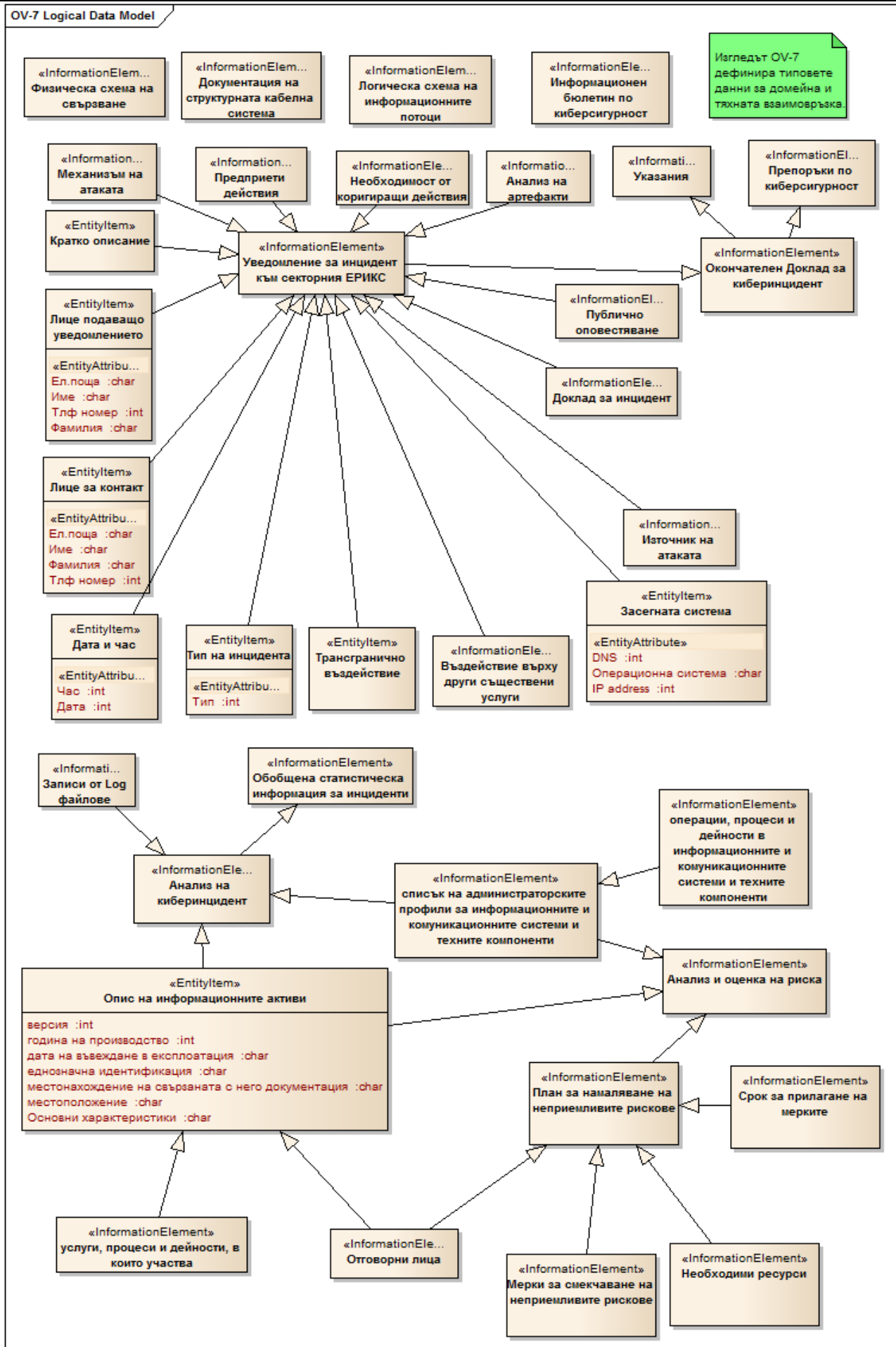
Съгласно Наредбата [3], в член 5 са определени видовете документация, които организациите трябва да поддържат. Един от основните документи е **опис на информационните активи**. В член 8 на съответната наредба са дефинирани елементите, които този опис трябва да съдържа. Сред тях са еднозначна идентификация на активите (например инвентарен номер, сериен номер или друг уникален идентификатор), основни характеристики, услуги, процеси и дейности, в които участва съответният актив, местоположение, година на производство, както и други релевантни параметри.

Информацията, извлечена от член 8 на наредбата, е интегрирана в представения модел чрез създаването на структура за **опис на информационните активи**, тъй като този елемент има ключово значение за процесите по **анализ и управление на риска**. В логическия модел на данните (OV 7) описът е представен на концептуално ниво, като включва основното понятие „опис на информационните активи“. При преминаване към физическия модел е необходимо да се въведат конкретните атрибути и полета, които описват детайлно характеристиките на активите.

Описът на информационните активи служи като основа за извършването на **анализ и оценка на риска**, както и за **анализ на киберинциденти**. Методиката за извършване на анализ и оценка на риска е регламентирана в **Приложение №3 към член 7, ал. 3 от Закона** [2], което представлява препоръчителна методика за оценяване на рисковете.



Фиг. 2 Диаграма на организационните взаимоотношения (OV-4)



Фиг.3 Логически модел на данните - OV-7 Logical Data Model

В рамките на тази методика се изготвя **регистър на риска**, който включва няколко основни компонента. В една от колоните се посочват информационните активи, идентифицирани в описа на активите. Следва колоната със съответните **заплахи и нежелани събития**, определени на базата на препоръчителната методика. За всяка идентифицирана заплаха се посочват **мерки за защита**, както и **оценка на въздействието**, която обикновено се извършва по скала от 1 до 5. Допълнително се оценява и **вероятността за реализиране на заплахата**, също по скала от 1 до 5. Получената информация може да бъде структурирана например под формата на електронна таблица, използвана за оценка и управление на риска.

Информационните активи играят съществена роля, както в процеса на **анализ и управление на риска**, така и при **анализа на киберинциденти**. В тази връзка важен елемент от системата е и **уведомлението за инцидент**, което представлява стандартизирана форма за регистриране и докладване на киберинциденти. Форматът на уведомлението е определен в **Приложение №7 към член 31 от Наредбата [3]**.

Уведомлението за инцидент съдържа редица полета, включително **тип на инцидента**, информация за самия инцидент и други описателни данни. Типът на инцидента е предварително дефиниран в нормативната уредба и се избира от предварително зададен списък. В уведомлението се включва също информация относно **възможно трансгранично въздействие**, като при необходимост се посочват и държавите, които могат да бъдат засегнати от инцидента.

В организационната структура за управление на киберинциденти, освен секторните и националните екипи за реагиране (СЕРИКС, НЕРИКС), е предвидено и **национално единно звено за контакт**. Това звено осъществява комуникацията с външни организации и международни партньорски структури. При установяване на трансгранично въздействие националното единно звено за контакт има задачата да осъществи взаимодействие със съответните европейски институции и механизми за координация.

