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STUDENT WILLINGNESS TO PARTICIPATE IN ENVIRONMENTAL PROJECT-BASED LEARNING

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Abstract: Project-based learning (PBL) plays a crucial role in environmental education, as it allows students to engage actively with sustainability challenges. The aim of this study is to evaluate the attitudes of students at a selected upper secondary school towards participation in project-based learning focused on environmental topics. The quantitative research was conducted in one selected secondary school in South Bohemia. A total of 168 students participated in the survey. Overall, the results indicate a generally positive attitude among the surveyed students towards environmental topics in education, as well as towards PBL focused on environmental issues. However, hypothesis testing showed that students' willingness to participate in such targeted PBL was not significantly influenced by selected socio-demographic variables or by the level of environmental knowledge acquired through formal education.

Keywords: environmental topics, project-based learning, secondary school, students

1 Introduction

When defining project-based learning (PBL), it is necessary to take into account the dynamic nature of the concept itself. This diversity of definitional features, coupled with the lack of a universally accepted model, can greatly complicate the definition of this teaching method (Du & Han, 2016). PBL can be defined as learning that focuses on deeper learning in context and develops key skills. Its core characteristics are interdisciplinary, rigorous, and student-centred. Students apply knowledge and skills through engaging experience (O'Brien & Defined Learning, 2024).

The empirical results confirm that PBL develops students' autonomy in learning, defining the basic questions, planning the project, monitoring and evaluating the progress of the project and finally verifying the results (Novalia et al., 2025). There is also a significant improvement in collaboration, problem solving, and critical thinking. There are also significant correlations between PBL and educational outcomes, ranging from moderate to significant (Rehman et al., 2024). Another advantage is the possibility to carry out cross-curricular projects (de Reviere et al., 2024; Alsmadi et al., 2024). The aim is to encourage interdisciplinary learning. It can also be concluded from the results that the students who approached believe that the project has more added value (de Reviere et al., 2024). There are also areas that need more attention in projects, such as managing project timelines, improving workflow strategies and integrating domain-specific knowledge (Alsmadi et al., 2024). According to Larmer et al. (2015), project-based learning is particularly time-consuming. It requires thorough preparation in order to achieve the desired quality. PBL also enhances students' ability to apply project management principles in practice. Both soft and technical skills are integrated (Marnewick, 2023). Another positive aspect of PBL may also be its focus on increasing students' self-confidence, discipline, responsibility and self-control (Novalia et al., 2025).

At the elementary school level, it was also found that PBL in the personalized project-based learning variant. In general, the approach improved student achievement and reduced the achievement gap between students (Lin et al., 2025). In the case of PBL in an elementary school in the context of developing websites, there was an increase in student creativity (Marini et al., 2025). In the context of upper secondary education, project-based learning has been shown to enhance students' problem-solving skills, including their ability to approach ethical issues, such as those related to AI, and to develop overall competence in problem-solving (Kong et al., 2024).

Environmental topics can be taught within PBL, for example, in the form of integrating life cycle thinking and circular economy into the curriculum. As a result, students will gain knowledge and skills about the sourcing of materials, the links between products and business models, and the impact on the environment (Reich & Vermeyen, 2025). Further connections between environmental issues, the circular economy, and PBL have been identified in the context of metal recycling within industrial design. Preliminary findings suggest that this approach can serve as a strong motivational factor for students (Schoch et al., 2025).

The circular economy is a key economic concept that supports the achievement of a carbon-neutral European Union (European Commission, 2015; European Commission, 2019). Educational institutions likewise play a critical role in this transition, particularly through their influence on students, parents, and the wider community (European Commission, 2019). A global perspective on the role of schools and the fundamental requirements for climate action in education (UNESCO, 2016) highlights the importance of engaging in school governance, curriculum, infrastructure, and community involvement. In this context, project-based learning emerges as a suitable pedagogical approach to support these objectives.

2 Methods

The aim of this study is to evaluate the attitudes of students at a selected upper secondary school towards participation in project-based learning focused on environmental topics.

The participants in the study are high school students from an upper secondary school (equivalent to a gymnasium in the Czech Republic) in a city located in the South Bohemian Region. After data filtering, a total of 168 questionnaires were used. Data collection took place across seven classes. Three classes belong to the first year, one class to the second year, one class to the third year, and the remaining two classes to the fourth year. The questionnaire was completed by all present students, resulting in a nearly 100% response rate. Data collection took place at the end of 2024. The questionnaire consisted of several interrelated sections. It included the following areas of questions: identification questions, formal environmental education, sources of environmental knowledge, and project-based learning, along with other organisational forms.

The following null hypotheses were set for statistical analysis:

- $H1_0$: *Female students do not show greater willingness to participate in internships at environmental centres or outdoor schools.*
- $H2_0$: *Students from rural areas do not show greater willingness to participate in internships at environmental centres or outdoor schools.*
- $H3_0$: *Completing a school subject focused on environmental topics does not affect the willingness to participate in internships at environmental centres or outdoor schools.*
- $H4_0$: *There is no significant correlation between the amount of environmental knowledge acquired at school and the willingness to participate in internships at environmental centres or outdoor schools.*

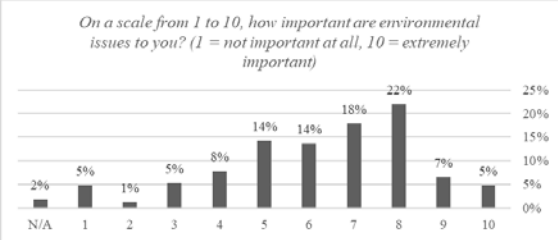
The gender distribution of the sample is as follows: 58% women, 36% men. A total of 6% of the students interviewed did not indicate their gender. Whether students live in a rural or urban area was also an important variable. A total of 64% of the respondents live in urban areas. On the other hand, 35% of the students reported living in a rural area. Only 1% of the respondents did not indicate their place of residence. A last significant variable, which is then also subject to correlation analysis, is whether students have encountered environmental

issues, climate change, or other related topics during their studies. A total of 79% of them have encountered this form of learning. On the contrary, 20% of them stated that they had never encountered such a form during their studies. Only 1% of the respondents did not give an answer.

3 Results

The first primary variable observed was the degree of importance students placed on learning about environmental topics. They were asked to indicate the level of importance on a scale of 1-10 (1 = not important at all, 10 = extremely important). Figure 1 shows that students give relatively higher importance to this teaching. In particular, they indicate values between 5-8, with 8 having the highest frequency, i.e. 22%.

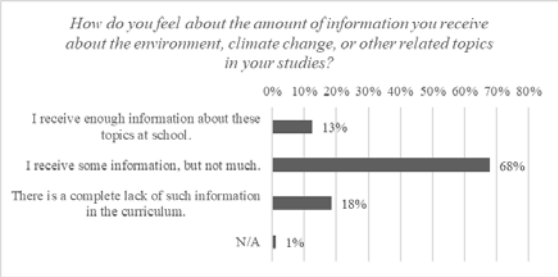
Figure 1: The importance of teaching environmental issues in schools



Source: Own research, n = 168

Another important variable to be monitored is how students themselves perceive the amount of information about the environment, climate change and other related topics. From Figure 2, it can be seen that most students, 68%, report that they get some information but not much.

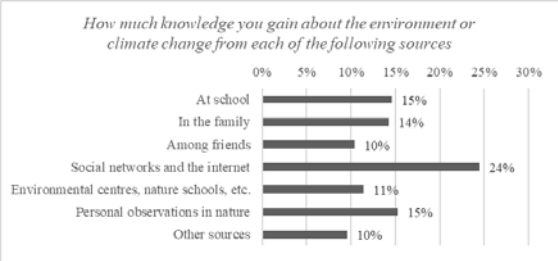
Figure 2: Do students receive sufficient information about the environment, climate change, and other related topics?



Source: Own research, n = 168

To clarify where students get their information about environmental knowledge, an additional question was asked that directly measured the amount of this information across different sources. Figure 3 shows that students obtain most of this knowledge from social networking sites and the internet, at 24%. This is followed by an identical 14% from their own observations outdoors and knowledge gained through formal education, i.e. at school.

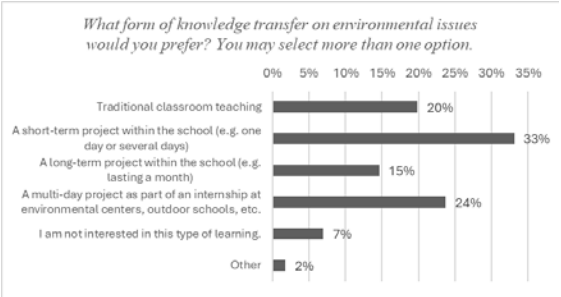
Figure 3: Sources of environmental knowledge according to students



Source: Own research, n = 168

Regarding formal education in schools, students were asked to indicate which form of instruction they considered most suitable for the transfer of environmental knowledge. Traditional classroom teaching was selected by only 20% of respondents. The most frequently chosen option was short-term project-based learning within the school (lasting one or several days), reported by 33% of students. Multi-day projects implemented as part of internships at environmental centres, outdoor schools, and similar settings were selected by 24% of respondents.

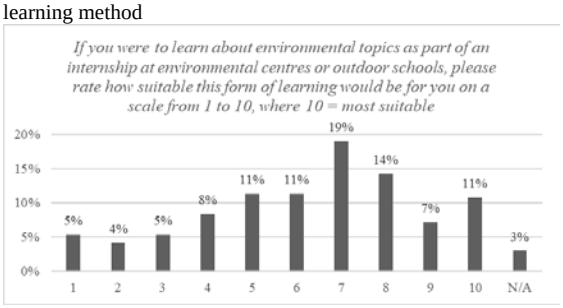
Figure 4: Preferred form of knowledge transfer on environmental issues



Source: Own research, n = 168

In the following question, students were asked to rate, on a scale from 1 to 10, how suitable they considered learning about environmental topics as part of an internship at environmental centres or outdoor schools, with 10 indicating the highest level of suitability. Students rate this form of teaching quite highly, with the most frequent values being 7 (19%) and 8 (14%).

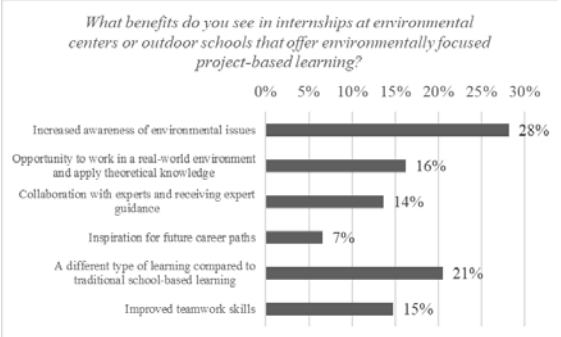
Figure 5: Student ratings of environmental internships as a learning method



Source: Own research, n = 168

The final variable examined was the perceived benefits of participating in the aforementioned form of instruction, as perceived by the students. The most frequently cited benefit was increased awareness of environmental issues, selected by 28% of respondents. This was followed by the opportunity to experience a different type of learning compared to traditional classroom-based education (21%).

Figure 6: Perceived benefits of internships at environmental centres or outdoor schools offering environmentally focused PBL



Source: Own research, n = 168

The original 10-point scale used to assess the perceived suitability of learning about environmental topics through internships at environmental centres or outdoor schools was recoded into three categories for the purposes of analysis. High interest included responses of 10, 9, and 8; medium interest included responses of 7, 6, 5, and 4; and low interest included responses of 3, 2, and 1.

There was no statistically significant relationship between willingness to participate in internships at environmental centres or outdoor schools and gender ($\chi2 = 6.773$; df = 6; p = 0.342). Although Table 1 shows that women show slightly more interest, we do not reject the null hypothesis 1 (*Female students do not show greater willingness to participate in internships at environmental centres or outdoor schools*).

Table 1: Testing of null hypothesis 1 (crosstabs)

Willingness to participate in internships at environmental centres or outdoor schools	Adjusted residual		
	Gender		
	Man	*I do not want to specify*	*Woman*
High interest	-1.8	1.0	1.3
Medium interest	0.6	-0.3	-0.5
Low interest	1.8	-0.6	-1.5

Source: Own research

We also do not reject the second null hypothesis tested (*Students from rural areas do not show greater willingness to participate in internships at environmental centres or outdoor schools*), as no statistically significant relationship was found between willingness to participate in internships at environmental centres or outdoor schools and place of residence ($\chi2 = 5.797$; df = 6; p = 0.446).

Table 2: Testing of null hypothesis 2 (crosstabs)

Willingness to participate in internships at environmental centres or outdoor schools	Adjusted residual	
	Do you live in the city or in the countryside?	
	In the countryside	*In the city*
High interest	-0.6	0.4
Medium interest	1.6	-1.3
Low interest	-1.2	0.9

Source: Own research

As in the previous cases, we also do not reject the third null hypothesis tested (*Completing a school subject focused on environmental topics does not affect the willingness to participate in internships at environmental centres or outdoor schools*), as there was no statistically significant relationship between willingness to participate in internships at environmental centres or outdoor schools and whether students encountered environmental education during their studies (3.744; df = 6; p = 0.711).

Table 3: Testing of null hypothesis 3 (crosstabs)

Willingness to participate in internships at environmental centres or outdoor schools	Adjusted residual	
	Encountered environmental education during studies	
	Yes	*No*
High interest	0.9	-0.8
Medium interest	-0.6	0.4
Low interest	-1.0	1.0

Source: Own research

The last null hypothesis (*There is no significant correlation between the amount of environmental knowledge acquired at school and the willingness to participate in internships at environmental centres or outdoor schools*) was tested using Pearson correlation. Based on the output of the correlation analysis, there was no statistically significant relationship between the variables (r = 0.147; p = 0.062) at the 0.05 significance level. We do not reject the null hypothesis.

To provide context for the last hypothesis tested, the other three most represented sources where students acquire environmental knowledge were also tested, along with the variable of interest - willingness to participate in internships at environmental centres or outdoor schools. Positive correlations were found in all three sources: in the family (r = 0.392; p = 0.000), social networks and the internet (r = 0.234; p = 0.003), and personal observations in nature (r = 0.212; p = 0.007).

4 Conclusions

The aim of this study was to evaluate the attitudes of students at a selected upper secondary school towards participation in project-based learning focused on environmental topics. Overall, the students surveyed perceive the teaching of environmental topics as important. Although they do receive some form of environmental education within the formal curriculum, it is perceived as insufficient. This suggests that the implementation of environmental content in formal education remains limited, indicating space for improvement in light of the EU's educational objectives (European Commission, 2019). The results also suggest that formal education is not the primary source of students' environmental knowledge.

Regarding PBL, the students interviewed would prefer short-term and multi-day forms of this instruction and overall give this form of instruction above average importance. However, the hypotheses tested showed that this willingness to participate in such thematic project-based learning is not influenced by gender, place of residence, or whether they have previously taken such a school-based course. Similarly, there is no correlation between the amount of environmental knowledge from formal schooling and willingness to participate in environmentally focused PBL. These findings can serve to complement existing empirical studies focused on environmental aspects of PBL (e.g. Reich & Vermeyen, 2025; Schoch et al., 2025).

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ASSESSING THE IMPACT OF CRISES ON MANAGERS' CHANGE OF MINDSET TOWARDS RISKS AND PREVENTIVE MEASURES IN MANAGEMENT SYSTEMS IN ENTERPRISES: THE CASE STUDY IN SLOVAKIA

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Abstract: The paper's essence is to assess and evaluate the perceived changes (differences) in the managers' approach to risks in management systems (QMS, OSHMS, EMS) and changes in the investment of funds for the implementation of preventive measures to reduce risks before and after crises (e.g. Covid-19 pandemic, energy crisis) in small, medium and large industrial enterprises in Slovakia. The research carried out consisted of two surveys in 2020 and 2022 using online inquiry. The sample of respondents consisted of a total of 662 industrial enterprises operating in Slovakia. The presented results have an added value as a best practice for owners, top managers and responsible quality managers, OSH managers, and environmental managers of industrial enterprises.
Keywords: Crisis Management; Management Systems; Covid-19 pandemic; Prevention; Mindset Change; In-vestments in Safety.

1 Introduction

Over the last four years, businesses have had to face and are constantly facing various crises in the business environment, whether it was the Covid-19 pandemic, the energy crisis, the war in Ukraine. The consequences of the pandemic, amplified by the Russian aggression in Ukraine, have brought about a rise in energy prices that has caused major problems for Europe. This has affected investors' decisions, reducing the competitiveness of individual countries. According to several authors, e.g. Waiho et al. (2020); Bartik et al. (2020); Carvalho et al. (2023); Coleman, Nautz (2023) the different crises brought with them a number of negative impacts that affected not only the business environment but also the whole society (slowing down the growth of the economy). According to Estiri et al. (2022); Belas et al. (2021), the Covid-19 pandemic contributed to the fact that managers began to feel a greater need to engage in a more comprehensive review of existing approaches to crisis prevention. According to Luburic (2021), the aftermath from the Covid-19 pandemic also highlighted some of the shortcomings in change management that were not addressed in a timely and adequate manner in a more stable environment for better functioning in crisis situations. Small businesses often suffered from a lack of resources, which in many cases was the reason why they were unable to prepare for a crisis. According to Mikusov, Horvath (2023), managers still do not consider crisis preparedness as part of their competitiveness and actual active prevention is still low. According to their findings, it is necessary to initiate their reflection on the necessity of crisis prevention. Dobrowolski (2020) states that the variability of the environment and the constant changes in the company's surroundings place increased demands on management, which must be able to respond quickly and in a timely manner to an adverse situation. If the enterprise is already going through a crisis, it must use the necessary approaches, methods, tools that will help it to get out of the crisis but also to set up prevention and increase resilience so that further crisis situations do not occur. According to the results of the Institute of Risk Management (IRM, 2023), it shows that every year there is a gradually growing international interest in risk management in any governmental, public and commercial spheres. The magnitude of individual negative impacts on businesses also depends on the ability and preparedness of the business to face these negative events (Mazzanti et al. 2020). Gavril et al. (2020) conducted a study in which they highlight the vulnerability of European countries to the impacts of negative environmental threats and recommend the use of innovative strategies to reduce their consequences. As negative events become more frequent and less predictable, the need for greater preparedness is growing, and associated with this is the need for risk assessment in business management systems. Ferreira de Araújo Lima et al. (2020); Tullo, (2020); Ślusarczyk & Grondys (2019) state that enterprises should be more concerned with the risk management process, creating a risk management strategy and linking it to key indicators, so that the impact of external threats can manage to reduce not only strategic but also operational risks. Ciocoiu et al. (2020) stresses the need to pay more attention to the measures proposed to increase risk resilience. Estiri et al. (2022) points out that it is necessary to create a matrix of responsibility for the implementation of risk management in the enterprise.

From the above, it can be concluded that the impact of individual crises in the business environment and their consequences on the management of enterprises has shown that the application of the risk management process is essential and helps to make enterprises more flexible and reliable in meeting their objectives. The authors Katanaeva et al. (2020); Akwei et al. (2018); Levashov et al. (2018), Ramos et al. (2015); Thimm, (2015); Krokhina et al. (2018); Vodolazhskaya et al. (2019), emphasize that it is essential to know the risks of management systems for quality, occupational health and safety (OSH) safety, environment in particular, which are key to thriving and achieving the strategic and operational objectives of the enterprise.

Businesses strive to offer products and services that not only meet but exceed customer expectations. At the same time, they are under pressure to reduce costs and continuously improve quality in order to remain competitive. In addition to accident prevention, safety of technical equipment and work procedures, OSH must also pay attention to ensuring a healthy working environment with an emphasis on the human factor and occupational health. More recently, also to ensure employees' sense of physical, psychological and social well-being (Hollá 2017). The adoption of new laws, regulations to contribute to environmental protection is creating pressures on businesses to respect the tightening requirements for environmental protection, while at the same time creating measures to mitigate climate change. On the other hand, according to Piatrik et al. (2003), the management systems in place in a company save costs associated with fines for regulatory violations and increase the credit of the organization with its customers, stakeholders and the general public. The above management systems should be in integration with risk management. According to Shandova (2018), risk management should be implemented in an organization so that it can continuously and systematically identify significant risks (including their interrelationships and interactions) across the enterprise. To increase the prevention of enterprise crises and the successful application of risk management, according to several experts, e.g. Katanaeva et al. (2020); Ramos et al. (2015), it is necessary to use the ISO 31000 standard (Risk Management – Principles and Guidance). The standard recommends that companies develop, implement and continuously improve a framework that aims to integrate risk management into enterprise-wide management processes and management systems.

Most of the papers by various authors focus on the assessment of the consequences of crises, the importance of prevention, risk management in the enterprise, the integration of management systems (QMS, OSHMS, EMS), or address risks, problems individually in management systems (QMS, OSHMS, EMS). The originality of the paper lies in the fact that so far no study has been conducted to assess changes in managers' perceptions of risks in management systems (QMS, OSHMS, EMS) and their willingness to invest funds for prevention before and after a crisis period in industrial enterprises. The paper provides an important and significant insight into managers' perceptions towards risks, preventive measures affected by negative threats from the business environment. It contributes to the formation of attitudes, attitudes and knowledge expansion of owners and

responsible managers in order to increase the need for continuous prevention in the enterprise.

The concept of the article is as follows. In the introduction, the authors present the need and importance of the issue addressed. In the literature review, they elaborated the issue of risks in connection with quality management systems, OSH, environment (QMS, OSHMS, EMS) and the view of prevention levels in the enterprise, in order to approach the current state of the problem addressed. In the next part of the paper they set the objective, scientific hypotheses, description of the data obtained, research methodology and methods for their evaluation. In the following section, they presented the results of the empirical research, evaluation and discussion with other related scientific studies. Finally, the authors presented the main contributions of the research, characterized the limitations of the research, and set out the future research activities of the research team.

2 Theoretical background

On the basis of various studies, surveys, scientific articles on the addressed issue, the authors of the article have elaborated a current overview with emphasis on attention to risks, problems in the quality management system, OSH, environment, and prevention in enterprises. The given part pays attention to the importance of risks, possibilities of improvement, and prevention in management systems in enterprises.

A quality management system, according to Gremyr et al. (2021) is seen as a dynamic, long-term, and never-ending process. At its core is the change in the approach of managers and the involvement of all employees at different levels of management in the process. Several authors e.g. Simchenko (2012), Putyatina et al. (2020) discuss the need to constantly look for ways, procedures, approaches to ensure the improvement of quality management systems in enterprises. One of the solutions for quality improvement is the application of risk management. Risks in a quality management system (QMS), e.g., according to Adreev et al. (2021), can be defined as a combination of the probability of damage and the severity of that damage. Where damage is understood as harm to health including damage that may occur due to loss of product quality or availability. According to Akwei et al. (2018), all risks that may have negative consequences in quality management should be assessed and minimized. Product quality is closely related to the quality of the business processes that are implemented in the enterprise system. Therefore, according to Alzamil, (2019), risk management should be applied in product creation, in all enterprise processes of product production, in the entire quality management system in the enterprise. Risks in QMS can also be seen from the perspective of the producer as well as the consumer. From the producer's perspective, according to Grimashevich et al. (2019), these risks can be defined as loss of reputation when supplying non-conforming products, loss of individual customers and entire markets, legal liability for poor quality, degradation of resources, wastage of human labour, and reduction of employee confidence in the capabilities of the enterprise. One of the ways to increase the level of risk management in the field of quality is the application of QMS according to ISO 9001: 2015 Quality Management System – ISO 9001 Requirements. The standard recommends risk-based thinking to integrate risks into the entire enterprise management system, into all processes included in the QMS. It gives attention to creating preventive measures that are part of strategic planning, operational processes and review. Novakova et al. (2017), Andreeva et al. (2019) emphasize the need to implement risk reduction measures in QMS and to evaluate the effectiveness of these measures. According to authors e.g. Samani et al. (2019) and Katanaeva et al. (2020), it is also necessary to develop models of risk management in QMS. Katanaeva et al. (2020) recommends a model that enables management actions to be carried out in a situation of uncertainty and decisions to be made aimed at preventing errors in the management of the organization and ensuring proper quality. Samani et al. (2019) favours the development of a risk-based conceptual model of QMS. Enterprises that seek to implement risk management should incorporate risk management methods and techniques into their processes. Zhang et al. (2022) developed an improved model of quality risk transfer in a new retail service supply chain. Huang et al. (2011) in their study highlights that the application of risk management influences the effectiveness of QMS. They recommend that enterprises should use an effective method to prevent and control verification risk as quality risks flow through the system and affect the overall performance of the enterprise. Pollakova et al. (2016) points out that a thorough process analysis and the use of appropriate risk management tools can minimize existing risks and maximize process efficiency. Along with Zhao et al. (2021) point out that risk management is of prime importance in the quality planning process. Its benefit is the early identification of potential non-conformance risks in systems, processes, products and other quality management risks, which is a good prerequisite for a successful business and a satisfied customer. In terms of prevention, according to several authors, Zhao et al. (2021); Katanaeva et al. (2020); Grimashevich et al. (2019); Samani et al. (2019); Akwei et al. (2018), it is necessary to pay even more attention to risk-based thinking, to look for new opportunities to improve the QMS, to make the customer satisfied and at the same time the business owners, by gaining competitive advantages and adding value to the business.

In the field of OSH, enterprises have to comply with the statutory conditions related to OSH as a priority, but at the same time, they implement a management system for more effective compliance with all safety rules and the achievement of enterprise objectives. Occupational health and safety management system (OSHMS), according to Ramos et al. (2015); Podgorski (2010), is a part of the overall management system of an enterprise that has established an OSH concept, manages health and safety risks, in accordance with the requirements of OSH management and through their implementation, achieves effective business results and objectives. Rudakov et al. (2021) state that the main task of all enterprises whether it is small, medium, and large is to improve occupational health and safety conditions with an emphasis on prevention and the use of risk management. According to ISO 45001, risk in an OSH management system is defined as the combination of the probability of a hazardous event or exposure occurring that is work-related and the severity of the injury or damage to health that may be caused by the event or exposure. Roberts, (2017) argues that OSH hazards should be assessed on priority to ensure the protection of employees, i.e. to look for and analyze their causes such as stress, workload, the monotony of work, working conditions, labour and industrial relations, psychosocial factors, equal opportunity (non-discrimination), fair remuneration, appropriate workplace facilities, etc. According to Levashov et al. (2018), the essence of risk management in OSH is to achieve a shift of injuries from post-injury response measures to preventive measures, i.e., management of worker health risks. They justify the possibility of implementing the concept of key risk indicators in the process of OSH management through a model control system and rigorous analysis of occupational risks. According to several authors, e.g. Garcia-Gomez et al. (2020); Beck et al. (2017); Dahler-Larsen et al. (2020), psychosocial risks, which are a concern for employers across Europe, need nowadays much more attention than ever. According to Guadix et al. (2015), psychosocial risk control prevents accidents and absenteeism. Their elaborated study shows the benefits of adopting psychosocial safety management systems to improve the performance of psychosocial risks. Psychosocial prevention activities mediate the relationship between psychosocial safety management and psychosocial performance. Guadix et al. (2015) and Garcia-Gomez et al. (2020); Beck et al. (2017); Dahler-Larsen et al. (2020) point to major benefits of effective psychosocial risk management. Under them, supporting systems of psychosocial prevention activities is likely to effectively improve overall psychosocial performance in European countries. One way to improve the level of OSH risk management is through the application of an occupational health and safety management system (OSHMS) according to ISO 45001:2018 Occupational health and safety management

systems – Requirements with guidance for use. The basic principle of the standard is the identification of all possible risks in workplaces and their effective management to minimise possible damage to the health of employees and the associated consequences. The standard provides a framework to prevent workplace accidents and worker ill health to improve and provide a safe and healthy workplace. According to several authors e.g. Felknor et al. (2021); Klimova et al. (2017), continuous improvement of OSH levels using risk management results in reduced losses, higher productivity, efficiency, and quality of work, which in turn affects the overall performance of the enterprise and especially the safety of employees. A properly implemented OSHMS helps in risk management, which can be used by businesses to improve the safety and health of their workplaces and increase the efficiency and competitiveness of their business. According to Matkovcik (2017), well-applied workplace risk management can protect employees and reduce the risks associated with their work. Bibire et al. (2020) also point out the importance of effective application of risk management as a factor in the prevention of negative OSH incidents.

Environmental management system (EMS), according to Bissacot et al. (2016), can be understood as a planned and coordinated set of all management activities, procedures, documentation aimed at environmental protection. Its main task is the prevention of negative impacts on the environment with the support of activities aimed at preserving or enhancing the quality of the environment (Zelenko et al. 2019). According to several authors e.g. Vodolazhskaya et al. (2019); Breitenstein et al. (2021), the environmental management system should be an integral part of the overall management system aimed at the gradual elimination of negatively impacting activities and products on the human environment. De Oliveira et al. (2019) points out that the objective of environmental compliance management is to ensure corporate compliance with given environmental regulations. Awareness of events that can cause a negative compliance status is a key factor in successful environmental compliance management. Risk management in EMS is understood as a complex system of considerations and analyses that use the results of individual risk management steps together with political, economic, and social formations to generate decisions on corrective actions to reduce a particular environmental risk (Aizaga et al. 2016). According to Algheriani et al. (2019), this is a systematic process that aims to control risks that could endanger the environment. Environmental risks in an enterprise are a direct characteristic of economic activities; therefore, it is necessary to organise a system for managing these risks in the enterprise. Risk can also be defined as a part of activities or products or services that is or can be related to the environment (Aizaga et al. 2016). Risks by their nature may have a direct or indirect or cumulative impact on the enterprise. The relationship between environmental aspects and environmental impacts is that of cause and effect (Weber 2006). Frolenkova et al (2022), Zelenko et al. 2019 defines environmental risk as the relationship between the expected loss (damage to health, loss of life, loss of property in certain specific circumstances) and the uncertainty of the loss under consideration, usually expressed in terms of probability or frequency of occurrence. The ISO 14001:2015 Environmental Management System (Requirements with Guidance for Use) standard is used by enterprises to apply EMS, which is based on the concept of risk-based thinking. The standard defines environmental requirements as needs or expectations that are stated, generally assumed or mandatory. Thimm (2015) proposes a risk management approach based on an information system for corporate environmental compliance management. He emphasizes a risk estimation method that aggregates all identified risks into a risk profile. Several authors point to the increased need to pay attention to environmental risks, e.g. Krokhina et al. (2018) identify the main factors (technological, economic, etc.) that affect the environmental risk of industrial enterprises. They also present a model of a two-level environmental risk management system aimed at complete control of the environmental risk of the enterprise. Yan (2022) highlights the countermeasures of pollution management, describing the relationship between pollution risk perception and pollution management. According to him, it is necessary to let the enterprise take responsibility for pollution management. Vodolazhskaya et al. (2019) paid attention to the identification of the sources of environmental risks of industrial enterprises and the development of new management mechanisms that can prevent the threats of their occurrence. They revealed the weaknesses of controlling the conditions of an industrial enterprise, which determine the adoption of preventive management decisions. De Villiers et al. (2022) and Darus (2016) found that the presence of board committees dedicated to risk management is associated with better environmental performance of the enterprise. The benefits of risk management committees should also extend to non-financial issues such as environmental performance. Kosyakova et al. (2019) also point out the need for the implementation of an environmental risk strategy in an industrial enterprise. They propose a new classification of environmental risk factors, taking into account the nature of the impact of the risk on the industrial enterprise, the degree of occurrence of the risk and the possibilities of its management. They reveal the need to develop a risk management system that minimises and reduces environmental damage and the economic costs caused by it. According to Kas'yanov et al. (2018), risk prevention or risk reduction should take into account not only quantitative, but also qualitative characteristics of risk, which are caused by various factors and mechanisms of environmental risk perception. Identified priorities in the public interest in the state of the environment should be taken into account in the preparation of the necessary environmental measures.

3 AIM, data collection, and statistical methods

The paper aims to assess and evaluate the perceived changes (differences) in the approach of managers to risks in management systems (quality – QMS, OSH – OSHMS, and environment – EMS) and changes in the investment of financial resources for the implementation of preventive measures to reduce risks before and after crises (e.g. Covid-19 pandemic, energy crisis) in small, medium and large industrial enterprises in Slovakia.

Data collection and structure of respondents

The present study consists of empirical research made up of two surveys, i.e. the first in 2020 before the crisis period (No. 1) and the second in 2022 after the crisis period (No. 2), through questionnaires, primarily intended for business executives, quality managers, health and safety managers, environmental managers, process managers, distributed to small, medium and large industrial enterprises in Slovakia.

The first survey was carried out in the 2020s before the outbreak of the aftermath of the Covid-19 pandemic and the energy crisis. An inquiry method with an online electronic questionnaire - Google questionnaire - was used to collect data. The questionnaire was created on the basis of a baseline analysis of the problem addressed as well as subtasks of individual projects solved at Faculty of Security Engineering, University of Zilina (FSE UNIZA).A wide range of owners and managers of small, medium and large industrial enterprises operating in Slovakia participated in the survey. The survey was carried out with the assistance of the National Business Centre (NBC) in Slovakia, which is covered by the Ministry of Economy of the Slovak Republic. The statistical dataset was identified on the basis of data provided by the Statistical Office of the Slovak Republic within the database - Industry Yearbook Slovakia 2020. Taking into account the statistical representative sample size created (Margin of error 4%, Confidence level 95%), despite the small sample size, the survey can be considered representative. A total of 662 enterprises participated in the survey. The sample size consisted of 51.1% small enterprises (11 to 50 employees), 34.8% medium enterprises (50 to 250 employees), 14% large enterprises (over 250 employees). The survey covered industrial enterprises operating in the following sectors: 8.7% energy sector, 4% machinery sector, 5.3% chemical and rubber sector, 9.6% electronic and electrical sector, 21.6% metalworking

sector, 9.6% woodworking sector, 10.7% food sector, 8% textile sector, 12.6% other.

The second survey was conducted in 2022 (No. 2) after the effects of the Covid-19 pandemic and the energy crisis on businesses in Slovakia. Telephone interviewing method (CATI) and inquiry method with the form of the online electronic questionnaire - Google questionnaire were also used for data collection. A wide range of owners and senior managers of small, medium and large industrial enterprises operating in Slovakia participated in the survey. The survey was conducted with the help of Median Ltd., which is one of the leading research agencies with a long tradition in the field of market research, media and public opinion in Slovakia. Based on the data collection, a representative sample size was created (Margin of error 4%, Confidence level 95%), despite the small sample size, the survey can be considered representative. A total of **662** enterprises participated in the survey. The sample size was made up of 56% small enterprises (11 to 50 employees), 32% medium enterprises (50 to 250 employees), 12% large enterprises (over 250 employees). In terms of industry representation: 3% energy industry, 4% machinery industry, 4% chemical and rubber industry, 3% electronic and electrical industry, 44% metalworking industry, 16% woodworking industry, 8% food industry, 8% textile industry, 10% other.