Посочените функции се реализират в рамките на компетентните структури на **Дирекция „Мрежова и информационна сигурност“**, която координира обмена на информация и взаимодействието между националните и международните участници в процеса на управление на киберинциденти.

В заключение може да се отбележи, че междуинституционалното взаимодействие представлява ключов фактор за повишаване на устойчивостта на организациите срещу киберзаплахи. Чрез координирани действия, ефективен обмен на информация и ясно разпределение на отговорностите се създават условия за своевременно откриване на инциденти, ограничаване на тяхното въздействие и гарантиране на сигурността на комуникационните и информационните системи. Ефективността на междуинституционалното взаимодействие зависи от ясното дефиниране на процедурите за комуникация, наличието на установени канали за обмен на информация и подготовката на персонала, който участва в управлението на инциденти. В тази връзка е необходимо разработването на стандартизирани процедури, провеждането на съвместни обучения и упражнения, както и изграждането на доверие и оперативна съвместимост между участващите институции.

Благодарности. Докладът е написан благодарение на финансиране от Министерство на образованието и науката в изпълнение на Националната стратегия за развитие на научните изследвания 2017 – 2030 по Национална научна програма

„Сигурност и отбрана“, приета с решение на Министерски съвет № 731 от 21 октомври 2021 г.

Acknowledgements

This publication was financed by the Ministry of Education and Science in implementation of the National Scientific Program – Security and Defence that is funded by Ministry of Education and Science of the Republic of Bulgaria in implementation of National Strategy for the Development of Scientific Research 2017-2030 and was adopted by Decision of the Council of Ministers No. 731 of October 21, 2021.

5. Литература

1. Национална стратегия за киберсигурност на Република България „Киберустойчива България 2023, https://egov.government.bg/wps/wcm/connect/egov.government.bg/2818/52dfe919-ea2f-4cc6-b4df-2836a5094941/%D0%9D%D0%B0%D1%86+%D1%81%D1%82%D1%80%D0%B0%D1%82%D0%B5%D0%B3%D0%B8%D1%8F+%281%29.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_PPGAHG800PLV6060GL92MR3OU3-52dfe919-ea2f-4cc6-b4df-2836a5094941-pMBvWj (посетен на 7.03.2026)
2. Закон за киберсигурност, https://egov.government.bg/wps/wcm/connect/egov.government.bg/2818/34e3083b-93e1-4c60-b05c-00b32d0d16a5/%D0%97%D0%B0%D0%BA%D0%BE%D0%BD+%D0%B7%D0%B0+%D0%BA%D0%B8%D0%B1%D0%B5%D1%80%D1%81%D0%B8%D0%B3%D1%83%D1%80%D0%BD%D0%BE%D1%81%D1%82.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_PPGAHG800PLV6060GL92MR3OU3-34e3083b-93e1-4c60-b05c-00b32d0d16a5-pP2mCG5 (посетен на 07.03.2026)
3. Наредба за минималните изисквания за мрежова и информационна сигурност, https://egov.government.bg/wps/wcm/connect/egov.government.bg/2818/8e3f3fb7-b24b-47af-b174-8e0a7e7daaa2/%D0%9D%D0%9C%D0%98%D0%9C%D0%98%D0%A1.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_PPGAHG800PLV6060GL92MR3OU3-8e3f3fb7-b24b-47af-b174-8e0a7e7daaa2-nZPWXGh (посетен на 07.03.2026)
4. Popov P., Smilenova D., Vasileva V., Architectural Approach Usage in the Public Sector and Personal Data Protection, Proceedings of the 9th International Conference on Application of Information and Communication Technology and Statistics in Economy and Education (ICAICTSEE – 2019), volume: 100, Publishing Complex – UNWE, Sofia, Bulgaria, pp. 125-135, ISSN 2367-7635 (PRINT), ISSN 2367-7643 (online)
5. Vasileva V., Information Sharing Processes in Public Sector Cybersecurity Structures, Proceedings of the 9th International Conference on Application of Information and Communication Technology and Statistics in Economy and Education (ICAICTSEE – 2019), volume: 100, Publishing Complex – UNWE, Sofia, Bulgaria, pp. 136-147, ISSN 2367-7635 (PRINT), ISSN 2367-7643 (online).
6. Popov P., Smilenova D., Vasileva V., Architectural Approach Application to Building a System during Emergency Medical Examination, Protection of Personal Data and Finite-State Automata Architecture, Proceedings of the 8th International Conference on Application of Information and Communication Technology and Statistics in Economy and Education (ICAICTSEE – 2018), volume: 100, Publishing Complex – UNWE, Sofia, Bulgaria, pp. 166-175, ISSN 2367-7635 (PRINT), ISSN 2367-7643 (online),

Предизвикателства пред обучението на студенти от инженерни специалности по дисциплини свързани с проектиране и документиране

Георгиева Десислава¹, Янева Светлана²
 Технически Университет - София, бул. „Климент Охридски“ №8 ^{1,2}
 desy@tu-sofia.bg¹, svetlana_ianeva@tu-sofia.bg²

Challenges to education of engineering students in disciplines related to design and documentation

Georgieva Desislava¹, Yaneva Svetlana²
 Technical University of Sofia, 8 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria ^{1,2}
 desy@tu-sofia.bg¹, svetlana_ianeva@tu-sofia.bg²

Анотация: Въз основа на дългогодишен преподавателски опит на авторите, в областта на обучението на студенти от инженерни специалности в ТУ-София, направено проучване и последващ анализ са идентифицирани предизвикателствата, пред които са изправени преподаватели и студенти в процеса на обучение. Обърнато е внимание на възможностите за подобряване успеваемостта на студентите и ефективното усвояване на учебното съдържание в дисциплини свързани с проектиране и документиране. Направен е преглед на настъпилите през годините промени в учебното съдържание, които са наложени от промяната на материалната база и развитието на САД системите. Разгледана е значимостта на мотивацията и качеството на положените усилия от студентите за придобиването на солидни и трайни знания и умения.

Ключови думи: АНАЛИЗ НА ОБУЧЕНИЕ, ИНЖЕНЕРНИ НАУКИ, ПРОЕКТИРАНЕ, ДОКУМЕНТИРАНЕ, АВТОМАТИЗАЦИЯ, МОТИВАЦИЯ.

Abstract: Based on the authors' long-term teaching experience in the field of education of engineering students at the Technical University of Sofia, a study and subsequent analysis have identified the challenges faced by teachers and students in the learning process. Attention has been paid to the opportunities for improving student success and effective learning of the curriculum in disciplines related to design and documentation. A review has been made of the changes that have occurred over the years in the curriculum, imposed by the change in the material base and the development of CAD systems. The significance of the motivation and the quality of the efforts made by the students for the acquisition of solid and lasting knowledge and skills has been examined.

Keywords: ANALYSIS OF EDUCATION, ENGINEERING SCIENCES, DESIGN, DOCUMENTATION, AUTOMATION, MOTIVATION.

1. Въведение

Инженерните кадри са специалисти, които намират професионалната си реализация в почти всички области на икономиката. Инженерните квалификации обхващат области като електроника, електротехника и енергетика, компютърни науки и информационни технологии, транспорт, машинно инженерство, технологии, роботика и др. Навлизането на нови технологии и автоматизация изисква интердисциплинарни знания и инженерен подход към решаването на проблеми, поради това необходимостта от инженерни кадри се забелязва и в области от икономиката, които на пръв поглед нямат нищо общо с техническите науки (например: медицина, фармация, екология, аграрно стопанство, логистика и дори изкуства). Преводът на латинският корен на думата "ingenerare", означава "създавам". Инженерът е специалист, чиято дейност е свързана с проектирането, производството, усъвършенстването и поддържането в изправност на технически системи, механизми и апарати, които трябва да работят при определени условия. Чрез прилагането на научни принципи инженерите решават практически проблеми, систематизират и оптимизират производствени процеси, участват в производствени процес, монтаж и тестване на продукти. Фундаментална цели на инженерните науки е разработването и прилагането на системни подходи за анализ и решаване на практически проблеми чрез формулиране на оптимални и ефективни решения, основани на инженерно моделиране, симулации и оценка на ефективността. Получаването на качествено инженерно образование, базирано на фундаменталните принципи и отразяващо съвременните технологии се явява ключово за „производството“ на висококвалифицирани инженерни кадри.

2. Исторически преглед на обучението по проектиране и документиране

Анализът на историческото развитие на инженерното образование показва, че макар дисциплините, фокусирани върху техническото проектиране и документиране, да са се променяли по наименование (Техническо чертане, Техническо документиране, Въведение в инженерното проектиране, ОК и САД, Основи на инженерното документиране, Инженерна графика и др.), то тяхната основна функция остава константна – осигуряване на теоретична и практическа подготовка по стандартизирания език на техническата документация, необходим за ефективна комуникация в инженерната практика. Всяка една нова идея, всяко предложение за промени трябва да бъде документирано еднозначно, разбираемо и на универсален „език“, така че да бъде правилно разчетено от всеки един потребител с технически познания в съответната област, независимо от неговата националност, вид и степен на образование.

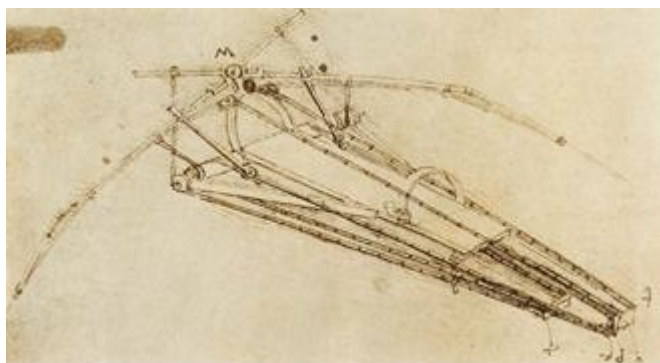
Науката, техниката и технологиите са в процес на непрекъснато развитие. Това поражда необходимостта преподавателите да следят новостите и периодично да актуализират учебните програми. Те трябва да запознават студентите не само с утвърдените принципи и методи за техническо документиране и проектиране, но и с актуалните тенденции и новости в съответната област. Наред с общовалидните принципи на техническото документиране, които могат да бъдат приложени във всички направления на инженерните науки, съществуват и специфични знания и умения. Те следва да бъдат усвоени в съответствие с профила на конкретната инженерна специализация.

Конструкторското документиране е вид визуализиране на модела с помощта на конструкторски документи, които трябва да отговарят на следните основни изисквания:

- да съдържат данните, които съответстват на предназначението на документа в конструкторския процес на изделието;
- да бъдат изпълнени на „технически език“, който е известен на специалистите по цял свят, за да може конструкторските документи да бъдат „прочетени“ от тях [1].

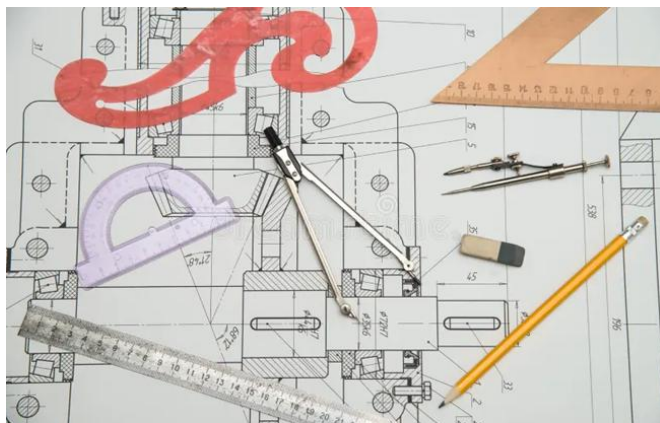
Извършеният анализ на методите за създаване на конструкторска документация на едно техническо изделие не установи, съществена промяна от миналото до днес. Все още се използват утвърдените правила за създаване на проекции по метода на Монж, и за означаване на размери в техническите чертежи. Същевременно се наблюдава приемственост и в процеса на изготвяне на схеми, при който се прилагат сходни принципи на графично представяне и стандартизация. Забелязват се несъществени разлики в начините на обозначаване на секущите равнини, на графичното изображение и място на поставяне на знак за грапавост, в оформянето на основния надпис и др. Несъществени промени има и при документирането на електрически схеми (промени в методиката за определяне на буквено цифров означение (БЦО), и в мястото на поставянето му на схемите). В своята същност графичните символи, които се използват при създаване на различните видове схеми и правилата за илюстриране на електрически връзки остават непроменени. Това създава известни затруднения при обучаването на студенти, завършили професионални гимназии, в които се използват стари помагала и учебници.

В древността изобретателите са представяли своите идеи с помощта на въглен върху платно или хартия (фиг. 1).



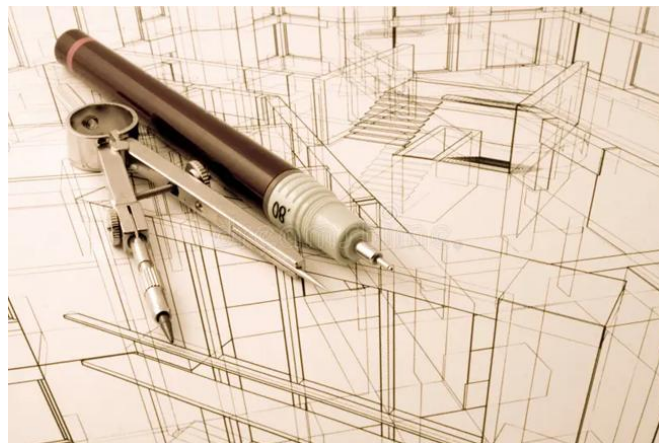
Фиг. 1 Проект на летателна машина от Леонардо да Винчи [2]

В недалечното минало конструкторското документиране се извършваше ръчно – върху хартиени формати с помощта на чертожни инструменти и графитни молив (фиг. 2).