Questionnaire and variables

In both the first and second surveys, the survey was addressed to owners, managing directors, senior managers and responsible managers for QMS, OSHMS, and EMS of industrial enterprises. All groups of respondents were represented according to demographic characteristics compared to the relative size of enterprises in the business environment at the national level. The questionnaire was developed on the basis of a baseline analysis of the issues addressed as well as sub-tasks of single-question projects addressed at FSE UNIZA. The questionnaire consisted of three parts i.e. the first part described the demographic data of the respondent, the second part focused on the research questions related to the issue under study and the third part focused on additional research questions.

Statistical hypothesis and statistical methods

Given the issues, it was necessary to establish null hypotheses (H0). Null hypotheses are crucial in statistical analyses because they provide a formal framework for testing claims objectively and accurately. They serve as a starting point for comparisons, assuming that there is no effect or difference between the groups or variables under study. This structured approach allows for systematic data collection and analysis, which is essential for reliable scientific conclusions. Null hypotheses help to minimize Type I and Type II errors, thereby allowing for controlling the level of significance and guiding statistical decision making. They are the basis for inference and generalization, support scientific testing of theories and hypotheses, and provide a framework for interpreting and communicating results. In this way, they contribute to accuracy, objectivity and research. Rejection of the null hypothesis indicates that the observed difference or relationship is statistically significant. This means that such a result is unlikely to be due to chance. Statistical significance was assessed using p-value; if the p-value is less than the set significance level of α=0.05, we reject the null hypothesis and accept the H1 hypothesis. We then examined the strength of the dependence using Cramer's V. Cramer's V is a statistical indicator used to measure the strength of association between two nominal (categorical) variables, providing a standardized measure of dependence that ranges from 0 (no dependence) to 1 (complete dependence). Its calculation includes the value of the chi-squared statistic, the total number of observations, and the smaller of the number of rows or columns in the contingency table. When examining dependence, we begin by obtaining data for two nominal variables, arranging them in a contingency table, and conducting a chi-square test for statistical significance. If the result is significant, we calculate Cramer's V, which allows us to determine the strength of the relationship. Cramer's V values close to 0 indicate a weak dependence, while values close to 1 indicate a strong dependence. This indicator thus provides a clearer picture of the relationships in the data, thus contributing to a better understanding of statistical dependence.

The null hypotheses focused on the priority of risks and the size of the enterprise that takes them. These hypotheses were examined separately for the survey conducted in 2020 and for the survey conducted in 2022 to observe if there were any changes in priorities.

1. H0: There is no dependency between the size of the companies from the 2020 survey and the priority of risks in the quality management system.
2. H0: There is no dependency between the size of enterprises from the survey in 2020 and the priority of risks in the HSE management system.
3. H0: There is no dependence between the size of enterprises from the survey in 2020 and the priority of risks in the environmental management system.
4. H0: There is no dependence between the size of enterprises from the survey in 2022 and the priority of risks in the quality management system.
5. H0: There is no dependence between the size of enterprises from the survey in 2022 and the priority of risks in the OSH management system.
6. H0: There is no dependence between the size of enterprises from the survey in 2022 and the priority of risks in the environmental management system.

We also focused on some of the indicators from the survey where we examined the minimum, maximum, median, mode, mean, direction, variance, and selection variance. We compared these results between the 2020 survey and the survey conducted in 2022.

4 Empirical results

The processed results were divided into the following sections:

1. Assessment of changes in perceptions, managers' attitudes towards risks in management systems in industrial enterprises in Slovakia

In Survey 1 (2020), when focusing on the priority of risks in QMS, option 1 was the most frequently indicated option for all sizes of enterprises, which meant the highest priority. However, in the next survey 2 (2022), across all enterprise sizes, the most commonly assigned option was numbered 3 which meant lowest priority – there has been a change.

When focusing on the priority of risks in the OSHMS in Survey 1 (2020), the options assigned were fairly even across all sizes of businesses. However, in Survey 2 (2022) the following year, 2022, for the same risk category, the largest proportion of options identified across all business sizes were numbered 1 as the highest priority – there has been a change.

When focusing on the priority of risks in the EMS, in Survey 1 (2020), for all sizes, the most frequently assigned option was numbered 2. In the next Survey 2 (2022), for small businesses, the most frequently assigned option was numbered 3. When focusing on medium and large enterprises, there was a significant decrease in the number of responses marked with option 1 and a significant increase in the number of responses marked with option 3.

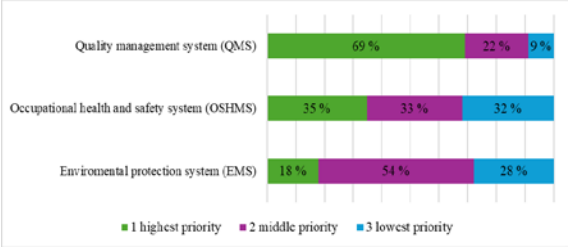

Figure 1. Percentage of perceived risks in QMS, OSHMS, EMS by owners and managers of enterprises in Slovakia in **2020**

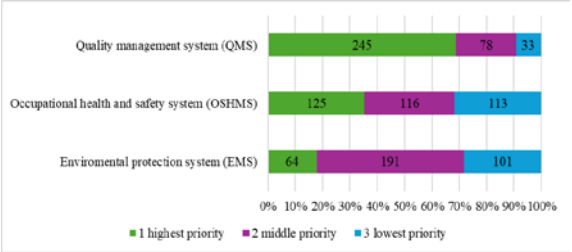

Figure 2 Percentage of perceived risks in QMS, OSHMS, EMS by owners and managers of enterprises in Slovakia in 2022

Table 1. Exploring the relationship between firm size and risk priority in QMS, OSHMS, EMS

Year 2021						
	Allocated weight	Small enterprises (%)	Medium-sized enterprises (%)	Large enterprises (%)	chi-square statistic	p-value *
Risk Priority – QMS	1	70.9	67.7	64	5.8	0.2146
	2	22	23.4	18		
	3	7.1	8.9	18		
Risk Priority – OSHMS	1	34.1	36.3	36	1.61	0.807
	2	31.3	35.5	30		
	3	34.6	28.2	34		
Risk Priority – EMS	1	19.2	13.7	24	3.02	0.5545
	2	53.3	55.6	50		
	3	27.5	30.6	26		
Year 2022						
	Allocated weight	Small enterprises (%)	Medium-sized enterprises (%)	Large enterprises (%)	chi-square statistic	p-value *
Risk Priority – QMS	1	22.9	23.2	32.4	2.38	0.6662
	2	32.4	30.3	21.6		
	3	44.7	46.5	45.9		
Risk Priority – OSHMS	1	63.5	67.7	64.9	8.08	0.0887
	2	31.2	18.2	27		
	3	5.3	12.1	8.1		
Risk Priority – EMS	1	13.5	7.1	2.7	9.8	0.0439
	2	36.5	51.5	51.4		
	3	50	41.4	45.9		

* test $p < 0.05$

Table 1 shows an examination of the relationship between firm size and risk priority. In testing this relationship, we use statistical methods that allow us to determine whether there is a significant relationship between the two variables. If the resulting p-value is less than 0.05, we reject the null hypothesis (H0), which states that there is no relationship between firm size and risk priority. Thus, we accept the alternative hypothesis (H1), which suggests that there is a statistically significant relationship between the variables under study. At the significance level of $\alpha = 0.05$, we reject only one null hypothesis for the survey years 2020 and 2022. The rejected null hypothesis was number 6 H0: There is no dependence between the size of the enterprises from the 2022 survey and the risk priority in EMS. Therefore, we accept the hypothesis H1: There is a dependence between the size of the enterprises from the survey in 2022 and the priority of risks in EMS. Consequently, the strength of the dependence was therefore investigated in this case using Cramer's V. Cramer's V is a statistical indicator that is used to measure the strength of association between two nominal variables such as the size of enterprises and the priority of risks in the environmental management system. Its calculation involves the value of the chi-squared statistic from a contingency table that shows the distribution of data between these variables, and the result in this case was V = 0.1265. This means that there is a very weak relationship between the size of the companies from the 2022 survey and the priority of risks in EMS.

Focusing on the strength of priority, with number 1 being the highest priority and number 3 the lowest, there were interesting year-on-year changes that were found for all businesses regardless of size. Enterprises changed their preferences between risk priorities, but even so, only the last null hypothesis was rejected across risk size and risk priority.

2. Assessment of changes in the approach of business managers to the implemented preventive measures in enterprises in Slovakia

We have classified firm size as a nominal variable in the analysis as this category of firm represents qualitative data without numerical meaning. However, we focused on the average amount of money spent on preventive measures and the expected amount of money planned to be spent on preventive measures in the future, which are cardinal variables. Firm size is a nominal variable, average finance and planned expenditure on preventive measures are quantitative in nature and therefore we analyzed them as cardinal data.

We focused on some important statistical indicators from the survey, which included minimum, maximum, median, mode, mean, standard deviation, and sampling variance. These indicators play a key role in analyzing the distribution and variability in the survey data between 2020 and 2022. The minimum and maximum denote the smallest and largest values in the dataset, while the median represents the middle value that divides the data in half. The modus represents the value with the highest frequency in the dataset, while the mean is the arithmetic average of all values. Standard deviation measures the dispersion of the data from the mean, which provides information about its diversity, while sampling variance can provide additional insight into the variability of the data. Comparing these indicators between 2020 and 2022 helps us to identify changes in the distribution and nature of the data over time, which is key to understanding the dynamics and evolution of the variables of interest in the context of the phenomenon under study. Such analyses provide businesses with important information on which they can form strategies and decision-making processes based on empirical data.

Table 2. Percentage of annual turnover **spent** on the implementation of preventive measures

	Year 2020			Year 2022		
	Small enterprises	Medium-sized enterprises	Large enterprises	Small enterprises	Medium-sized enterprises	Large enterprises
Minimum	0	0	0	0	0	0
Maximum	10	15	5	35	30	30
Median	0.15	0.15	0.32	3	4	2
Modus	0	0	0	2	2	1
Average	0.54	0.6	0.78	4,82	6,74	5.03
Directional deviation	1.24	1.72	1.15	5.53	6.74	6.39
Selection variance	1.56	2.99	1.35	30.81	45.85	41.92

A comparison of the statistical characteristics between 2020 and 2022 for small, medium and large enterprises reveals significant changes in their distribution and variability. In 2020, we observe values for all categories of enterprises at lower levels. Conversely, in 2022 these values increase significantly. Focusing on the average in 2020, small, medium and large enterprises spent 0.54%, 0.6 and 78% of their annual turnover respectively on implementing preventive measures. However, in the next survey, these figures averaged 4.82%, 6.74% and 5.03% of annual turnover for small, medium-sized and large enterprises respectively on the implementation of preventive measures.

3. Assessment of changes in the approach of business managers to planned preventive measures in enterprises in Slovakia

We applied the same procedure in this section, where we examined year-on-year differences, focusing on the amount of

annual turnover they plan to spend in the future on the implementation of preventive measures.

Table 3. Percentage of annual turnover planned to be spent in the future on the implementation of preventive measures

	Year 2020			Year 2022		
	Small enterprises	Medium-sized enterprises	Large enterprises	Small enterprises	Medium-sized enterprises	Large enterprises
Minimum	0	0	0	0	0	0
Maximum	20	23	5	25	35	30
Median	0.75	0.85	0.80	3	5	3
Modus	0	0	0	0	2	1
Average	1.15	1.33	1.24	4.89	7.19	5.95
Directional deviation	2.16	2.51	1.35	5.29	7.13	7.14
Selection variance	4.67	6.33	1.86	28.12	51.30	52.33

The results in Table 3 show that a comparison of the percentage of annual turnover planned to be spent on implementing preventive measures between 2020 and 2022 shows significant changes in the strategies of companies, which vary according to their size. In 2020, on average, small enterprises allocated 1.15% of their annual turnover to preventive measures, medium-sized enterprises 1.33% and large enterprises 1.24%. In contrast, by 2022 these percentages have increased significantly: small businesses plan to spend on average 4.89%, medium-sized businesses 7.19% and large businesses 5.95% of their annual turnover on preventive measures.

5 Discussion and evaluation of the results

Within the framework of the conducted research it was found that managers whether in small, medium, large industrial enterprises before the occurrence of crises placed a higher priority on the risks in the quality management system, then on the risks in the environmental management system and then on the OSHMS. Their attitudes and risk perceptions have changed due to the impact of crises (Covid-19 pandemic, energy crisis). The aftermath of the crises influenced their attitude towards risks and they started to give more priority to the risks of the OSH management system, whether it was all types of risks. Risks in the quality management system were perceived as the second priority by the small enterprise, followed by risks in the environmental management system. The medium and large enterprise gave second priority to risks in the environmental management system, followed by risks in the quality management system.

The above results can be confirmed by authors who address QMS risks either before or after the crisis period, e.g., Grimashevich et al. (2019); Katanaeva et al. (2020), who emphasize the importance and relevance of continuously identifying risks in QMS even with the acceptance of ISO 9001 focused on risk-oriented thinking. Zhang et al. (2022) emphasise the need for establishing a regular QMS risk inventory and the use of different models and approaches to streamline it in an industrial enterprise. From the perspective of the OSHMS, it is not only important to comply with legal obligations but also to implement the OSHMS, ensuring the monitoring and control of the assessed risks of individual processes. It is declared by Bibire et al. (2020); Ramos et al. (2015) that, risk management should be part of OSHMS and emphasis should be placed on its development, integration and implementation of OSH policy and risk management. Felknor et al. (2021); Levashov et al. (2018); Klimova et al. (2017) emphasize that the continuous improvement of OSH with the integration of risk management results in the reduction of losses, occupational hazards, accidents, incidents, crashes, higher productivity, efficiency and quality of work, which affects the overall performance of the enterprise and especially the safety of employees. Also from the point of view of environmental protection, it is important not only to fulfil legal obligations but also to introduce QMS. Environmental protection increasingly requires attention, the importance of finding solutions and managing risks in the near future. The authors Yan (2022); Vodolazhskaya et al (2019); De Villiers et al (2022); Darus (2016) state that the environmental risk assessment of an industrial enterprise is very important, also the creation of committees in the board of directors with an orientation towards EMS risk management. They are inclined to the view that there is a need for companies to take responsibility for managing environmental pollution and as evidenced by the forthcoming revision of ISO 9001 with a climate change orientation.

Other findings in the research conducted were that managers whether in small, medium, large industrial enterprises before the occurrence of crises actually invested some financial resources on preventive measures that would reduce the probability and consequences of the assessed risks. Before the crisis period, a small enterprise was willing to invest 0.54%, a medium enterprise 0.6%, a large enterprise 0.78% of annual turnover. The consequences of the crises affected their attitude to risks and there was a radical change in the increase in the amount of funds invested, with a total increase of up to 764%. Small enterprises were willing to invest 4.82%, medium enterprises 6.74%, large enterprises 5.03% of annual turnover.

As part of the research, the findings included not only the actual status of the funds invested in preventive measures, but also the amount of funds planned for the coming years. Managers whether in small, medium, large industrial enterprises before the crises occurred had plans to invest funds for preventive measures that would reduce the probability and consequences of the assessed risks. Before the crisis period, a small enterprise was willing to increase the amount of investment in preventive measures to 1.15%, a medium enterprise 1.33%, a large enterprise 1.24% of annual turnover. The aftermath of the crises affected their attitude and there was also a radical change in terms of the amount of investment of funds for the future, with an overall increase of 384.68%. Small enterprise was willing to invest 4.89%, medium enterprise 7.19%, large enterprise 5.95% of annual turnover. Comparing the change in the perception of managers before the crisis period in terms of actual reported and planned funds for preventive measures there was an increase of 93.75%, after the crisis it was only an increase of 8.68%.

In the current business management, the importance of prevention with emphasis on risk management in QMS, OSHMS, EMS is constantly increasing and its activities significantly determine the success of the enterprise. This is declared by several authors e.g. Katanaeva et al. (2020); Akwei et al. (2018); Levashov et al. (2018), Ramos et al. (2015); Thimm, (2015); Krokhina et al. (2018); Vodolazhskaya et al. (2019), that proper application provides enterprises with a comprehensive and holistic view of the critical factors affecting product quality, as well as worker and consumer safety, environmental protection, and contributes to the streamlining of key internal enterprise processes. According to the authors Montoya-Quintero et al. (2022), Rebelo et al. (2016), Kafel (2016), risk management should be an integral part of the management of an enterprise enabling better coordination and collaboration between different departments and levels of the organization. Especially in the planning function, which is related to the trend towards prevention-oriented, early identification of risks and translates risk potential into possible scenarios of development. A good event analysis can help pave the way for proper risk management in the areas of quality improvement, safety with emphasis on environmental protection in the enterprise. Risk management becomes a prerequisite for increasing the success of the implemented business activities of the organization in terms of safety and sustainable development. The basis should be the correct approach of owners, top managers to risks, the creation of a risk culture and the established responsibility of managers for risk management in the management systems QMS, OSHMS, EMS and emphasis on the need to invest funds for the application of preventive measures.

6 Conclusion

The article highlights the fact that quality, OSH, environmental protection are nowadays, with the growing global business trends, considered as the most important management systems in connection with risk management in the enterprise. Every enterprise is affected by negative threats of the business environment, which is evidenced by changes in the perception of risks and attitudes towards preventive measures by managers also in industrial enterprises in Slovakia. The main findings presented in the paper can be summarized as follows: there are differences in the attitudes and risk perceptions of managers of QMS, OSHMS, EMS systems before and after the period of crises. Managers whether in small, medium, large industrial enterprises before the emergence of the crisis put more priority on risks in QMS. The aftermath of the crises influenced their attitude towards risks and they started to give more priority to OSHMS risks. Also, the aftermath of the crises has affected their attitude towards risks and there has been a radical change in the amount of money invested to implement preventive measures. There has been a change in attitude, albeit to a lesser extent in the increase of planned funds for the implementation of preventive measures in the future. On the basis of the processed results, it can be stated that some enterprises in Slovakia have learnt from the consequences of the crises. The question is to what extent they will continue to invest funds in preventive measures. Some enterprises in Slovakia still do not pay the necessary attention to risks, they only deal with the consequences caused by crises, despite knowing how highly the importance of crisis preparedness is rated.

The presented results have enormous added value as a “best practice” for owners, managing directors, senior managers and responsible managers of QMS, OSHMS, EMS industrial enterprises. The benefit to businesses is that if risk management is incorporated into the QMS, OSHMS, EMS of an enterprise, the likelihood of achieving the organisation's objectives will increase, compliance of individual outputs will be achieved, customers will be more confident that they will receive the expected product, the number of workplace accidents will be reduced, and employees will feel that they are working in a safe and healthy workplace improving the reputation of the enterprise. Properly applied, QMS, OSHMS, EMS in conjunction with risk management helps to achieve specified product quality, workplace safety and enhanced environmental protection. This contributes to increasing the efficiency of production and business processes, improving the bottom line and achieving sustainable business development. The results can form a treasure for the creation of national and supranational rules, guidelines, documents dealing with the prevention of corporate crises, risk management in QMS, OSHMS, EMS. The results can also serve for educational institutions oriented to the improvement of managerial qualification.

The processed results represent limiting characteristics, i.e. the set objective, hypotheses processed survey results are oriented only on QMS, OSHMS, EMS in industrial enterprises in Slovakia. The scientific article does not analyze other management systems such as information security system, socially responsible business system. The survey was oriented only on industrial enterprises, it did not assess service enterprises. As it was a challenging assessment of the development of managers' perception of attitudes towards risks and preventive measures in 2020 and 2022-23, the results are processed only at the national level, i.e. within Slovakia.

The results are also baseline data for the implementation of further surveys, i.e. the continuation of the development of attitudes and risk perception of business managers in Slovakia as well as in the Visegrad Four (V4) countries or in other European countries. Further direction of the authors' research lies in linking the normative requirements of management systems and the obligations arising from laws, especially for OSH and the environment, with an emphasis on the Compliance Management System. The authors are also interested in contributing to the development of the concept of risk culture for more effective risk enforcement in the company as well as to the comparison of the results obtained in Slovakia in comparison with the V4 countries.

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Appendix A: Questionnaire - Integrated risk management

Question - Your company ranks according to the number of employees among:

- Small enterprises (from 11 to 50 employees)
- Medium-sized enterprises (50 to 250 employees)
- Large enterprises (over 250 employees)

Question - In which industry does your business operate?

- Energy sector
- Engineering sector
- Chemical and rubber industry
- Electronic and electrical engineering sector
- Metalworking industry
- Woodworking industry
- Food processing industry
- Other

Question - Which risks in the above management systems do you give the highest priority to reduce? (please rank 1-3, where 1 is the highest priority, 3 is the lowest priority)

- Quality management system
- Occupational health and safety system
- Environmental protection system

Question - What % of funds from annual turnover do you invest on average for the implementation of preventive measures in your company (current situation)?

Question - What % of the financial budget do you plan to invest for the implementation of preventive measures in your enterprise (plan)?

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TERRORIST ATTACKS ON ENERGY INFRASTRUCTURE

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Abstract: This paper focuses on terrorist attacks targeting energy infrastructure. Energy infrastructure is much more important nowadays than in the past. Terrorist attacks on this infrastructure could have enormous consequences for a large number of people, their activities, and, of course, the impact on the environment. The threat of terrorist attacks is growing worldwide. In the modern world, it is imperative to concentrate on protecting energy infrastructure against terrorist attacks. The regular supply of energy at affordable prices with environmental protection is an important activity of states and their security forces.

Keywords: assassination, bomb attack, energy infrastructure, guerrilla, infrastructure, critical infrastructure, terrorism.

Introduction

Energy security is currently the subject of intense debate. Energy is an important part of every society, every individual. In this article, I will discuss terrorism and examine the differences between terrorism and guerrilla. I will give a basic overview of the types of terrorist attacks.

Terrorist attacks can involve explosive devices, arson, various forms of threats, and other attacks on energy infrastructure. I will also analyse both energy and critical infrastructure. In the last part, I will provide a brief overview of past terrorist attacks and incidents targeting energy infrastructure.

1 Terrorism

When people talk about terrorism in general, it is assumed that the meaning of this word is clear. In reality, however, there is still no universally accepted definition. Countries refuse to sign global agreements on anti-terrorism cooperation, either due to disagreement or reluctance to define which actions, individuals, or organisations should be categorized as terrorist (5). The greatest challenge remains at the global level. The attempt to develop a single, universally acceptable legal definition of terrorism is nothing new. Throughout history, such efforts have emerged repeatedly, often in response to major terrorist acts that, at the time, shook the 'conscience of humanity', stunned the public and political circles. These events have consistently sparked discussions on the necessity of coordinated anti-terrorism efforts (1).

The Latin word terrere means 'to frighten,' while terrore translates as 'in horror' or 'with fear'. Thus, the term terrorism is derived from the Latin root terror, which originally signified extreme fear or anxiety arising from an obscure and unpredictable danger (11).

The term terrorism encompasses those actions and methods that evoke feelings of fear and terror (4). This word was first used in France in the years 1793 to 1974 in connection with the Jacobin terror. It characterised the actions of the government against the population (9). The first official definition of terrorism of international importance was formulated in 1937 during the League of Nations' talks on the Convention for the Prevention and Suppression of International Terrorism. Twenty-four states signed the Convention, and only India ratified it (13).

In 1980, a definition of terrorism was published in the United States, which has become the basic standard for evaluating and analysing terrorist acts. It states: ‘Terrorism is the calculated use of violence or the threat of violence, usually directed against uninvolved people, to create fear by which political, religious or ideological objectives are achieved. Terrorism also includes symbolic criminal acts that are a means of achieving objectives other than those to which the criminal act is directed’ (4). Luis de la Corte defined terrorism in The Logic of Terrorism: 'It is a deliberate series of violent and intimidating acts directed against an uninvolved people and planned in such a way as to psychologically influence many more people than the immediate victims and thus serve a specific, almost always political, purpose’ (5). In the most general terms, terrorism (as noted above) is understood as a form of organised violence, usually directed against uninvolved people to achieve political, criminal, or other objectives. Terrorist methods are characterised by high danger, ruthlessness, and brutality. Their choice and use are driven by the desire to maximise psychological impact. The violence used by terrorists is not the result of circumstances, but is designed to induce a sense of fear and threat in the widest possible range of people. The more brutal, the scale of the attack, and its consequences, the more likely it is to achieve the intended goal (12).

1.1 Differences between terrorism and partisanship

For many people, the concept of ‘terrorism’ is identical to the concept of ‘guerrilla’. In the following section, I will attempt to clarify the differences using available information. It is also important to realise that often what some interpret as terrorism is defined by others as guerrilla or conventional armed conflict. In other words, terrorism is a type of political violence that we often confuse with other forms, especially guerrilla or conventional armed conflict (5). Guerrilla warfare and insurgency are good to start with. Terrorism is often confused with guerrilla and insurgency or treated as a synonym. This is not entirely surprising as guerrillas and insurgents often use the same tactics (assassination, kidnapping, hostage-taking, etc.) for the same purposes (intimidation or coercion, thereby influencing behaviour through fear arousal) as terrorists. Like guerrillas, terrorists do not wear uniforms or identifying marks, making them difficult to distinguish from uninvolved people. However, despite the tendency to put terrorists, guerrillas, and insurgents into one category of 'irregulars', there are fundamental differences between them (3).

Terrorists are distinguished from guerrilla groups by two main features. Firstly, they live openly within the society they later target with their attacks. Secondly, they ‘blindly and ruthlessly attack the civilian population’ (8). A small group of terrorists or even an individual carries out an attack. In such attacks, a small group or individual uses minimal forces against significantly larger ones. Using limited personnel and minimal costs, they achieve devastating effects with a huge psychological impact (7). Terrorists do not wear uniforms or live in the forests; instead, they operate in the society that they later attack. Terrorism never acts directly. The attack serves as a tool of coercion, influencing decisions on how to respond after the terrorist act. (7). Guerrillas or guerrilla groups have the name guerrilla, which means a small war that takes place on the periphery. Unlike terrorists, guerrillas usually live in the forests, hidden by the terrain, they are paramilitary organisations, they have a pyramidal command and control system, and they do not live dispersed in society, which is the main distinguishing feature from terrorists.

1.2 Types of terrorist attacks

Terrorists use various types of terrorist attacks to realise their intentions. These include all kinds of attacks, from bomb attacks, kidnappings, assassinations, and all sorts of possible and impossible actions.

Bomb attack

An attack using explosive devices is the most common form of terrorist action. The use of such a device allows for a successful attack while significantly lowering the chances of the perpetrator being identified. From a tactical perspective, bomb attacks can be classified into four categories:

1. Attacks targeting people. Explosive devices are placed in crowded areas, ensuring that an explosion results in mass casualties. Such devices are hidden in parked cars, trash bins, etc.
2. Attacks on symbolic targets. This type of attack is generally directed against targets that represent symbols of one country or another.
3. Attacks on significant targets. These attacks are based on a careful selection of targets. Typically, important industrial centres, power plants, government buildings, or individuals in key leadership positions are chosen. The main objective in such cases is to cause damage and losses that are difficult to compensate for in the long term.
4. A series of attacks (campaigns). Terrorists use a series of bomb attacks to draw attention to some of their special goals and demands, such as the release of imprisoned perpetrators of terrorist acts (4).

A bomb comprises an explosive object, an explosive or incendiary substance or pyrotechnic devices, and functional initiating elements (12). These attacks have been carried out in various ways in the past: dropping a bomb on a vehicle of an important person or directly on the person being attacked, or placing a bomb in luggage to be sent by plane, train, bus, etc.

Hostage-taking, kidnapping

Kidnapping and hostage-taking are not new phenomena. They have been used for centuries as an effective means of achieving strategic or tactical objectives (14). Hostage-taking can be used by terrorists to put pressure on a government to negotiate or provoke negotiations on certain issues or topics. Terrorists use kidnapping in a political context as a way to influence government behaviour or to put pressure on the public or private sector. Very often, it is used to get financial resources that are extorted as ransom payments. These funds are then used to finance other operations. Aircraft hijackings are frequently conducted to achieve political goals (4).

Assassinations of prominent figures, assassination attempts

Assassination is a distinct form of violence and an effective weapon used by terrorists. The victims are usually people of significant social position, representing a political current, government policy, public authority, or certain industries and economies. The key condition is that the potential victims must be well known enough to ensure widespread publicity and attention in case they are attacked (4). Assassins use a wide range of weapons: explosives, firearms, knives, sniper rifles, etc. (14). From a technical perspective, two main categories of attacks are considered. The key distinguishing factor between them is the distance from which the attack is conducted (4). Depending on the distance, knives, machetes, axes, i.e. bladed weapons, can be used at short personal distances. Terrorists also use handguns and grenades for short-distance attacks. At longer distances, they use rifles, automatic weapons, anti-tank weapons, rockets, etc. Typically, all types of attacks are usually preceded by intensive reconnaissance activities focused on pre-selected targets. Its quality and effectiveness are the main conditions for the success of a prepared attack (4).

New threats of terrorism

Terrorists are seriously concerned about the possibility of acquiring knowledge and then actually producing weapons of mass destruction or their destructive components, most notably chemical, biological and toxin weapons. These weapons are significantly cheaper than nuclear weapons, and their production is not accompanied by the technical and technological difficulties that characterise nuclear weapons (12). For multiple reasons, terrorists may consider detonating a bomb with a conventional non-nuclear filling that is designed to spread radioactive material. For example, a Semtex bomb designed to scatter a container carrying radioactive material that the terrorists have managed to steal or buy somewhere. This would be the so-called dirty bomb (6).

During the 1993 World Trade Centre attack, Islamist terrorists planned to use hydrogen cyanide alongside explosives. Sodium cyanide was added to the explosives to generate hydrogen cyanide. The intent was to use hydrogen cyanide to kill both survivors of the explosion and rescue workers who arrived on the scene (16). The unexpected rise of Aum Shinrikyo as the only known ultra-terrorist group in the world is a phenomenon that most Japanese have difficulty understanding. The words 'ultra-terrorism' and 'ultra-terrorist' refer to a terrorist group that possesses or uses chemical, biological, or nuclear weapons – classified as weapons of mass destruction - for political objectives (2).

Cyber terrorism

Potential cyberattacks on computers and network systems are very destructive for developed societies. Advanced societies are increasingly dependent on computer networks. Cyber operations at a computer can remotely cause enormous damage and infrastructure problems. Examples include disabling water, electricity, or gas distribution systems. Chaos can be easily caused in air, rail and bus transportation, as well as in fully automated financial transactions (12). Moreover, terrorist organizations widely use the Internet as a popular information platform for posting their agendas and proclamations there (12).

2 Energy infrastructure

Disabling critical infrastructure is the first method of terrorism. It is a non-lethal method that has become increasingly serious in recent years due to scientific advancements and growing automation. This is because the risk of catastrophic terrorist attacks targeting critical infrastructure is significantly increasing. An attack on the control systems of chemical plants or liquefied natural gas infrastructure could lead to great loss of life and extensive damage. Critical infrastructures exist in a wide variety of economic sectors, including banking and finance, transportation and distribution, energy, utilities, healthcare, food supply chains, communications, and key government services (13).

2.1 Infrastructure

Infrastructure is, in the most general sense, the set of interconnected structural elements that hold the whole structure together. It typically refers to artificial structures. The term 'infrastructure' is used in different senses in several fields, though it is most commonly associated with economics, to describe physical infrastructure such as buildings or roads. Infrastructure can be built and maintained by either the private sector or government (15). In terms of focus and internal characteristics, infrastructure can be classified into several categories, including economic (energy, water, etc.), research and development, administration and management, information and socio-cultural. As economic and social development progress and integration trends deepen, the importance of infrastructure increases. Infrastructure performs multiple functions: production-supporting or social-supporting, agglomeration and urbanisation, integration, homogenisation, enhancement of socio-economic efficiency, innovation, and rationalisation.

Infrastructure, as a framework, is a system of long-term foundational facilities (human, material, and institutional) that support the efficient division of tasks within a national economy. In this context, the term ‘public infrastructure’ is frequently used, which is further divided into technical and social infrastructure (15). Due to the interconnected nature of infrastructure sectors, a failure in one area can trigger a cascading effect, sometimes referred to as the domino effect, where the collapse in one system leads to the failure in others. For instance, an attack on a power company that results in an interruption of the electricity supply could lead to the failure of wastewater treatment plants because the turbines and other electrical systems stop working (13).

2.2 Critical infrastructure

Every society has a part of its infrastructure that is important for functioning. This infrastructure is known as vital or critical infrastructure. The task of society is to protect such infrastructure and ensure its functionality in all situations - whether normal, emergency, or critical (15). Critical infrastructure has become a modern phenomenon. Governments and their executive branches have recognized their importance during a period marked by the increasing intensity and aggression of terrorism. National infrastructure facilities - crucial for political, economic, social, and cultural development - have also become targets of international terrorism (17).

Network structure of critical infrastructure.

The structure of any network consists of individual elements and the links between them. In every network, there are places where several links come together to form a single element, known as a node. While many nodes may be insignificant, some are crucial; disrupting them can lead to reduced functionality or even the collapse of the entire system. Therefore, critical infrastructure defence should prioritize protecting these essential nodes. Critical infrastructure is a term used by government leaders to refer to assets that are essential to the functioning of society and economy. Many definitions explain critical infrastructure as a system designed to protect society and its interests. Security management terminology defines critical infrastructure as '...a set of physical or virtual systems, institutions, facilities, and other services whose disruption, deficiency, or destruction could undermine the social stability and national security, cause a crisis, or seriously impact public administration at both state and local levels in times of crisis ...' (17).

The EU Commission's Communication to the Council and the European Parliament provides an overview of critical infrastructure components, including the following:

Energy infrastructures and networks (e.g., electricity generation, oil and gas extraction, storage and refineries, transmission and distribution systems);
Communications and information technology (e.g., telecommunications, broadcasting systems, software platforms, hardware systems, and the Internet);
Financial services (e.g., banking, securities and investments);
Health care (e.g., hospitals, medical facilities and blood banks, laboratories and pharmaceuticals, search-and-rescue and emergency services);
Food industry (e.g., food safety, manufacturing facilities, wholesale and food processing);
Water management (e.g., dams, water storage and treatment, networks);
Transportation infrastructure (e.g., airports, ports, railway and public transport networks, traffic management systems);
Production, storage, and transportation of hazardous products (e.g., chemical, biological, radiological, and nuclear materials);
Government infrastructure (e.g., essential services, strategic facilities, information networks, national assets, key government landmarks) (13).