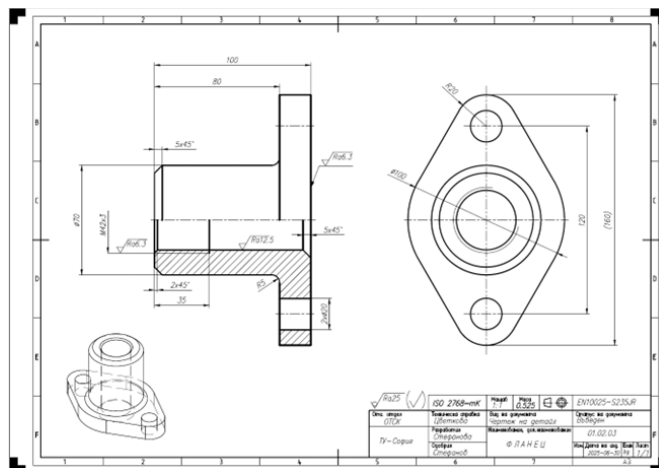
Фиг. 2 Ръчно изработване на конструкторска документация [3]

В определени случаи, в миналото, чертежите се пренасяха върху паус с мастило и рапидограф, с цел създаване на архивни или копируеми версии (фиг.3).



Фиг. 3 Конструкторски документ изпълнен с рапидограф [4]

Понастоящем визуализацията на документите може да се осъществи чрез различни видове изображения, изпълнени ръчно или автоматично, благодарение на бързото развитие на CAD (Computer Aided Design) системите (фиг 4).



Фиг. 4 Чертеж на детайл Фланец изработван от студентите в часовете по Инженерна графика запознаване със съществената функционалност на избрани CAD системи

CAD системите обединяват софтуерни и хардуерни похвати за геометрично моделиране, позволяващи проектиране и изпитване във виртуална среда (с помощта на компютър и компютърни симулации) на промишлени изделия, както и на инструментите, необходими за тяхното производство. Те успешно заменят чертожната дъска, както и много рутинни дейности, свързани с процеса на изработване на конструкторската документация. Според предназначението си CAD системите могат да позволяват както 2D, така и 3D моделиране [5] и документиране. Развитието на CAD инструментите увеличава прецизността на описанието на продукта и позволява технологичните инструкции да се извличат направо от CAD модела [6].

Учебните програми свързани с проектиране и документиране включват часове насочени както към усвояване на „технически език“ за представяне и разчитане на инженерни решения, така и с часове необходими за придобиване на умения за изработване точна, ясна, четлива и естетически издържана техническа документация. Ако преди 30 години графичното представяне на конструкторската техническа документация в учебния процес в ТУ-София се осъществяваше изцяло ръчно, преди 20 години бе въведен малък брой часове (например: 4 часа на семестър от общо 30

часа) за запознаване с възможностите на системите за компютърно проектиране и документиране. Понастоящем часовете в някои специалности са разпределени 50/50 (ръчно към компютърно документиране). Създаването на техническа документация изисква познаване и прилагане на утвърдените правила и стандарти за нейното изготвяне. Усвояването на тези умения се осъществява чрез практически занятия, в които се акцентира върху ръчното създаване на документи, най-често под формата на скици. В допълнение, в учебния процес са включени и занятия, насочени към запознаване със съществената функционалност на избрани CAD системи, използвани за 2D документиране и 3D проектиране и моделиране, с цел изграждане на практически умения за работа в съвременна дигитална инженерна среда и повишаване на подготовката на студентите за реални професионални предизвикателства.

3. Предизвикателства при обучението по дисциплини свързани с проектиране и документиране

Понастоящем преподавателите са изправени пред редица предизвикателства в процеса на обучение на студенти по дисциплини свързани с проектиране и документиране. Едно от тях е свързано с въвеждането на повече часове за запознаване и работа със съвременните CAD системи за 2D документиране и 3D проектиране и моделиране, на фона на намаляване на общия хорариум на дисциплините свързани с проектиране и документиране. Друго предизвикателство се явява и необходимостта от съвременната материална база (мощни работни станции, скъп софтуер). Поради тази причина за постигането на висококачествено обучение е необходимо за всеки студент да бъде осигурено индивидуално работно място, оборудвано с компютър, с подсигуриен специализиран софтуер.

Предизвикателство се явява и ограниченото учебно време, предвидено за работа в университета с изучаваните CAD системи. Ето защо постигането на устойчиви знания и умения изисква активна самоподготовка от страна на студентите. В рамките на тази самоподготовка студентите следва да прилагат и затвърждават усвоените по време на практическите упражнения знания. Това поражда необходимост от осигуряване на свободен достъп до изучаваните CAD платформи. В ТУ-София този проблем е разрешен благодарение на партньорството между университета и официалните представители на съответните CAD системи за България. По този начин студентите получават безвъзмезден достъп до лицензирани студентски версии на необходимите програмни продукти, инструкции за инсталация и при необходимост индивидуални кодове за активирането им. За студентите, които не разполагат със собствени технически средства, е осигурен достъп до специализирани компютърни работни станции в Библиотечно-информационния център (БИЦ) на ТУ-София. Усвоените знания се прилагат в процеса на разработване на курсови задачи и проекти. Степента на придобитите практически умения за работа с CAD системи за проектиране и техническо документиране се оценява чрез провеждане на контролни работи и изпити.

Предизвикателство се явява и отчетената от анализа негативна тенденция към понижаване на качеството на придобиваните знания и умения сред студентите в последните години. Този спад може да бъде обяснен чрез два основни фактора:

- редуциран брой учебни часове, предвидени за дисциплини, свързани с инженерно проектиране и техническо документиране в актуалните учебни планове;

- по-ниска мотивация за активно участие в учебния процес, задълбочаване на знанията и системна самоподготовка в част от студентите.

При преглед на стари учебни програми става видно, че в миналото дисциплините свързани с проектиране и документиране са изучавани в два или три семестъра в зависимост от професионалното направление. Като пример може да се посочи учебна програма по дисциплината „Приложна геометрия и инженерна графика“ за студентите от Машиностроителен факултет от 1998 г. [7]. Курсът е включвал:

- за I семестър: 30 часа лекции, 45 часа лабораторни упражнения, от които 3 часа за автоматизирано проектиране, 4 задачи с 9 подзадачи за курсова работа и 2 контролни работи (общ хорариум 75 часа);
- за II семестър – 15 часа лекции, 30 часа лабораторни упражнения, от които 2 часа за автоматизирано изпълнение на чертеж на детайл и 2 часа в измервателна лаборатория, 4 задачи с 8 подзадачи за курсова работа и 1 контролна работа (общ хорариум 45 часа);
- за III семестър – 15 часа лекции, 30 часа лабораторни упражнения, от които 4 часа за автоматизирано изпълнение на конструкторска документация, 3 задачи с 8 подзадачи за курсова работа и 1 контролна работа (общ хорариум 45 часа).