2.3 Energy infrastructure

To ensure energy supply to the site, the necessary infrastructure must be established, including systems for transportation and distribution of energy resources, storage facilities, and mechanisms for converting energy sources into alternative forms. Conversion encompasses, for example, the generation of electricity in power plants as well as the refining of petrol and diesel in refineries. Energy storage is used both to balance consumption and supply and in case of supply disruptions (10).

The Annex to Directive (EU) 2022/2557, issued by the European Parliament and Council on 4 December 14, 2022, describes sectors, sub-sectors and categories of entities relevant to energy infrastructure:

In the electricity sub-sector, the following entities are categorized:
- electricity utilities,
- distribution system operators,
- transmission network operators,
- electricity producers,
- designated electricity market administrators,
- electricity market participants.

The district heating and cooling sub-sector includes the following operators:
- operators of district heating
- operators of district cooling.

The petroleum sub-sector includes the following:
- pipeline operators,
- operators of oil production, refining and processing facilities,
- operators of storage and transportation facilities,
- central reserve administrators.

In the Natural Gas sub-sector are the following organisations:
- supplier companies,
- distribution system operators,
- transmission network operators,
- storage system operators,
- LNG terminal operators,
- gas companies,
- operators of natural gas treatment and processing facilities.

The hydrogen sub-sector includes the following operators:
- operators of hydrogen production, storage and transportation.

This is an overview of the EU's energy infrastructure. This Directive replaced Directive 2008/114/EC and came into force on October 18, 2024.

3 Terrorist attacks

I analysed and documented terrorist attacks and incidents targeting energy infrastructure, categorizing them into two groups. The larger group included attacks on energy infrastructure without nuclear facilities, while the second smaller group consisted of attacks targeting energy infrastructure with nuclear facilities. This section provides an overview of terrorist attacks on energy infrastructure from 2001 to 2020. I have used two main sources Global Terrorism Database and Global Incident Map.

3.1 Terrorist attacks on non-nuclear energy infrastructure

During the reporting period, I documented more than two thousand one hundred terrorist attacks and incidents targeting non-nuclear energy infrastructure worldwide. Most of the attacks and incidents were conducted using bombs or explosives. These were bomb attacks. I recorded a total of 1815 bomb attacks. These attacks occurred continuously and throughout the reporting period. For example, on July 21, 2012, a bomb attack targeted an oil pipeline in Turkey. On July 7, 2013, Egyptian militants detonated a gas pipeline connecting Egypt and Jordan in El Arish in the Sinai Peninsula, where several other attacks took place around the same time. On July 28, 2014, a female suicide assassin attacked a fuel station in Nigeria—the third bomb attack in Kano within 24 hours. On April 12, 2015, two eight-kilogram bombs were discovered attached to an energy tower. They were remotely neutralized using water cannons before detonation. On November 8, 2016, Nigerian militants detonated an oil pipeline—the third attack on the Trans Forcados pipeline network within eight. On March 14, 2017, a 132kV power transmission pole was blown up in Pakistan. On September 2, 2019, in Libya, a fire erupted at the Gharani power plant in Ain Zara after an artillery shell hit one of its turbines. This brief overview of terrorist attacks illustrates the wide scope of bomb incidents, ranging from explosions on power grids to attacks on pipeline networks. The second most frequent type is a gunfire attack. For example, on July 25, 2010, in Yemen, al-Qaeda militants targeted oil fields and killed six Yemeni soldiers. That was the fourth attack on government targets since June. On July 13, 2013, an oil tanker came under gunfire in Pakistan.

On October 15, 2020, a convoy of Pakistani oil and gas workers escorted by paramilitary troops was ambushed, and 15 people were killed. The third most frequent type of attack is an arson attack. On July 4, 2010, terrorists set fire to a power plant in Mukalla, Yemen. During an attack on April 2, 2013, in Pakistan, terrorists set fire to seven parked vehicles in the substation. On 10 March 2015, IS members burned down a substation in Iraq. On January 5, 2016, at least four oil storage tanks were set on fire during an IS attack in Libya. Kidnappings are another form of terrorist attacks. For example, in Nigeria, the father of an oil tycoon was kidnapped on June 12, 2008. On December 4, 2013, militants kidnapped 13 workers at a power plant in Pakistan. Assassinations are another form of terrorism. For example, on June 17, 2009, Taliban terrorists assassinated the director of the Oil and Gas Department in Afghanistan. On October 18, 2011, there was an assassination attempt on an official of Iran's Oil Ministry, who fortunately escaped the attempt. Biological attacks often involved the delivery of envelopes containing unidentified or suspected substances. For example, on September 10, 2020, a suspicious envelope was delivered to Green Mountain Power in the United States.

3.2 Terrorist attacks on nuclear energy infrastructure

During the reporting period in the second group, I recorded 107 terrorist attacks and incidents targeting nuclear facilities. Radiation incidents were the most frequently reported. I recorded a total of 66 radiation incidents. These include, for example, the arrest of two men on May 21, 2008, on suspicion of attempted sabotage, one of whom was carrying a plastic bag containing traces of explosive substances. On October 9, 2009, an engineer working at the CERN nuclear research laboratory was arrested on suspicion of being in contact with an Al-Qaida network and planning terrorist attacks. On March 11, 2010, the head of the Rawatbhata nuclear power plant was found dead in Kota, India. On September 22, 2010, a radioactive gamma projectile was reported missing in Pakistan. The projectile is used to store a dirty bomb or a nuclear bomb. On May 3, 2011, five men were arrested on suspicion of terrorist activities. Another terrorist attack happened in Brazil on March 19, 2019, when gunmen attacked members of a convoy transporting uranium to one of the nuclear power plants. On 3 May 2018, a terrorist attack took place in Pakistan on a bus carrying employees of the Pakistan Atomic Energy Commission. Three people were killed and 13 others were injured in the attack when a suicide bomber blew himself up next to the bus in the Punjab province in Pakistan. In India, on October 8, 2014, a soldier shot and killed three security personnel and wounded two others after an argument. The cyberattack between May and June 2017 was considered one of the largest. It consisted of an attack on twelve nuclear power plants in the US.

Conclusion

Terrorist attacks on energy infrastructure can threaten democratic states, so this is an area that requires attention. Bomb attacks or other possible attacks on oil pipelines, gas pipelines and power grids can have immeasurable consequences or even cause a domino effect across society.

In the first part of this paper, I have tried to offer a brief overview of terrorism. I have selected a few definitions of terrorism. I have outlined the differences between terrorism and guerrilla warfare. Terrorists use various attack methods to achieve their goals, which I also briefly described. In the next section, I have also examined the general infrastructure focusing on critical and energy infrastructures. Based on the discovery of over 2,100 terrorist attacks targeting non-nuclear energy infrastructure and more than 100 incidents involving nuclear facilities worldwide, I began to intensify my research. This article serves as an introduction to a subject I plan to analyse in more detail. Moreover, more and more attacks by aerial, ground and water drones are taking place, I intend to examine them in the context of energy infrastructure protection. These types of attacks are advancing in complexity. They can have much more serious consequences than previously thought.

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Primary Paper Section: A

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CIRKULAR ECONOMY AND ITS CHALLENGES

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Abstract: The primary objective of this article is to assess the impact of increased investments in the circular economy on municipal waste generation and recycling rates in the EU27 countries. The article is structured into two main sections. The first section explores the historical development and theoretical foundations of the circular economy with a particular focus on the role of private investments in this advancement. The second section presents the findings of an empirical analysis. In the introduction, this study examines the trends in key statistical indicators of the circular economy, specifically highlighting private investments in the circular economy, the municipal waste recycling rate and the generation of municipal waste. The second section investigates the relationship between private investments in the circular economy and the recycling rate of municipal waste as well as the relationship between these investments and municipal waste generation in the EU27 countries. The analysis covers the period from 2012 to 2020, chosen to ensure a balanced dataset. The study employs fixed effects model and a random effects model for panel data analysis. The findings reveal a statistically significant positive impact of private investments in the circular economy on the recycling rate of municipal waste. Differences were observed between groups of countries based on their annual investment growth rates. However, the anticipated effect of increased investments in the circular economy on reducing municipal waste generation was not confirmed. The data for empirical analysis was sourced from Eurostat, and calculations performed using the Gretl software.

Keywords: circular economy, investments, municipal waste, panel data, recycling rate.

1 Introduction

In 2023, the EU´s circularity rate was 11.8%, slightly up compared with the previous year and 3.6 percentage points up from to 2004, the first year for which data are available (Eurostat, 2024). Despite the increase, the value of 11.8% is still low, indicating that the majority of materials used in the EU come from primary sources (European Commission, 2023). The material circularity rate, an important indicator of the circular economy, reflects the extent to which the economy uses recycled materials and reduces the consumption of primary raw materials. The upward trend in its development is encouraging, though the slow pace of growth remains a concern. From 2014 to 2023, the average annual growth rate was just 0.68%. Global consumption of materials such as biomass, fossil fuels, metals and minerals projected to double over the next four decades OECD, 2019), while annual waste production is projected to rise by 70% by 2050 (Kaza et al., 2018). To achieve its climate and environmental targets by 2030, such as doubling the circularity rate to approximately 23%, the EU must implement additional fundamental measures.

The European Commission adopted the first Circular Economy Action Plan (CEAP) in December 2015. Four years later, the European Green Deal was adopted. The European Green Deal established a common strategy for a climate-neutral and competitive economy (European Commission, 2019**)**. It states that the EU must accelerate the transition to a regenerative growth model, which is an essential part of the EU's new industrial strategy. The new CEAP was adopted in March 2020. According to the European Green Deal, the EU's transition to a circular economy will slleviate pressure on natural resources, foster sustainable growth and generate new jobs. It is essential for achieving the EU's goal of climate neutrality by 2050 and stopping biodiversity loss (European Commission, 2020)**.**

The concept of a circular economy (CE) is built on the following principles: optimizing the use of limited resources for maximum efficiency, prioritizing the utilization of renewable resources, recovering materials at the end of their life cycle, and restoring natural ecosystems. (Lewandowski, 2016). This concept aligns with the EU's new Circular Economy Action Plan and the European Green Deal. A more comprehensive explanation of this concept is outlined in the Bellagio Declaration in 2020, endorsed by several European countries, including Germany, France, Slovakia, Switzerland, the Netherlands, Austria and Italy, Bellagio outlines seven fundamental principles for an effective transition to a circular economy (EEA, 2020).

The European Commission is implementing legislative and non-legislative measures focused on areas where EU-level action can deliver significant added value. The new Action Plan aim to establish sustainable products as the standard in the EU, empower consumers and public buyers, reduce waste, promote circularity across people, regions and cities, and drive the global transition to a circular economy.

2 Theoretical background

The circular economy is based on three principles: a) design production to minimize waste and pollution, b) extend the lifespan of products and materials through repair, recycling, and reuse, and c) regenerate natural systems and reduce their environmental impact (Ellen MacArthur Foundation, 2013). The goal of the circular economy is to preserve the value of products, materials, and resources for as long as possible by reintegrating them to the production cycle after their use, while minimizing waste. (Le Hesran et al., 2020).

The cornerstone of progress in the field of circular economy lies in the efforts of Pearce and Turner (1989), who laid groundwork for the circular economy within the framework of natural resources and environmental economics. Their work combines a theoretical framework with practical insights, offering a robust foundation for understanding the economic aspects of environmental policy. This work established the foundations upon which other authors have built. For example, Jackson (1996) in his book "Prosperity without Growth: Foundations for the Economy of Tomorrow" emphasizes that environmental problems such as biodiversity loss, water, air and soil pollution, resource depletion and overuse of land are increasingly threatening the systems that support life on Earth. This approach further develops the idea of the circular economy and its connection to sustainable development. Kinnaman and Fullerton (1999) provide an overview of the latest trends in solid waste and recycling, as well as related public policy issues. Their work plays a significant role in the broader discussion on the circular economy and its practical implementation.

In 2015, the Ellen MacArthur Foundation introduced the Circular Economy Principle (CEP) to transition the traditional linear economy towards a circular economy model (Ellen MacArthur Foundation, 2013). This approach was elaborated in the foundation's work "Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition." (Ellen MacArthur Foundation, 2013).

Lewandowski (2016) proposed a new business model for the circular economy, which includes nine building blocks. The transition from the current linear economic model to a circular one has recently attracted increased attention from large global companies such as Google, Unilever, Renault, and policymakers attending the World Economic Forum. The motivation lies in the substantial financial, social and environmental benefits (Lewandowski, 2016). The integration of circular economy principles into the value chains across various economic sectors is gaining significance, as highlighted by numerous studies and research, including the work of Ávila-Gutiérrez et al.(2019). Yamamoto & Eva (2022) define a circular economy as an economy based on the 3R principle: 1. reduce, 2. reuse and 3. reccle. These definitions and approaches enhance the understanding and promote the implementation of the circular economy.

Tracking the circular economy indicators, including waste generation, utilization and proper management is crucial for sustainable development. The core concept of the circular economy revolves around waste minimization (López Ruiz et al., 2020; Popovic et al., 2022). Various studies, such as those by Cagno (2012), Cooper (2017), and Geissdoerfer *et al. (2017) have explored* the issues related to waste elimination and processing, as well as the adoption of new technologies to enhance waste processing. *Alongside waste minimization, improving the efficiency of waste collection and processing is another critical solution* (Gutierrez et al., 2015; Goutam Mukherjee et al., 2021). Podľa Lohri et al. (2013) ensuring the financial sustainability of solid waste management remains a significant challenge for cities in developing countries. Ferronato et al. (2019) addresses the issue of solid waste management in these urban areas.

In 2023, the European Commission updated the Circular Economy Monitoring Framework originally adopted in 2018. It monitors circular economy indicators in five areas: production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience **(**European Commission, 2023**).** The monitored areas and circular economy indicators in the Eurostat database are listed in the table 1.

Tab.1: Areas and indicators of the circular economy reported in Eurostat

Area	**Indicators**
Production and consumption	Material footprint
	Resource productivity
	Waste generation per capita
	Generation of waste excluding major mineral wastes per GDP unit
	Generation of municipal waste per capita
	Food waste
	Generation of packaging waste per capita
	Generation of plastic packaging waste per capita
Waste management	Recycling rate of municipal waste
	Recycling rate of all waste excluding major mineral waste
	Recycling rate of packaging waste by type of packaging
	Recycling rate of waste of electrical and electronic equipment (WEEE) separately collected
Secondary raw materials	Circular material use rate
	Contribution of recycled materials to raw materials demand – end-of-life recycling input rates (EOL-RIR)
	Trade in recyclable raw materials
Competitiveness and innovation	Private investment and gross added value related to circular economy sectors
	Persons employed in circular economy sectors
	Patents related to recycling and secondary raw materials
Global sustainability and resilience	Consumption footprint
	Greenhouse gases emissions from production activities
	Material import dependency
	EU self-sufficiency for raw materials

Source: *European Commission, 2023*

This study explores the indicators generation of municipal waste per capita (area production and consumption), the recycling rate of municipal waste (area waste management) a private investment and gross added value related to circular economy sectors (area competitiveness and innovation).

Municipal waste generation is influenced by several factors. Demographic factors encompass elements such as population size, population density and the age distribution of individuals within a community or region. Economic factors also play a role, such as higher living standards leading to increased waste generation, household incomes affecting the consumption of semi-finished food products, and the more frequent replacement of durable consumer products. (Fullerton & Kinnaman, 1995). Technological factors are crucial, particularly regarding e-waste management and advancements in production methods (Ghisellini et al., 2018). *Social and cultural factors, such as of the population´s education level, significantly impact waste management. Higher education levels are associated with increased rates of waste sorting and recycling. Conversely, in marginalized communities, social exclusion and limited access to infrastructure contribute to inefficient waste management practices and the development of illegal landfills* (Dokoupilová et al., 2022). The generation and recycling of municipal waste can be governed by laws and legislative regulations. Equally important is fostering environmental awareness among the population to encourage waste reduction and promote recycling. By combining effective planning, robust legislation and public education, society can significantly decrease the overall volume of municipal waste and mitigate its environmental impact.

3 Sources of private investment for the introduction of the circular economy

The implementation of circular activities requires the mobilization of various financial resources to support the transition to a circular economy. Collaboration among the public, private and non-profit sectors is essential for optimizing the use of available resources and ensuring the successful implementation of circular initiatives. The availability of funds, the quality of companies' financial resources and access to public subsidies positively influence the adoption and implementation of circular economy initiatives within enterprises. (Aranda-Usón et al., 2019). Investments can support this philosophy by funding innovations in areas such as recycling, renewable energy and resource efficiency. (EEA, 2024).

Targeted financing for circular activities is rapidly gaining traction around the world. Capital-rich organizations are testing creative ways to finance circular strategies in debt capital markets. For example, fashion retailer H&M Group issued a €500 million sustainability bond in February that ties pricing to everal of the company’s 2025 goals, including increasing the share of recycled materials used in its products to 30%. With less than 1% of the materials used to make clothing globally currently recycled into new clothes, this commitment could be an unprecedented step towards a circular economy in fashion if achieved.

Total assets under management through public equity funds dedicated solely or partially to the circular economy have grown more than 25-fold in just a year and a half, from $300 million at the beginning of 2020 to $8 billion by the end of June 2021. BlackRock’s BlackRock Circular Economy Fund 2 reached $2 billion in assets under management in June 2024, reflecting the explosive growth in the sector (BlackRock, 2024). The fund invests at least 80% of its total assets in equity securities of companies worldwide that benefit from the development of the "circular economy" or contribute to environmental or social objectives. (De Smet, 2024).