При справка с учебния план към настоящия момент, може да се види, че дисциплината „Приложна геометрия и инженерна графика“ за студентите от Машиностроителен факултет е преименувана на „Инженерна графика“ [8], и че същата се изучава само в зимен семестър на втори курс (III семестър). Хорариумът включва 30 часа лекции, 45 часа лабораторни упражнения (общо 75 часа аудиторна заетост) и 135 часа извън аудиторна заетост (самостоятелна подготовка). Вижда се, че аудиторната заетост е намалела с повече от 50%, като в същото време учебния материал, който трябва да бъде усвоен се е увеличил, заради предизвикателствата от бързото развитие и внедряване на CAD системите за проектиране и документиране, както и от необходимостта бъдещите инженери да усвоят необходимите знания и умения за работа с тях. Тук трябва да споменем, че в част от учебните дисциплини, в някои от професионалните направления часовете предвидени за лекции са намалени до 15 часа (например: ИГ за студенти Автомобилна Електроника, ФЕТТ [9], 60 часа аудиторна заетост и 120 часа извън аудиторна заетост), а също така има специалности, в които часовете за лабораторни упражнения са сведени до 30 часа (например: ИГ за студенти Интелигентни системи и изкуствен интелект, ФИТ [10], 60 часа аудиторна заетост и 120 часа извън аудиторна заетост). Курсовите задачи са намалени като брой и съдържание.

Съществено предизвикателство пред преподавателите се явява и повишаването на качеството на усвоените знания и умения чрез стимулиране на вътрешната мотивация на студентите. От особено значение е системната самоподготовка за усвояване на придобитите по време на лекции и практически упражнения знания, изграждането на навики за самостоятелно учене и целенасочено надграждане. Ефективна стратегия в този контекст е насърчаването на творческото мислене и критичния подход към усвоявания материал.

Въвеждането на съвременните технологии, в частност CAD системите и широката достъпност до информация в интернет също може да бъде разгледано като предизвикателство при обучението по дисциплини свързани с проектиране и документиране. В процеса на разработване и предаване на задачи за самостоятелна работа (курсони задачи и проекти) се наблюдава възможност за прилагане на т. нар. Copy/Paste. Някои студенти биват изкушавани от възможността вместо

сами да разработят поставената им задача, да потърсят в интернет пространството нещо разработено от друг, или да прибегнат до помощта на изкуствен интелект. Така те не успяват да разгърнат и използват пълноценно своя интелектуален и творчески потенциал. Резултатът от подобен подход е формалното изпълнение на поставената задача, без съгответстващо усвояване на реални знания и умения. Тук преподавателят трябва да съумее да премести акцента от стремеж към получаване на оценки без реално съдържание, към стремеж за постигане на трайни и приложими знания, които да подпомогнат успешната професионална реализация на студента.

По време на проучването се проведеха срещи и разговори с бивши възпитаници на ТУ-София, завършили инженерни специалности. Те потвърждават, че придобитите в рамките на дисциплините по проектиране и документиране знания и умения са оказали съществено влияние върху тяхната професионална реализация. В редица случаи посочването на компетентности, свързани с работа в CAD среди (както за 2D документиране, така и за 3D моделиране), в автобиографията е допринесло за успешното им наемане на работа. Подобна информация се потвърждава и от представители на бизнеса в областта на проектирането на машини и съоръжения, които подчертават, че търсените кандидати трябва да притежават комплекс от умения – както за правилно интерпретиране и създаване на техническа документация, така и за ефективна работа с CAD системи за 2D и 3D проектиране.

4. Заключение

Направеният анализ показва, че част от основните предизвикателства, пред които са изправени преподавателите, обучаващи студенти от инженерни специалности по дисциплини, свързани с проектиране и техническо документиране, произтичат от динамичното развитие на техниката, технологиите и по-специално на CAD системите за 2D документиране и 3D проектиране и моделиране. Това развитие води до непрекъснато нарастване на обема от нови знания и умения, които трябва да бъдат включени в обучителния процес. В същото време се наблюдава трайна тенденция към намаляване на хорариума на тези дисциплини в актуализираните учебни планове. Така се стига до парадоксалната ситуация, при която значително по-голям обем от учебно съдържание следва да бъде преподаван и усвояван в значително по-кратки времеви рамки.

Съвременният преподавател е изправен пред предизвикателството не само да предаде необходимата учебна информация, но и да я представи по начин, който ангажира вниманието на студентите и провокира тяхното познавателно любопитство. Те трябва да прилагат ефективни педагогически подходи, като основна цел на обучението следва да бъде стимулирането на умения за критично мислене и т.нар. „четене с разбиране“, както и мотивирането на студентите да надграждат знанията и уменията си чрез активна самоподготовка и самоосъзната извън аудиторната заетост.

За повишаване на мотивацията и осъзнаване на практическата значимост на учебния материал, е препоръчително организирането на срещи между студенти и представители на бизнеса. Тези взаимодействия предоставят възможност за запознаване с реалните изисквания на пазара на труда и очертават ясно какви компетенции е необходимо да бъдат придобити по време на обучението с оглед бъдеща професионална интеграция.

5. Литература

1. Сандалски Б., Горанов П., Динев Д., Николова И., *Основи на кнструирането и CAD* (Софттрейд, София, 2007), ISBN 978-954-334-062-0
2. https://en.wikipedia.org/wiki/Leonardo_da_Vinci
3. <https://thumbs.dreamstime.com/b/technical-drawing-architectural-tools-41001617.jpg>
4. <https://thumbs.dreamstime.com/b/architecture-blueprint-8185193.jpg>
5. https://en.wikipedia.org/wiki/Computer-aided_design
6. Стоев А., Горанов П., *Инженерна графика и CAD* (Софттрейд, София, 2010), ISBN 978-954-334-109-2.
7. Curriculum for the discipline "Applied Geometry and Engineering Graphics" for students of the Faculty of Mechanical Engineering since 1998.
8. <https://tu-sofia.bg/uplan/МФ/Бакалавър/uplan-BME-BG-4y.pdf>
9. https://tu-sofia.bg/uplan/ФЕТТ/Бакалавър/UPlan_5-2_FETT_BAME.pdf
10. <https://tu-sofia.bg/uplan/ФИТ/Бакалавър/uplan-BISAI.pdf>

Връзка на обучението по стандартизация в ЕС с нивата на българската и европейска квалификационни рамки за образователни потребности

Станчев Георги¹, Илиева Боряна², Янева Светлана³
 Технически Университет - София, бул. „Климент Охридски“ №8^{1,2,3}
 gstanchev@tu-sofia.bg¹, bilieva@tu-sofia.bg², svetlana_ianeveva@tu-sofia.bg³

Connection of standardization training in the EU with the levels of the Bulgarian and European qualification frameworks for educational needs

Stanchev Georgi¹, Ilieva Boriana², Yaneva Svetlana²
 Technical University of Sofia, 8 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria^{1,2,3}
 gstanchev@tu-sofia.bg¹, bilieva@tu-sofia.bg², svetlana_ianeveva@tu-sofia.bg³

Анотация: В настоящата публикация са разгледани нивата на Българската квалификационна рамка, в съответствие с Европейската квалификационна рамка за образователни потребности в контекста на стандартизацията. Предложена е интеграцията на Българската квалификационна рамка с обучението по стандартизация. По този начин може да се уеднакви до голяма степен обучението по стандартизация в Европа, да се улесни признаването в различните държави на дипломи и сертификати от обучения, да се насърчи мобилността и да се повиши конкурентоспособността на българската работна сила.

Ключови думи: СТАНДАРТИЗАЦИЯ; ОБУЧЕНИЕ; ЕВРОПЕЙСКА КВАЛИФИКАЦИОННА РАМКА, БЪЛГАРСКА КВАЛИФИКАЦИОННА РАМКА.

Abstract: The publication discusses the levels of the Bulgarian Qualifications Framework, in accordance with the European Qualifications Framework for educational needs in the context of Standardization. The integration of the Bulgarian Qualification Framework with standardization training has been proposed. In this way, standardization training in Europe can be largely unified, the recognition of diplomas and training certificates in different countries can be facilitated, mobility can be encouraged, and the competitiveness of the Bulgarian workforce can be increased.

Keywords: STANDARDIZATION, TRAINING, EUROPEAN QUALIFICATIONS FRAMEWORK, BULGARIAN QUALIFICATIONS FRAMEWORK.

1. Въведение

В днешния динамичен свят на войни, бурно развитие на технологиите и икономически натиск върху Европа от страна на Китай и САЩ е от особено важно значение стандартизацията да подпомага колкото е възможно повече икономиката на Европа. На среща в Делфт на 17 и 18 юни 2024 г., в която взеха участие представители на високо ниво от Европейската комисия, CEN/CENELEC, DIGITALEUROPE, Технологичния университет в Айндховен, Министерство на икономиката и политиката в областта на климата, ETSI, национални и европейски органи по стандартизация, академици и др. бе подчертана важната роля на стандартизацията и необходимостта от обучение в тази област във всички нива на образованието.

С развитието на глобалната икономика и увеличаващата се свързаност между различните пазари и индустрии, стандартизацията играе ключова роля за улесняване на международната търговия и обмен на технологии. Стандартизацията не само осигурява съвместимост и качество на продуктите и услугите, но също така допринася за устойчивото развитие и иновациите в европейската икономика. В този контекст, обучението по стандартизация става все по-важно за професионалната квалификация и адаптивност на работната сила в Европа.

Въвеждането на стандартизацията в учебните програми на всички образователни нива предоставя възможност за изграждане на ключови компетенции у учащите, които не само отговарят на нуждите на пазара на труда, но и подпомагат професионалната мобилност в рамките на Европейския съюз.

Свързването на обучението по стандартизация с Българската, респективно с Европейската квалификационна рамка създава обща основа за признаване на умения и

компетенции в различните държави членки, като по този начин допринася за по-голяма съгласуваност и прозрачност в образователната система на ЕС.

Целта на изследването е да се направи връзка на обучението по стандартизация в ЕС с нивата на Българската и Европейската квалификационни рамки за образователни потребности. По този начин може да се уеднакви до голяма степен обучението по стандартизация в Европа и да се улесни признаването в различните държави на дипломи и сертификати от обучения.

2. Образователни квалификационни рамки

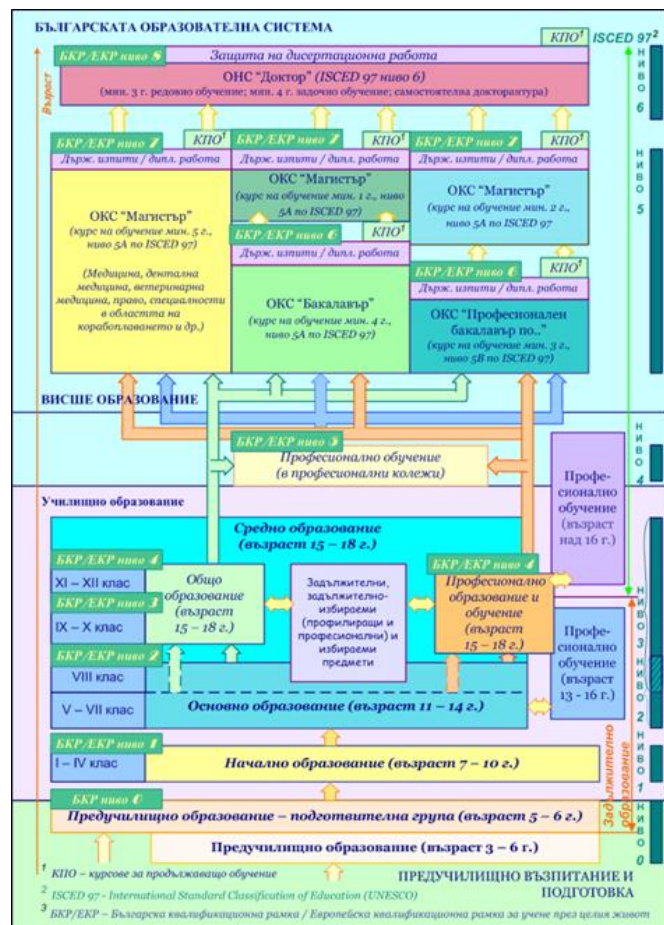
Европейска квалификационна рамка (ЕКР) е ключов инструмент в усилията на Европейския съюз за насърчаване на прозрачността, съпоставимостта и преносимостта на квалификациите между държавите членки и извън тях. Той служи като обща референтна рамка, която свързва различни национални квалификационни системи и рамки (НКР), улеснявайки взаимното разбирателство и признаване. ЕКР играе важна роля за подпомагане на трансграничната мобилност на учащите и работниците и ученето през целия живот.

ЕКР съдържа осем референтни нива определени от гледна точка на резултати от обучението (знания, умения, отговорност и самостоятелност). Резултатите от обучението изразяват това, което хората знаят, разбират и могат да правят в края на учебния процес. Отделните държави развиват национални квалификационни рамки (НКР) за прилагане на ЕКР. Всички държави, ангажирани с ЕКР, считат такива национални рамки за необходими, за да направят своите квалификации сравними между секторите и държавите.

До януари 2024 г. 36 държави официално са свързали своите НКР към ЕКР. Това са Албания, Австрия, Белгия

(Фландрия и Валония), България, Хърватия, Кипър, Чешката република, Дания, Естония, Финландия, Република Северна Македония, Франция, Германия, Гърция, Унгария, Исландия, Ирландия, Италия, Косово, Латвия, Лихтенщайн, Литва, Люксембург, Малта, Черна гора, Холандия, Норвегия, Полша, Португалия, Румъния, Сърбия, Словакия, Словения, Швеция, Швейцария и Турция. Останалите държави се очаква да ги последват през до края на 2025 г., което означава, че първият етап от съпоставянето на ЕКР е почти завършен [1].

На фиг. 1 е представена структурата на националната квалификационна рамка на българската образователна система.



Основно чрез държавните образователни стандарти е отбелязан значителен напредък в насърчаването на подхода, основан на резултатите от обучението в общото и професионалното образование, както и във валидирането на неформалното и самостоятелното учене. Прилагането на БКР на институционално ниво беше и все още е предизвикателство, особено във висшето образование, изискват се постоянни усилия за прилагането ѝ, за да може БКР да постигне целите си [5].