European Investment Bank (EIB). From 2019 to 2023, the EIB provided EUR 3.83 billion to co-finance 132 circular economy projects in various sectors (EIB, 2024). In addition to capital, the EIB provides financial and technical advisory support to improve the bankability and investment readiness of circular economy projects. Together with the European Investment Advisory Hub, they launched the Circular City Financing Guide website and the Circular City Centre – C3 (EIB & EC, n. d.), a competence and resource centre within the EIB aimed at supporting EU cities in their transition to a circular economy. The EIB is also an active member of the Multilateral Development Bank (MDB) Circular Economy Working Group, together with the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, the Inter-American Development Bank, the International Finance Corporation, and the World Bank. The World Bank is actively involved in investing in projects and initiatives that lead to sustainable development, including

the circular economy (Al-Hagla, 2024). Its aim is to ensure that investments provided to governments contribute to protecting people and the environment from possible negative impacts.

Specialized banking products designed to promote the development of the circular economy are increasingly emerging in the financial market. Intesa Sanpaolo has established a €6 billion loan facility to support circular activities, while ABN Amro facilitated nearly €850 million in circular economy transactions between early 2019 to the end of 2020 (Lawlor & Spratt, 2020). Additionally, several companies are now linking debt financing to circular economy key performance indicators (KPIs). For example, AB InBev's $10 billion revolving credit facility incorporates terms tied to the use of recycled materials in its primary packaging (Abbott et al., 2021).

Analysing the level of private investment in the circular economy and its influence on waste reduction is crucial for assessing the private sector´s role in driving the ecological transition. Private investment plays a crucial role in funding technological advancements, innovations and processes that support the circular economy, such as advanced recycling systems, eco-design and digital platforms. It often serves as a valuable complement to public funding. Investments in recycling infrastructure and waste collection systems increase the share of recycled materials and reduce the amount of waste that ends up in landfills or incinerators. Private investments can support educational campaigns aimed at encouraging sustainable consumer behaviour. A low level of private investment hinders the implementation of circular measures, leading to slower progress and sustained high levels of waste. Investments must be effective to achieve waste reduction targets. A supportive regulatory environment and legislative framework are also crucial. Given the assumption that private investment influences the amount of waste generated, four research on European Union countries to analyse the impact of private investment on waste generation. Analysing private investment enables us to assess the significance of the private sector´ contribution to achieving circular economy goals. Furthermore, we investigated how the level of private investment in the circular economy impacts municipal waste recycling rates.

Tab. 2: Estimated investment in the circular economy in mill. $

Organization	Value (MUSD)	Unit/sector
McKinsey	$2,140,000	Whole economy
World Economic Forum	$5,350,000	Whole economy
World Economic Forum	$340,000 - 380,000	
Closed Loop Partners and Closed Loop Foundation	$2,000,000	Manufacturing
Closed Loop Partners and Closed Loop Foundation	$7,000	Recycling
Danish Ministry of Environment and Food	$713 – 1,740	Savings on raw materials and manufactured goods
McKinsey	$2,140,000	Whole economy
Accenture	$25,000,000	Whole economy
Veolia	$1,960	Whole economy
Circular Fashion Report	$5,000,000	Fashion
PS consulting	$12,000,000	Plastics
Ellen MacArthur Foundation	$1,180,000	Whole economy
ESA, 2013	$14,000	Whole economy
TNO, 2013	$8,680	Whole economy
TNO, 2013	$1,000 per year	Waste
European Commission	$1,100	Waste
European Commission	$32,000	Paper and cardboard
McKinsey (2011)	$145,000	Iron and steel efficiency
McKinsey (2011)	$132,000	Steel efficiency
European Commission	$1,720	Mobile phone
European Commission	$1,730	Light commercial vehicles
WRAP	$385,000 by 2023	Resource efficiency initiatives
WRAP	$99,000 by 2030	Resource efficiency initiatives
C&A Consulting	$51,000 by 2023	Fashion resale market
C&A Consulting	$2,000	Fashion resale market
Ellen MacArthur Foundation	$605,000	FMLG
Ellen MacArthur Foundation	$10,000,000	Whole economy

Source: (Lawlor & Spratt, 2021)

Table 2 provides an estimate of the investment levels in Central Europe, offering an annual assessment of the circular economy´s scale, which was estimated to account for 8.6% of the total economy in 2021 (down from 9% in 2020).

Many of these estimates lack coherence, with one sector´s contribution in certain estimates exceeding the economy-wide contribution in others. This inconsistency likely stems from varying methodologies and assumptions, as well as a lack of uniform definitions. These estimates primarily focus on investments and potential material cost savings, while often overlooking the costs associated with implementing circular solutions.

4 Data and methods

The main objectives of this study were:

1. to explore the theoretical foundations and historical evolution of the circular economy with specific focus on private investments in the circular economy,
2. to examine the relationship between the level of private investment in the circular economy and the recycling rate of municipal waste in the EU27 countries,
3. to examine the relationship between the level of private investment in the circular economy and municipal waste generation in the EU27 countries.

The analyses were based on data from the Eurostat database on circular economy indicators: private investment and gross added value related to circular economy sectors (cei_cie012) (hereinafter referred to as private investment in the circular economy), waste generation per capita (cei_pc034) a recycling rate of municipal waste (cei_wm011) in the period 2000–2021 in EU countries 27 (UK was not included).

The following research hypotheses were established to evaluate the research:

H_1: There is a statistically significant positive relationship between the amount of private investment in the circular economy and the recycling rate of municipal waste.
H_2: The growth rate of private investment in the circular economy determines the strength of its impact on the rate of municipal recycling rate.
H_3: There is a statistically significant negative relationship between the amount of private investment in the circular economy and municipal waste generation.

We used descriptive time series analysis and panel data models in our analyses. The choice of time period was determined by data availability and the purpose of the analysis. The panel data analysis was performed for all EU27 countries from 2012 to 2020. We used two panel data models: a fixed effects model and a random effects model.

Models built on panel data can generally have different shapes. They differ in the coefficients of the cross-sectional or time component. These can be constant for all countries or time periods, or they can differ from each other in both the time and spatial components.

The basic panel data model has the form:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \alpha_1 z_{i1} + \alpha_2 z_{i2} + \cdots \alpha_q z_{iq} + \varepsilon_{it} \quad (1)$$

Where: $i = 1, 2, ..., n$ denotes cross-sectional unit, $t = 1, 2, ..., T$ denotes time, X_1, ...X_k are explanatory variables, Z_1, ... Z_k are individual effects that characterize individual countries and are invariant over time, εit represents a random component with zero mean and constant variance.

If we allow different countries' response to changes in explanatory variables, then individual cross-sectional units would also differ in the values of coefficients β, and equation (1) would have the form:

$$y_{it} = \beta_0 + \beta_{1i}x_{it1} + \beta_{2i}x_{it2} + \cdots + \beta_{ki}x_{itk} + \alpha_1 z_{i1} + \alpha_2 z_{i2} + \cdots \alpha_q z_{iq} + \varepsilon_{it} \quad (2)$$

The Fixed Effects Model (FEM) assumes that the individual effects Z_1 to Z_k are unobservable and at the same time correlated with the explanatory variables. The model has the form:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \varepsilon_{it} \quad (3)$$

The Random Effects Model (REM) contains a composite random component γ_{it}, in which the random component of a particular observation in the *i*-th cross-sectional unit uit and the random component specific to the *i*-th cross-sectional unit are combined:

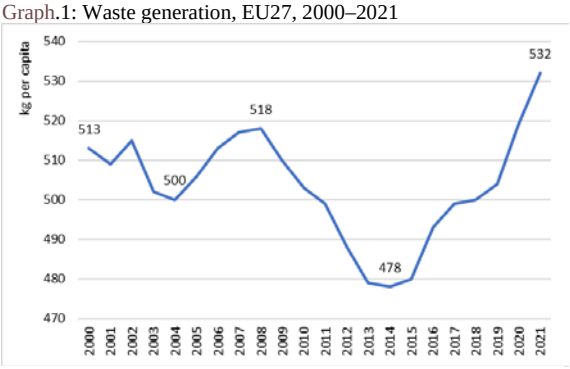
$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \gamma_{it} \quad (4)$$

We used Hausman's test to determine if a fixed-effects (FEM) or random-effects (REM) model better fits our panel data. Under the null hypothesis, REM model are preferred due to higher efficiency, while under the alternative hypothesis FEM model are at least as consistent and thus preferred (Baltagi, 2014).

4 Results

The amount of municipal waste generated in the EU 27 has increased by 19 kg per person/year over the past 22 years (2000–2021). Its development can be positively assessed by the downward trend in the years 2008 to 2014, when its total volume decreased by 40 kg per person. The average annual rate of decrease in this period was 98.67%, which in absolute terms is a decrease of 6.67 kg per person per year. This positive trend changed to the opposite in 2014 and continued until 2021 (an increase of 54 kg per capita). The acceleration of the growth of municipal waste was faster than its decrease in the previous period. The average growth rate in this period was at the level of 1.54% (7.71 kg per capita per year) (Graph 1).

Graph.1: Waste generation, EU27, 2000–2021



Source: Eurostat [cei_pc034], own processing

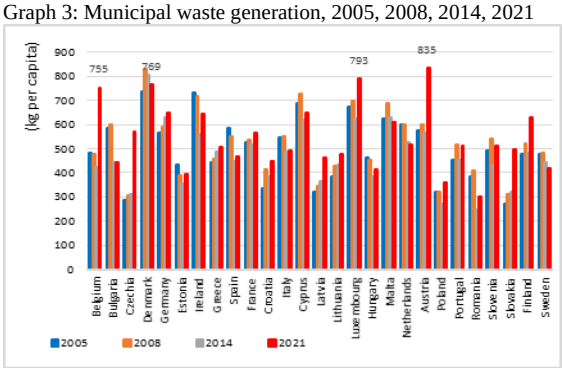
Private investment in the circular economy also grew during the period of increasing municipal waste generation (2016–2020) (Graph 2). In 2014, when the largest decrease in municipal waste generation was recorded, there was the largest year-on-year increase in private investment in the circular economy (by 0.3% of GDP), followed by an equally sharp decline in the following year (Graph 2).

Graph 2: Private investment and gross added value related to circular economy sectors, EU27, 2005–2021

Source: Eurostat [cei_cie012], own processing

The situation in individual EU27 countries reflects spatial variability, manifested both in the volume of municipal waste generated (Graph 3) and in the amount of private investment in waste management (Graph 4).

Graph 3: Municipal waste generation, 2005, 2008, 2014, 2021

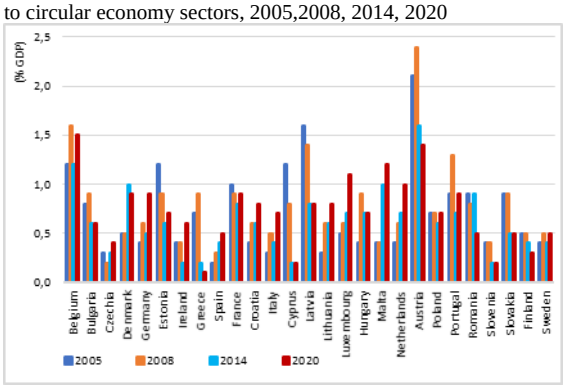


Source: Eurostat [cei_pc034], own processing

In 2021, Austria (835 kg per capita), Luxembourg (793 kg per capita), Denmark (769 kg per capita) and Belgium (755 kg per capita) generated the most municipal waste. In 2005, these were Denmark (736 kg per capita), Ireland (731 kg per capita), Cyprus (688 kg per capita) and Luxembourg (672 kg per capita). Romania (302 kg per capita), Poland (362 kg per capita) and Estonia (395 kg per capita) were the countries that generated the least municipal waste in 2021. Changes in municipal waste generation in individual countries are reflected in the average growth rate of this indicator. During the period of increasing acceleration of municipal waste generation (2014–2021), its volume, expressed as an average annual growth rate, grew fastest in the countries of Czechia (9.09%), Belgium (8.56%), Slovakia (6.49%), Austria (5.74%), Poland (4.17%) and Finland (3.90%). On the other hand, there are countries where this process slowed down significantly. The average growth rate was negative in Sweden (-0.83%), Denmark (-0.70%), Malta (-0.39%) and the Netherlands (-0.33%). In the years 2008–2014, when the trend of municipal waste generation at the EU27 level was decreasing, its volume decreased fastest in Romania (-8.01%), Bulgaria (-4.94%) and Ireland (-4.00%). The opposite trend, although not significant, was recorded in Germany, Greece, Lithuania, Czechia, Slovakia and Latvia.

The positive impact of investments in the circular economy, which increased from 0.7% of GDP in 2015 to 0.9% of GDP in 2020, on the amount of municipal waste generated has not been evident. We expected that increasing investments in the circular economy would affect reducing the volume on reducing the volume of municipal waste generated. As examples of countries for which this relationship does not apply, we cite Austria, Belgium and Poland. Austria and Belgium are among the countries with the highest municipal waste generation, while investing the most in the circular economy. Poland is a country with low investment to the circular economy, but also to the low volume of municipal waste (Graph 4).

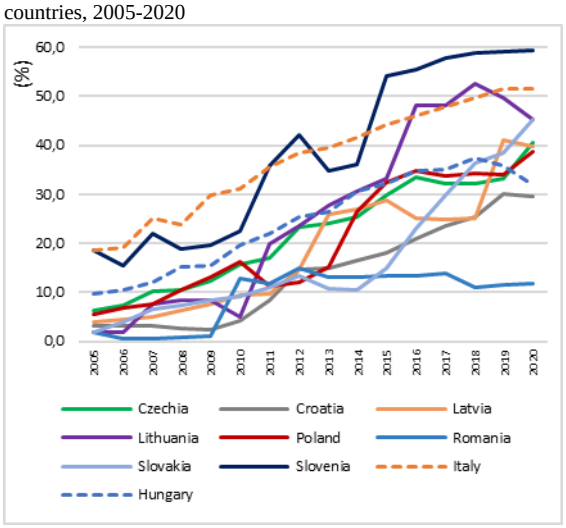
Graph 4: Private investment and gross added value related to circular economy sectors, 2005,2008, 2014, 2020



Source: Eurostat, [cei_cie012], own processing

The trend in the development of municipal waste recycling rates is increasing, which is a positive phenomenon. Between 2005 and 2020, the recycling rate, which expresses the share of recycled municipal waste in the total municipal waste generation (in %), in the EU27 countries increased by almost 1.5 times from 32.5% to 48.7%. It increased annually during this period by an average of 1.03 times. It grew the fastest in the countries that joined the EU in 2004: Italy, Slovenia, Hungary, Cyprus, Czechia, Romania, Poland, Croatia, Latvia, Slovakia and Lithuania. The average annual growth rate in these countries ranged from 1.08 (Italy) to 1.24 (Lithuania) (Graph 5).

Graph 5 Recycling rate of municipal waste, selected EU27 countries, 2005-2020



Source: Eurostat [cei_wm011], own processing

Sweden, Belgium, Austria, Denmark, and Germany are the countries in which the average growth rate of this indicator was negative, or did not exceed 1%. In the rest of the countries, it ranged between 1.21% (Malta) and 4.46% (Bulgaria).

In the next part, we verified the validity of the formulated hypotheses. We used a fixed and random effects model for panel data. The cross-sectional component consisted of 27 EU countries; the time component was from 2012 to 2020. We used Hausman's test to determine if a FEM model or REM model better fits our panel data.

H1: There is a statistically significant positive relationship between the amount of private investment in the circular economy and the recycling rate of municipal waste.

RE model confirmed a statistically significant impact of the amount of investment in the circular economy (INVEST) on the recycling rate (Tab.3).

Tab. 3: Random Effects Model (Dependent variable: Recycling rate of municipal waste), EU27 countries

coefficient		std. error	t-ratio	p-value
const	27.0644	3.56282	7.596	3.05e-014***
INVEST	13.2877	3.86444	3.438	0,0006***

Source: own processing in Gretl

H2: The growth rate of private investments in the circular economy determines the strength of its impact on the rate of municipal waste recycling.

Based on the results of the descriptive analysis (investment growth rates), we divided the countries into three groups: Model 1 (growth rate 1.08 – 1.24), Model 2 (growth rate 1.01 – 1.04), Model 3 (growth rate 0.99 – 1.01).

The results of all three random effects models are in tab. 4.

Tab. 4: Random Effects Model (Dependent variable: Recycling rate of municipal waste), groups of countries

Model 1	**Italy, Slovenia, Hungary, Cyprus, Czechia, Romania, Poland, Croatia, Latvia, Slovakia and Lithuania**			
coefficient		std. error	t-ratio	p-value
const	15.2190	3.77978	4.026	5.66e-05 ***
INVEST	26.8998	5.52270	4.871	1.11e-06 ***
Model 2	**Malta, Luxembourg, Netherlands, Spain, Finland, Estonia, Ireland, France, Greece, Portugal, and Bulgaria**			
coefficient		std. error	t-ratio	p-value
const	32.5542	3.50239	9.295	3.05e-014 ***
INVEST	1.46191	4.35053	0,3360	0.7368
Model 3	**Sweden, Belgium, Austria, Denmark, and Germany**			
coefficient		std. error	t-ratio	p-value
const	52.9847	2.61276	20.28	1.96e-091 ***
INVEST	1.30452	2.15982	0.6040	0.5458

Source: own processing in Gretl

Compared to the results for the entire panel, the impact of the amount of investment in the circular economy on the recycling rate is significantly higher in the group of countries with a high annual growth rate of investment. In the remaining two groups of countries (Model 2, Model 3), the recycling rate did not change statistically significantly with the growth of investment.

H3: There is a statistically significant negative relationship between the amount of private investment in the circular economy and municipal waste generation.

An analysis of the development of municipal waste and investments in the circular economy in the EU27 countries shows significant spatial and temporal differences in both indicators. The average growth rate of municipal waste in the period 2016-2020 was 1.54%, with countries such as Austria, Luxembourg, Denmark and Belgium generating the most waste per capita (Graph 1, Graph 3). Paradoxically, these countries are also characterized by the highest investments in the circular economy, which suggests that the amount of investment may not have directly affected the reduction of municipal waste generation, at least not in the short term. Private investments in the circular economy grew in the monitored period, especially between 2016 and 2020, when they increased by 0.3% of GDP year-on-year (Graph 2). Despite this growth, the expected impact of investments on waste reduction at the EU27 level has not yet been achieved, which may indicate the long-term nature of the return on these investments.

Even the results of panel data models (RE model) did not confirm the validity of hypothesis **H3.** On the contrary, with the increasing volume of private investments in the circular

economy, the volume of generated municipal waste also increases. (Tab. 5).

Tab. 5: Random Effects Model (Dependent variable: Municipal waste), EU27 countries

coefficient		std. error	t-ratio	p-value
const	459.315	27.8223	16.51	3.17e-061***
INVEST	49.4798	21.1737	2.337	0.0194***

Source: own processing in Gretl

5 Conclusion

To meet the challenges of today and ensure sustainable development, it is essential to transform the linear economic model into a circular, cyclical model. This model is characterized by the efficient use of resources, the recovery of materials, products and their components, as well as the practices of sharing, renting, reusing, repairing, renovating and recycling. Its aim is to extend the life cycle of products and minimize the amount of waste.

Recycling, and in particular municipal waste recycling, has become a key issue in implementing the principles of the circular economy. The availability of finance, the quality of companies owns financial resources, as well as public subsidies play a crucial role in stimulating circular economy initiatives in enterprises (Aranda-Usón et al., 2019). Investments can contribute to the development of the circular economy by inancing innovations in areas such as recycling, renewable energy sources and resource efficiency (EEA, 2024).

Recycling, and in particular municipal waste recycling, has become a key issue in implementing the principles of the circular economy. The availability of finance, the quality of companies owns financial resources, as well as public subsidies play a crucial role in stimulating circular economy initiatives in enterprises (Aranda-Usón et al., 2019). Investments can contribute to the development of the circular economy by financing innovations in areas such as recycling, renewable energy sources and resource efficiency (EEA, 2024).

In this paper, we present the results of an analysis of three key indicators of the circular economy: the amount of private investment in the circular economy, the rate of municipal waste recycling, and the generation of municipal waste. We conducted the analysis on data for 27 EU countries from 2012 to 2020. We found that increasing private investment in the circular economy statistically significantly increases the rate of municipal waste recycling, which is a positive phenomenon. However, their increase did not produce the desired effect of gradually reducing the volume of municipal waste.

The application of the principles of the circular economy is essential for achieving the goals of sustainable development in the EU countries. In accordance with these goals, it is necessary to increase the efficiency of resource use, introduce innovations and improve the quality of the entire process of waste management. All changes need to be implemented taking into account the differences between individual countries.

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Primary Paper Section: A

Secondary Paper Section: AH

INFORMATION AND COMMUNICATION TECHNOLOGIES AND ECONOMIC DEVELOPMENT: A CROSS-COUNTRY ANALYSIS

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Abstract: The rapid adoption of Information and Communication Technologies (ICT) is creating new opportunities and challenges for businesses, people and economy in terms of increased efficiency, creation of new services, improved human well-being, economic productivity, employment and economic development (ED). This paper aims to analyze impact of ICT on ED in advanced (AM), emerging (EM), and low-income and developing (LIC) countries. A panel econometric model with fixed effects is used to analyze situation in 183 countries from 1997 to 2022. The main conclusion is that ICT positively and significantly impacts ED. The positive effect was most significant in LICs, where the biggest ICT boom occurred. While in 1997, only 0.125% of people in LIC used Internet, by 2021, it was 46.05%. A similar situation can be observed for mobile phone subscriptions (0.173 in 1997; 84.11 in 2021). Progress in ICT was also observed in EM and AM, but not as fast as in LIC. The positive impact of ICT in all countries is also evident when several control variables are considered.

Keywords: ICT, economic development, panel model, Robin Hood algorithm.

1 Introduction

Economic development is multifaceted process encompassing transformation of low-income economies into modern industrial economies. It involves a range of programs, policies, and activities to improve the community's economic well-being and quality of life. The primary goal of development cooperation is to enhance material living standards by increasing per capita income. However, definition and drivers of ED vary significantly across countries, influenced by their unique socio-economic characteristics, opportunities, challenges, and priorities. One critical factor influencing ED is investment in ICT. ICT includes all communication devices and applications, such as mobile phones, computers, network hardware and software, and satellite systems. ICT facilitates storing, retrieving, transforming, and transmitting information, automating processes, controls, and information production. It plays pivotal role in shaping new global economy, transforming societies, and altering communication patterns and business relationships. The COVID-19 pandemic accelerated adoption of ICT across globe, affecting individuals, companies, and governments. The pandemic underscored necessity of ICT for maintaining economic activities and highlighted its role in driving growth in online product purchases. ICT facilitates innovation, increases productivity, reduces operating costs, can help create new job opportunities while transforming existing ones, improves efficiency in various sectors, and opens up new economic opportunities by creating digital industries, innovation ecosystems and rise of digital economy. However, ICT diffusion also improves governance by increasing transparency, efficiency and accessibility of public services, thereby creating environment that facilitates economic growth. While ICTs can significantly enhance ED, extent and nature depend on several factors, such as infrastructure, policy frameworks, digital literacy and inclusiveness of access. Thus, understanding impact of ICT on ED is crucial for promoting sustainable growth.

Existing literature has extensively explored relationship between ICT and ED. Adeleye and Eboagu (2019) or Yang (2021) emphasize importance of ICT and its impact on economies and societies, while Lechman (2014) and Albiman and Sulong (2018) emphasize its role in enhancing productivity. Moşteanu et al. (2020) discuss critical role of ICT during pandemic, highlighting how enabled businesses and governments to continue operations amidst lockdowns, while De' et al. (2020) and Brychko et al. (2021) highlight shift in service usage patterns and growth of online commerce and payments. From sectoral point of view, Niebel (2018) found that ICT investment boosts productivity in services sector more than in manufacturing, while Hallová and Hanová (2018) underscore its role in job creation and resilience to economic crises. Many studies, such as those by Yousefi (2011), Cheng et al. (2021), or Mura and Donath (2023) employ cross-country regressions to estimate impact of ICT on GDP growth, which provides robust insights into dynamic relationship across different economic contexts. The literature on relationship between economic growth and ICT is rich and diverse, highlighting ICT's significant positive impact on productivity, economic activities, and resilience during crises. However, existing research reveals several gaps. First, while there is evidence that ICT enhances ED, extent and nature of its impact vary across countries with different ED. Second, most studies assume linear relationship between ICT and ED, but there may be non-linear dynamics at play, particularly concerning diminishing returns of ICT investments at higher levels of adoption.

Therefore, presented paper aims to address gaps by exploring research questions: What is level of ICT in economies with different levels of ED? To what extent does increasing ICT improve ED? To answer these questions, there is a need to explore these dynamics, particularly using advanced econometric techniques. It helps us to provide more comprehensive understanding of how ICT can drive sustainable and inclusive economic growth. We employ panel data approach, using both linear and non-linear methods. The novelty of this paper lies in introducing Robin Hood algorithm, enabling us to determine whether impact of ICT on ED changes after certain point.

We use three proxies for ICT infrastructure: percentage of individuals using Internet, mobile phone subscriptions and ICT services export as indicator of its ICT capabilities. These indicators reflect digital inclusion, connectivity, and technological readiness, which are crucial for understanding potential of ICT to drive ED. Our dependent variable is GDP per capita in constant prices, representing ED. Additionally, we incorporate control variables such as trade openness, urbanization rate, gross fixed capital formation, government consumption expenditure, CO2 emissions, financial development index and governance indicator in form of political stability to provide comprehensive analysis.

The structure of paper is as follows. Section 2 presents overview of studies. Section 3 provides information about data and methodology. Section 4 analyses effects of ICT and discusses main findings.

2 Literature review

ED and ICT have been extensively studied, with researchers employing various indicators and methodologies to explore this relationship. This review synthesizes key findings, highlights methodological approaches, and identifies gaps and contradictions in literature. Most studies measure ED using indicators such as GDP per capita, natural logarithm of GDP per capita, or annual GDP values. ICT is commonly measured through proxies such as adopting new technologies, mobile subscriptions, fixed telephone subscriptions, individuals using Internet, or Internet coverage, while only a few consider ICT services export in their evaluations (e.g. Kashif et al., 2024). Therefore, examining ICT´s role not only from traditional point of view will contribute to ED and technology-related literature.

The empirical literature showed studies with different findings when examining ICT and ED. These studies can be divided into two main groups. The first proved that ICT facilitates development process from social, political and economic perspectives (e.g. Sharma, 2016, Alshubiri et al., 2019, Sharma et al., 2021, Younas et al., 2022, Verma and Giri, 2022). Also, OECD (2010) shows that ICT is vital in reducing poverty, increasing employment, and improving living standards. Brychko et al. (2021) say that active use of ICT positively

impacts share of non-cash payments, financial services diversification, and financial and economic development. Therefore, Zhang et al. (2022), or Mura and Donath (2023) pointed to the fact, that countries should focus on new business models based on digitalization and adopt measures that support digitalization-related policies to encourage investment in digital technologies, improve labor efficiency and contribute to stable economic recovery and growth. The second group found negative or no impact of ICT on ED (e.g. Ishida, 2015, Nabi et al., 2022). Yousefi (2011) finds that ICT plays a vital role in economic growth for high- and upper-middle-income countries but does not contribute to growth in LIC countries. In these countries, economic growth may be driven mainly by mobile growth but not by Internet growth. The policy implications suggest that middle- and LIC should step up their mobile development in short term, as this will be more cost-effective and profitable. However, lack of competition in Internet services could lead to unreasonable prices and under-investment in infrastructure, with high prices being natural barrier to Internet. In longer term, policies should increase investment in infrastructure.

The literature mainly indicates that ICT positively impacts ED, but this relationship is contingent on various factors. Studies suggest that education, infrastructure, government policies, and innovation ecosystems are crucial for maximizing benefits of ICT on ED. Seo et al. (2009) found that high-quality economic infrastructure and open trading regimes acquire more investments in ICT, which can bring higher ED. According to Mura and Donath (2023), when public spending are not efficient enough and contribute to debt accumulation, they negative impacts ED. Also, Shi et al. (2023) pointed out that good governance plays a crucial role in creating conditions for firms and individuals, which can increase access to resources and their effective usage, leading to higher ED. Arcand et al. (2015) and Cheng et al. (2021) pointed to another determinant: financial development index (IMF, 2023). They report negative relationship between financial and economic development, mainly due to surge of financial crises. We can see that digitalization benefits specific sectors differently, with traditional industries requiring significant adaptation. Therefore, measuring ICT's impact on ED is challenging due to different methodologies and data limitations.

However, existing research reveals several gaps. Methodologically, majority of studies use panel linear analysis. Also, limitations include availability of data for extended periods, granularity of data (often only available at country level), and need to analyze sub-samples of countries with different ED. More research is needed to explore non-linear relationships between ICT and ED, particularly using advanced econometric techniques and examining impact of ICT in economies with different stages of ED.

Building on reviewed literature, this paper aims to analyze ICT in economies with different ED to determine if increasing ICT enhances ED similarly across LIC, EM, and AM. The hypotheses are:

Hypothesis 1: The level of ICT is not higher in countries with higher ED.

Hypothesis 2: The use of ICT has no linear impact on ED in LIC/EM/AM countries.

We employ GDP per capita as dependent variable and three proxies for ICT (Individuals using Internet (% of population), Mobile cellular subscriptions (per 100 people) and ICT services export measured in current US$). In line with previous studies, these proxies are indispensable prerequisites of digital development, which has evolved mainly through mobile devices and Internet. As Mura and Donath (2023) mentioned, it represents degree of penetration of new ICT in economy.

Using Robin Hood algorithm, we will verify presence of U-shape between ICT and ED. Panel model with control variables, including trade openness, urbanization rate, gross fixed capital formation, government consumption expenditure, CO2 emission, financial development index, and governance indicator in form of political stability indicator, will be tested to provide comprehensive insights.

By addressing the identified gaps and incorporating a novel methodological approach, this paper aims to contribute to deeper understanding of dynamic relationship between ICT and ED, offering valuable policy implications for leveraging ICT to promote sustainable and inclusive economic growth.

3 Data and methodology

3.1 Data information

The annual data selected from official sources (World Development Indicator, Worldwide Governance Indicators, IMF) are used to analyze situation in 183 countries from 1997 to 2022. Tab. 1 presents all relevant details of selected variables. Column one contains abbreviation. Next columns show basic descriptive statistics. The seventh column contains complete name and measure scale of variables. The last column presents expected impact (based on literature review) on dependent variable.

Tab. 1 Descriptive statistics of selected variables

Variable	Average	Maximum	Minimum	Std. Dev.	Obs.	Explain	Exp. sign
GDP	12630.40	112417.88	246.39	17693.29	4648	GDP per capita (constant 2015 US$)	Dep. variable
INTERNET	31.7474	99.6870	0.0002	30.7623	4421	Individuals using Internet (% of population)	+
MOBILE	70.1625	420.8531	0.0009	53.2530	4458	Mobile cellular subscriptions (per 100 people)	+
ICTExp	2402836	206000599	14.54	9741199	3914	ICT services export measured in current thousands of US$	+
TRADE	87.7250	442.6200	2.6988	54.2205	4250	The sum of exports and imports of goods and services (% of GDP)	+
URBAN	54.8036	99.3180	7.6180	22.4293	4654	People living in urban areas (% of population)	+
CAPITAL	22.8741	81.0210	-2.4244	7.6191	4023	Gross domestic fixed investment (% of GDP)	+
GOV	16.6706	147.7189	0.9126	8.9991	4100	Government current expenditures for purchases of goods and services (% of GDP)	+ / -
CO2	4.3149	47.6570	0.0218	5.5463	4291	Carbon dioxide emissions (metrics tons per capita)	+
FDI	0.3015	1.0000	0.0038	0.2271	4556	Financial development index	+ / -
POLITIC	48.2977	100	0	28.0510	4678	Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism. (Percentile rank among all countries (ranges from 0 (lowest) to 100 (highest))	+

Source: Prepared by authors

According to GDP, countries are divided into three groups: LIC, EM and AM. Within AM, we can see the most developed countries, where average in 2022 was 44743.95. Most countries are within EM (average 10529.33), and last group consists of LIC (average 2426.07). The differences between countries result from several factors. Historical events, colonialism, wars, and geopolitical influences have shaped economic environment of nations. Some countries have benefited from previous industrialization or natural wealth, while others have faced exploitation or natural resource scarcity problems. Second, countries with stable political systems, low levels of corruption and effective legal frameworks tend to attract investment and foster development. The last factor involves country's demographics and education. Countries with productive working-age population and educated and skilled labor force can experience higher ED.

Mobile cellular telephone subscriptions are subscriptions to public mobile telephone service that provides access to public switched telephone network using cellular technology. The indicator includes number of postpaid subscriptions and number of active prepaid accounts. The indicator applies to all mobile cellular subscriptions that offer voice communications. It

excludes subscriptions via data cards or USB modems, subscriptions to public mobile data services, private trunked mobile radio, tele point, radio paging and telemetry services. The average for LIC was 84.11, for EM 121.24; for AM 137.47. The significant differences between countries can be attributed to several factors. Developed countries often have more robust and widespread telecommunication infrastructure, making establishing and expanding mobile networks easier. In contrast, developing nations might struggle with inadequate infrastructure, limiting access to mobile services in rural or remote areas. The second factor is costs of mobile services and devices, which influence accessibility. In LIC, individuals might face challenges affording mobile devices and services, impacting subscription rates. The next factor is that government policies and regulations significantly influence telecommunications sector. Favorable policies in developed nations might encourage healthy competition, leading to better services and lower prices, while regulatory hurdles in developing countries can hinder market growth.

Internet users are individuals who have used Internet in last three months. Also, in this indicator exists significant differences between countries. The average for LIC was 46.05, for EM 76.12; for AM 91.04. Based on averages, we expect ICT to increase with country's ED. Also, in this case, we can speak about factors that lead to significant differences between countries. Developed nations typically have better-developed and widespread Internet infrastructure. They often invest more in broadband networks, leading to better access and higher penetration rates than developing countries. The second factor is cost of internet services and devices. In LIC, availability can limit access for significant portion of population due to high prices. On the other hand, higher-income and advanced countries often have more individuals who can afford internet services and devices, leading to higher penetration rates. The next factor is technological progress. Developed nations often adopt new technologies more rapidly, contributing to higher internet usage rates due to better access to advanced services and devices. Among other factors, we can mention digital literacy and education in country, share of urban population, and cultural and social factors.

As can be seen, differences exist between countries regarding ICT and ED. These findings able us to reject Hypothesis 1. We can conclude that level of ICT is higher in countries with higher ED. This lack of homogeneity in ED and ICT can influence results. On the other hand, we can see some homogeneity within countries divided according to stage of ED. We can see that most countries with the lowest ICT are located within LIC. In contrast, the highest ICT is within AM. The next signal of homogeneity is that LIC recorded the highest ICT growth between 1997 and 2022 and the highest economic growth.