Съпоставяйки ЕКР и БКР се наблюдава, че двете квалификационни рамки имат много общо, но съществуват и някои различия между тях. Едно се изразява в тяхната приложимост и контексти на развитие. Докато ЕКР има за цел да предостави единна структура за квалификациите в рамките на ЕС, която да улесни мобилността и признаването на квалификации между държавите-членки, БКР е по-специфична и фокусирана върху нуждите на българската образователна и трудова система. Българската рамка, въпреки че е съобразена с принципите на ЕКР, се адаптира към локалните изисквания, като същевременно осигурява съответствие с европейските стандарти. По отношение на основните функции на двете рамки също може да се отбележи разлика: докато ЕКР има основно регионален (европейски) фокус, със задачи, свързани със стандартизацията и признаването на квалификациите между страните-членки на ЕС и е инструмент, който цели да улесни мобилността на гражданите в рамките на Европейския съюз и да осигури по-голяма съгласуваност на образователните системи. БКР е със силен национален фокус, насочена към регулирането на образователните и професионалните квалификации в България, с акцент върху местните нужди и особености. Тя има за цел да осигури съответствие на българските квалификации със стандартите на ЕКР, като същевременно отговаря на специфичните изисквания на националния трудов пазар. Разлика има и в контекста на нивата на обучение, както ЕКР, така и БКР разпределят квалификациите в осем нива, които обхващат всички етапи на образование – от началното и средно до висше и професионално обучение. Въпреки сходството в структурата, нивата в БКР са подредени в съответствие с националните образователни изисквания, което може да води до някои разлики в интерпретацията и прилагането на тези нива в българския контекст.

Въпреки тези различия, синхронизацията между двете рамки осигурява интеграция на българските квалификации в по-широкия европейски контекст и подпомага адаптацията към глобалните образователни стандарти, което допринася за улесняване на мобилността на специалистите и тяхното професионално развитие както в България, така и в ЕС.

3. Връзка на БКР и обучението по „Стандартизация“

Понастоящем На базата на своя дългогодишен преподавателски и експертен опит в областта авторите на публикацията предлагат следната връзка на нивата на БКР с обучението по „Стандартизация“:

Ниво 1

Ниво 1 обхваща: Общо образование – Начален етап на основното образование.

Обучаваните в това ниво следва да се запознаят с основни въпроси на стандартизацията, които са с познавателен и практически характер.

Теми и съдържание:

- Развитие на стандартизацията. Исторически преглед на развитието на стандартизацията.

- Стандарти. Същност на стандартите.
- Роля и значение на стандартите.

Ниво 2

Ниво 2 обхваща: Общо образование – Основно образование/ I Степен на професионална квалификация.

Обучаваните в това ниво следва да се запознаят с основните въпроси на стандартизацията, които са с професионален и практически характер.

Теми и съдържание:

- Международна стандартизация. Международни организации по стандартизация - Международна електротехническа комисия (IEC), Международна организация по стандартизация (ISO).
- Европейска стандартизация. Европейски организации по стандартизация – Европейски комитет по стандартизация (CEN), Европейски комитет по стандартизация в електротехниката (CENELEC).
- Национална стандартизация. Сведения за националната стандартизация.
- Фирмена стандартизация. Фирмените звена по стандартизация.

Ниво 3

Ниво 3 обхваща: II Степен на професионална квалификация.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са с професионален и практически характер.

Теми и съдържание:

- Основни понятия и цели на стандартизацията.
- Подходи и видове стандартизация. Пазарен подход и пазарна стандартизация. Непазарен подход и държавна стандартизация. Характеристики на двата вида стандартизация.
- Механизъм на „задължителност“ на стандартите. Познаване в технически нормативен акт. Пазарен механизъм на условна задължителност.
- Европейско техническо законодателство (ЕТЗ). Технически нормативни актове – регламенти, директиви, решения и др. Общи изисквания.
- Маркировка „CE“. Същност.

Ниво 4

Ниво 4 обхваща: Средно образование, Общо образование/ III Степен на професионална квалификация.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са с професионален и практически характер.

Теми и съдържание:

- Развитие на стандартизацията. Начало на техническата стандартизация. Развитие на органи по техническа стандартизация.
- Международна стандартизация. Международна електротехническа комисия (IEC). Структура на IEC. Международна организация по стандартизация (ISO). Структура на ISO.
- Европейска стандартизация. Европейски организации по стандартизация – Европейски комитет по стандартизация (CEN), Европейски комитет по стандартизация в

електротехниката (CENELEC). Структура. Технически работни органи на CEN.

- Национална стандартизация. Сведения за националната стандартизация до 1997 г. Национална стандартизация след 1997 г.

- Фирмена стандартизация. Предназначение и организация на фирмените звена по стандартизация.

Ниво 5

Ниво 5 обхваща: IV Степен на професионална квалификация.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са с професионален и практичен характер.

Теми и съдържание:

- Характеристики и методи на стандартизацията. Характеристики на стандартизацията – всеобхватност, системност, динамизъм. Методи на стандартизацията – унификация, симплификация, модификация, агрегатиране, взаимозаменяемост.

- Функции на стандартите. Главни функции на стандартите – енергетична функция, функция за въвеждане на ред. Второстепенни функции – посредническа функция, функция за безопасност, функция за определяне на качество, намаляваща функция.

- Същност на основните процеси за оценяване на съответствието на продукти. Видове процеси за оценяване на съответствието. Същност на процеса „изпитване“. Същност на процеса „сертификация“ на продукт. Същност на процеса „контрол“ на продукт.

- Европейско техническо законодателство (ЕТЗ). Основни принципи на ЕТЗ. Развитие на ЕТЗ – Стар подход, Нов и Модулен подход, Нова законодателна рамка.

- Маркировка „СЕ“. Принципи на разпоредби. Правила за нанасяне и оформяне на маркировка „СЕ“.

Ниво 6

Ниво 6 обхваща: Подниво 6А - Професионален бакалавър, 180 кредита по ECTS; Подниво 6Б - Бакалавър, 240 кредита по ECTS.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са с професионален и практичен характер.

Теми и съдържание:

- Международна стандартизация. Международна дейност по стандартизация. Роля на ISO/IEC за Световната търговска организация (СТО).

- Европейска стандартизация. Цели и задачи на европейската стандартизация. Видове европейски стандартизационни документи. Хармонизирани европейски стандарти.

- Национална стандартизация. Задачи и роля на Българския институт за стандартизация (БИС).

- Фирмена стандартизация. Задачи и дейност на фирменото звено. Фирмена стандартизация, ноу-хау, интелектуална собственост.

- Стандартизационни изисквания към органите за оценяване на съответствието. Изисквания към изпитвателните лаборатории. Изисквания към органите за сертификация на продукти. Изисквания към органите за контрол на продукти.

- Акредитация на органи за доброволно оценяване на съответствието. Понятия и условия за оценяване на компетентността на органи чрез акредитация. Европейска регламентация на акредитацията. Стандартизационни изисквания за акредитация.

Ниво 7

Ниво 7 обхваща: Магистър - Магистър след „професионален бакалавър по...“ от същото професионално направление, 120 кредита по ECTS; Магистър след бакалавър по същата специалност, 60 кредита по ECTS; Магистър след бакалавър по друга специалност, 120 кредита по ECTS; Магистър по специалности, за които се предвижда обучение само в тази степен, 300 кредита по ECTS.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са с професионален и практичен характер.

Теми и съдържание:

- Стандартизация на системи за управление на качеството. Стандартизация и качество. Стандарти за системи за управление на качеството. Одит и сертификация на системи за управление на качеството.

- Стандартизация на типове системи за управление. Обща характеристика. Интегрирана система за управление. Система за управление на околната среда. Система за управление на здравето и безопасността при работа. Система за управление на безопасността на хранителните продукти. Система за управление на сигурността на информацията.

- Европейско техническо законодателство (ЕТЗ). ЕТЗ за хармонизация – обхванати продукти от ЕТЗ, предоставяне на пазара, преходен период, икономически оператори (производител, упълномощен представител, вносител, дистрибутор), съществени изисквания и изисквания за проследимост.

- Нотификация в Европейския съюз. Същност. Европейски разпоредби за нотификацията. Национално законодателство по нотификация.

- Модулен подход за задължително оценяване на съответствието. Европейски разпоредби за Модулния подход. Систематизирано описание на модулите. Образуване на модулни процедури. Избор на модулни процедури.

- Отговорност за продукта и защита на потребителите. Разпоредби на ЕТЗ за хармонизация за отговорност за продукта. Законодателство за защита на потребителите.

- Надзор на пазара. Европейска регламентация на надзор на пазара. Предпазна клауза. Условия за административно сътрудничество. Национално законодателство по надзор на пазара.

Ниво 8

Ниво 8 обхваща: Доктор, без кредити по ECTS.

Обучаваните в това ниво следва да се запознаят с въпросите на стандартизацията, които са професионален и научен характер – задълбочени анализи, изследвания и разработки с научни и научно-приложни приноси.

Теми и съдържание:

- Стандартизация. Математическа база на стандартизацията.

- Международна стандартизация. Процедура по стандартизация в ISO/IEC.

- Европейска стандартизация. Общи и работни принципи на работната процедура за създаване на европейски

стандарти. Основни етапи на работната процедура. Специфика в процедурата за хармонизирани стандарти.

- Национална стандартизация. Стратегически приоритети.
- Фирмена стандартизация. Процедура за създаване на фирмени стандарти.
- Оценяване на съответствието на продукти. Първична принципна процедура за сертификация на продукт. Изисквания към документираната процедура за сертификация на продукти. Първична принципна процедура на видовете контрол.
- Акредитация. Първична процедура за акредитация.
- Системи за управление. Първична принципна процедура за сертификация на система за управление.

Обучаваните в това ниво разработват и защитават дисертационен труд в конкретна област на стандартизацията, който е с професионален и научен характер – задълбочени анализи, изследвания и разработки с научни и научно-приложни приноси.

В процеса на формулиране на темите и тяхното съдържание за различните нива е използван [7].

Интеграцията на БКР с обучението по стандартизация представлява стратегически важен процес за синхронизиране на образователните и професионалните изисквания с международните стандарти. БКР, като инструмент за определяне на нивата на квалификация, предоставя основата за ясна и прозрачна квалификация на специалистите в различни области, включително и в сферата на стандартизацията. Връзката между тези две области е от съществено значение за създаването на обучителни програми, които отговарят на европейските и глобалните изисквания за качество и ефективност. Този процес не само улеснява признаването на българските квалификации в международен контекст, но и повишава конкурентоспособността на българската работна сила, като същевременно съдейства за стандартизацията на образователните подходи и професионалните компетенции в областта. В този контекст, успешната интеграция на БКР и обучението по стандартизация ще съдейства за подобряване на качеството на образованието и улесняване на мобилността на специалистите в Европа и по света.

4. Заключение

Направеният анализ на нивата на Българската квалификационна рамка в контекста на Европейската квалификационна рамка показва значителен напредък в адаптацията на българското образование към европейските стандарти. Въпреки различията в историческите и социално-икономическите контексти, синхронизирането на тези рамки предоставя възможност за по-добро интегриране на българските квалификации в европейския образователен и трудов пазар.

Интегрирането на БКР с ЕКР отразява актуалните образователни потребности и изпълнява критичната роля на създаването на ясни и разпознаваеми квалификационни нива. По този начин се увеличава прозрачността на квалификациите и сертификатите, които се издават в България, улеснява се признаването им в други държави от ЕС, предоставя се възможност за по-лесна мобилност на учениците, студентите и работната сила, като се подобрява достъпа до образование и възможностите за професионално развитие в международен контекст.

Връзката между обучението по стандартизация и квалификационните рамки е от съществено значение за гарантирането на качество и ефективност в образованието. Разработването на унифицирани програми за обучение,

отговарящи на общите европейски изисквания ще осигури високо качество на обучението по стандартизация, като едновременно с това ще минимизира разликите в образователните подходи и изисквания между различните европейски държави.

Обвързването на БКР и обучението по „Стандартизация“ е стратегически важен етап за подобряване на конкурентоспособността на българската работна сила. Това ще осигури по-добро интегриране на българските кадри в общия европейски трудов пазар и ще повиши икономическата ефективност на страната.

Пътят към пълноценното интегриране на ЕКР, БКР и обучението по „Стандартизация“ е процес, който изисква съответствие и продължаваща адаптация и мониторинг. За успешното изпълнение на този процес е необходимо активно сътрудничество между образователни институции, държавни органи и професионални асоциации, за да се гарантира, че системата остава актуална и отговаря на променящите се образователни и трудови изисквания.

В публикацията са предложени конкретни теми по стандартизация, съответстващи на нивата на обучение в България. Чрез въвеждането им в учебните програми в определени дисциплини (например: „Технологии и предприемачество“, „Предприемачество“ и др.), постепенно и по подходящ начин обучаемите ще се запознаят със смисъла, значението и важността на стандартизацията и ще се подготвят за участие в изграждането на по-конкурентна българска и европейска индустрия.

5. Литература

1. <https://www.cedefop.europa.eu/en/projects/european-qualifications-framework-EKP>
2. <https://www.navet.government.bg/bg/natsionalna-kvalifikatsionna-ramka/>
3. http://noks.mpn.gov.rs/wp-content/uploads/2017/08/referencing_EKP_with_nqf.pdf
4. https://www.cedefop.europa.eu/files/bulgaria_-_european_inventory_of_nqfs_2022.pdf
5. <https://www.cedefop.europa.eu/en/tools/nqfs-online-tool/countries/bulgaria-2022>
6. https://www.navet.government.bg/bg/media/NQF_bg.pdf
7. Сандалски Б., Горанов П., Динев Д., Николова И., *Основи на кнструирането и CAD* (Софттрейд, София, 2007), ISBN 978-954-334-062-0