3.2 Empirical model

To verify presence of U-shape between ICT and ED, we first apply Robin Hood algorithm presented by Simonsohn (2018). He suggests testing possibility of U-shape by merely testing if effect of x (an indicator of ICT) on y (ED) changes sign for low versus high x values. Such test involves computing two average slopes, which is done by estimating two regression lines, one for $x \leq x_c$ and other for $x \geq x_c$, where x_c is breakpoint. One may increase statistical efficiency by simultaneously estimating both lines in single regression, relying on what is often referred to as interrupted regression. Specifically, interrupted regressions conform to following general formulation:

$$y = a + bx_{low} + cx_{high} + d \times high + ZB_Z$$

where $x_{low}=x-x_c$ if $x < x_c$ and 0 otherwise, $x_{high}=x-x_c$ if $x \geq x_c$ and 0 otherwise, and high = 1 if $x \geq x_c$ and 0 otherwise, $\mathbf{Z}$ is (optional) matrix with covariates, and $\mathbf{B_Z}$ is its vector of coefficients.

Then, we test panel model with control variables, which can be expressed as follows:

$$\log(y_{i,t}) = a + \beta X_{m,i,t-1} + \sum_{k=1}^{7} \gamma C_{k,i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

where y is ED indicator (GDP), X is ICT indicator (INTERNET, MOBILE, ICTExp), C is vector of control variable (TRADE, URBAN, CAPITAL, GOV, CO2, FDI, log(POLITIC)), μ_i and τ_t represents country's fixed and time-specific effect, $\varepsilon_{i,t}$ is random error term, i and t are indicators of country and time.

The model is estimated separately for each ICT indicator. Logarithmic measure for dependent variable and ICT services export is used to reach smaller amplitude and better interpret results. The other variables are not transformed. The main assumption of our study is that ICT positively impacts ED in all types of countries.

The lagged explanatory variables are used to overcome problem of endogeneity concerns in observational data. The VIF test is applied to test potential multicollinearity. Tab. 2 shows no coefficient value more than 3, suggesting that model has no issue with multicollinearity.

Tab. 2 VIF test

Model	ICT indicator	TRADE	URBAN	CAPITAL	GOV	CO2	FDI	POLITIC
Model 1	2.0575	1.2751	2.0389	1.0430	1.1250	2.0532	2.6110	1.7561
Model 2	1.3749	1.2832	1.9789	1.0584	1.1031	2.0530	2.3169	1.7485
Model 3	2.7986	1.1252	1.9457	1.0467	1.1639	2.1913	4.2207	1.1902

* ICT indicator in models: INTERNET (Model 1), MOBILE (Model 2), ICTExp (Model 3)

Source: Prepared by authors

The standard procedure for panel model is applied. The Breusch-Pagan test is used to choose between pooled and fixed-effect model, and Hausman test is used to select between fixed- and random-effects models. The F-test tested time- and country-specific effects.

Quantile Regression (QR) is used to test robustness of model. As presented by Naseem et al. (2023), advantage of QR is its robustness against data outliers in response measurement. If data series are affected by heterogeneous effects concerning dependent and independent variables, QR avoids this issue and helps obtain accurate results. The standard methodology of QR is applied. Using QR, model of this research is presented below:

$$\log(y_{i,t}) = a + \beta^{\theta} X_{m,i,t-1} + \sum_{k=1}^{7} \gamma^{\theta} C_{k,i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

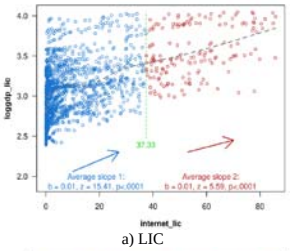
where theta (θ) is representative of QR. QR provides nuanced insights into effects of predictors across different points of dependent variable's distribution. By interpreting coefficients and graphical representations, we can better understand how ICT indicators influence entire distribution, not just mean. It is particularly useful for policy analysis and decision-making, highlighting differential impacts that mean-based regression methods might miss.

4 Analysis and discussion

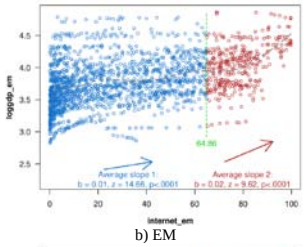
The results of Robin Hood algorithm for selected ICT indicator (INTERNET) separately in LIC, EM and AM are presented in Figure 1. The U-shape relationship was not confirmed, but constant positive relationship can be seen in LIC, EM and AM. The lowest ICT could be seen in LIC. We can see that increasing ICT lead to higher ED, where speed of positive influence increases after some breakpoint. However, as Figure 1a presents, most countries are under those breakpoints. So, increase in ICT could benefit ED. Similar situation could be seen in EM (Figure 1b), but breakpoint is higher. In AM (Figure 1c), impact of ICT on ED was not as significant as in previous groups. The reason could be that level of ICT is very high, so there is not so much space to increase it (e.g., for Individuals using Internet, close to 100%, representing overall population in country). In Mobile subscriptions and ICT services export, results are very similar. It

confirmed our assumption that ICT positively impacts ED, while intensity is lower in AM. Based on Robin Hood algorithm results we cannot confirm Hypothesis 2. Therefore, we must reject the assumption that ICT has no linear impact on ED.

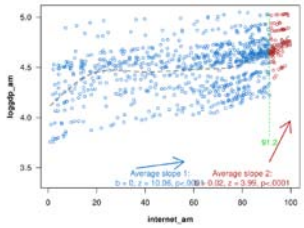
Figure 1 Two-line test – ED vs. Internet use



a) LIC



b) EM



c) AM

Source: Prepared by authors

Next, we tested linear model presented in methodology part, which was separately estimated for LIC, EM, and AM. We apply fixed effects with time and individual effects based on Breusch-Pagan, Hausman and F-test results. The results are presented in Tab. 3. Based on results of F-statistics, we can conclude that results were associated with significance level lower than 1%, which suggests that models' estimations are correct and statistically significant.

Tab. 3 Empirical results of panel regressions

Independent variables	LIC		
INTERNET	0.0063 *** (0.0005)		
MOBILE		0.0031 *** (0.0002)	
ICTExp			0.0659 *** (0.0083)
TRADE	0.0004 (0.0003)	-0.0002 (0.0003)	-0.0020 *** (0.0003)
URBAN	0.0137 *** (0.0018)	0.0035 * (0.0019)	0.0145 *** (0.0017)
CAPITAL	0.0026 *** (0.0007)	0.0011 * (0.0006)	0.0045 *** (0.0007)
GOV	-0.0015 (0.0011)	0.0001 (0.0010)	0.0001 (0.0011)
CO2	0.0836 *** (0.0228)	0.0602 *** (0.0219)	0.2426 *** (0.0239)
FDI	1.5363 *** (0.2423)	1.1625 *** (0.2328)	1.8698 *** (0.222)
POLITIC	0.0029 *** (0.0004)	0.0032 *** (0.0004)	0.0020 *** (0.0004)
Unbalanced panel	n = 54, T = 6-23, N = 1024	n = 54, T = 6-23, N = 1013	n = 52, T = 1-23, N = 842
Adjusted R-squared	0.5607	0.5896	0.5452
F-statistics	170.833 ***	189.386 ***	133.385 ***

Independent variables	EM		
INTERNET	0.0036 *** (0.0002)		
MOBILE		0.0022 *** (0.0001)	
ICTExp			0.2190 *** (0.0117)
TRADE	0.0001 (0.0002)	-0.0002 (0.0003)	-0.0010 *** (0.0003)
URBAN	0.0130 *** (0.0015)	0.0119 *** (0.0014)	0.0126 *** (0.0015)
CAPITAL	0.0007 (0.0008)	-0.0024 *** (0.0008)	-0.0009 (0.0006)
GOV	-0.00664 *** (0.0015)	-0.0087 *** (0.0014)	-0.0075 *** (0.0015)
CO2	0.0519 *** (0.0047)	0.0445 *** (0.0046)	0.0382 *** (0.0056)
FDI	1.0995 *** (0.0918)	0.9091 *** (0.0928)	1.6406 *** (0.0925)
POLITIC	0.0031 *** (0.0004)	0.0034 *** (0.0004)	0.0023 *** (0.0004)
Unbalanced panel	n = 74, T = 5-23, N = 1611	n = 74, T = 5-23, N = 1633	n = 67, T = 5-23, N = 1401
Adjusted R-squared	0.5982	0.6179	0.6527
F-statistics	309.711 ***	339.948 ***	338.096 ***

Independent variables	AM		
INTERNET	0.0062 *** (0.0002)		
MOBILE		0.0039 *** (0.0001)	
ICTExp			0.3246 *** (0.0001)
TRADE	0.0007 *** (0.0002)	0.0011 *** (0.0002)	0.0013 *** (0.0002)
URBAN	-0.0144 *** (0.0022)	-0.0041 * (0.0022)	-0.0005 (0.0021)
CAPITAL	0.0078 *** (0.0011)	0.0059 *** (0.0011)	0.0049 *** (0.0012)
GOV	-0.0057 ** (0.0026)	-0.0093 *** (0.0027)	-0.0114 *** (0.0027)
CO2	0.0097 *** (0.0028)	-0.0038 (0.0028)	0.0124 *** (0.0029)
FDI	-0.0693 (0.0683)	-0.1298 * (0.0718)	0.3429 *** (0.0666)
POLITIC	0.0021 *** (0.0005)	0.0016 *** (0.0005)	0.0020 *** (0.0005)
Unbalanced panel	n = 34, T = 20-23, N = 779	n = 34, T = 23, N = 782	n = 34, T = 9-23, N = 703
Adjusted R-squared	0.6837	0.6608	0.6889
F-statistics	215.313 ***	195.308 ***	194.444 ***

Notes: ***, **, and * denote significance levels 99%, 95% and 90%, respectively. The standard errors are reported in parentheses.

Source: Prepared by authors

All ICT indicators were marketed as significant, positively impacting ED in LIC, EM and AM. As presented in other studies, ICT is crucial for ED, mainly in LIC, while significance decreases in EM and AM, which aligns with our findings. It confirmed our assumption and results of two-line tests that ICT is significant factor, where intensity is lower in countries with higher ED.

Mura and Donath (2023) state that trade openness impacts ED by increasing income per capita and boosting productivity through competition. Openness supports technological transfer across borders and, hence, a more efficient economic organisation. As can be seen in Table 3, positive impact was confirmed only in AM. We can suppose that for those countries, increasing competition is one of crucial factors in improving ED and well-being of people in country.

According to World Bank (2023), gross fixed capital formation includes land improvements, plant, machinery, and equipment purchases, and construction of roads and railways, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Meyer and Sanusi (2019) state that gross fixed capital formation, as primary component of domestic investment, is seen as essential process that could accelerate economic growth. Our analysis confirmed similar results through positive significant impact of capital in LIC and AM.

CO2 emissions stem from burning fossil fuels and cement manufacture, from solid, liquid, and gas fuels and gas flaring consumption. Acheampong (2018) states that CO2 emissions positively cause economic growth, while Onofrei et al. (2022) found that higher ED leads to increased demand for environmental protection. The findings of previous authors are in line with our results. Based on regression coefficients, we can see that CO2 was always significant variable with positive impact. Also, decreasing regression coefficients signalise that effect is the highest in LIC. In contrast, in AM, intensity was lower.

Government consumption expenditure includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most national defence and security expenditures but excludes government military expenditures that are part of government capital formation. Mo (2007) states that identifying impact of government consumption expenditure is not so clear as it affects development through three channels – total factor productivity, investment and aggregate demand. If we exclude government investments, we can expect that government expenditure will hurt ED. However, positive effect could be expected in government investments. Therefore, question is if investments' impact is higher than other government expenditures' effect. According to results, this variable significantly negatively impacted ED in EM and AM. As most government expenditures have unproductive nature, we can suppose that effect of other

government expenditures, usually associated with social policy, was higher than that of government investments.

Urban population refers to people living in urban areas defined by national statistical offices. Nguyen & Nguyen (2018) found that relationship between urbanisation and ED is non-linear. Urbanisation tends to increase ED while urbanisation rate is low. However, after some threshold, when urbanisation is relatively high, it can hurt ED. It is in line with our results presented in Table 3. The variable was significant in LIC, EM and AM, but signs differed. While impact was positive in LIC and EM, it was negative in AM. The effect of urban populations on ED in developed countries can be negative due to various factors. For example, urban areas in advanced economies often face higher living costs, traffic congestion and housing shortages. These problems can hamper further economic growth as business costs increase, and firms may seek more affordable locations.

The FDI is relative ranking of country's financial institutions and financial markets. Van and Anh (2019) and Nguyen et al. (2022) pointed to positive effect of financial development on ED. However, they mentioned that it is necessary to pay attention to characteristics of each group (AM, EM, LIC) in evaluating financial development. We see significant impact of FDI, where in LIC and EM (weaker in EM), influence is positive, while in AM it is negative (or weakly positive in case of ICTExp). So, we can conclude that increasing financial development benefits ED, but after some breakpoints it is negative. We can suppose that in AM, financial services are used by majority of population daily and form normal part of economy. Therefore, space to increase this development within the economy is relatively small. Thus growing interconnectedness of financial market can lead to institutions' ability to provide financial services and higher activity in capital markets. The disadvantage is that during crisis in another country, its adverse effects can be transferred to other countries, leading to decreased ED.

As mentioned by Singha and Singh (2022), political stability and good governance are important in influencing economic growth. They can promote rule of law, transparency, accountability, and even efficient use of resources. Also, results of our study confirmed importance of political stability in increasing ED in analysed countries, where the highest impact could be seen in EM countries. Stable political conditions create conducive environment for foreign investments, ensuring continuity in economic activities, strengthening institutional quality, reducing macroeconomic volatility, supporting infrastructure development and improving international trade relations. Therefore, promoting and maintaining political stability should be priority for governments aiming to achieve sustained ED.

In last step, QR is used to check robustness of our findings. QR estimation results in detail for Model 1 are displayed in Tab. 4, while selected ICT indicator for each model of QR is displayed in Figure 2.

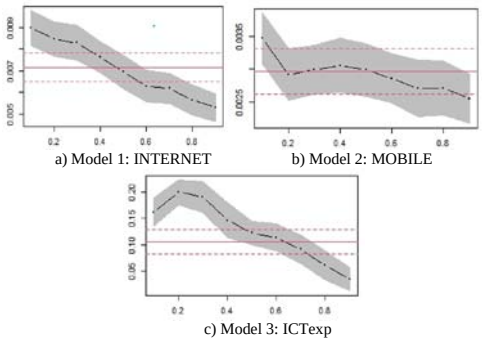
Tab. 4 Empirical results of quantile regressions – Internet as ICT indicator

Quantiles	INTERNET	TRADE	URBAN	CAPITAL	GOV	CO2	FDI	POLITIC
0.1	0.0090 ***	0.0005 ***	0.0206 ***	0.0090 ***	-0.0034 ***	0.0533 ***	1.7312 ***	0.0094 ***
0.2	0.0085 ***	-0.0001	0.0213 ***	0.0093 ***	-0.0032 ***	0.0529 ***	1.8911 ***	0.0101 ***
0.3	0.0083 ***	-0.0005	0.0232 ***	0.0075 ***	-0.0062 ***	0.0465 ***	1.8360 ***	0.0110 ***
0.4	0.0079 ***	-0.0003	0.0230 ***	0.0043 ***	-0.0060 ***	0.0462 ***	1.8163 ***	0.0118 ***
0.5	0.0069 ***	-0.0001	0.0222 ***	0.0020 **	-0.0036	0.0428 ***	1.8117 ***	0.0128 ***
0.6	0.0063 ***	0.0007 *	0.0213 ***	-0.0022 **	-0.0005	0.0405 ***	1.7973 ***	0.0132 ***
0.7	0.0062 ***	0.0012 ***	0.0203 ***	-0.0047 ***	-0.0010	0.0411 ***	1.7601 ***	0.0132 ***
0.8	0.0056 ***	0.0021 ***	0.0186 ***	-0.0068 ***	-0.0027 ***	0.0486 ***	1.7257 ***	0.0130 ***
0.9	0.0053 ***	0.0017 ***	0.0149 ***	-0.0026	-0.0061 ***	0.0723 ***	1.5970 ***	0.0129 ***

Notes: ***, **, and * denote significance at the 99%, 95% and 90% levels, respectively.

Source: Prepared by authors

Figure 2 QR results



a) Model 1: INTERNET b) Model 2: MOBILE

c) Model 3: ICTexp

Source: Prepared by authors

The horizontal red line and red dot lines represent regression coefficient and confidence interval of panel regression, while black line with grey zone represents coefficients and confidence interval of QR. We can see that we have significantly different results from panel regression for lower and upper quantiles in case of Internet use and ICT services export. In medium quantiles we don't have significant difference from panel regression. Also, in Model 2, results of QR are in line with panel regression. However, we can conclude that ICT indicators are positively significant from 1st to 9th quantile in all estimations, which confirms that these variables positively contribute to ED in all countries. The decreasing value of coefficients in upper quantiles indicates decreasing impact of ICT on ED in countries with higher ED, which confirmed our previous findings that effect is the lowest in AM.

Conclusion

The aim was to analyse effects of ICT on ED in LIC, EM and AM. Based on literature review, we supposed that ICT positively impacts ED. We can see constant positive relationship from plots of two-line tests. The results of analysis did not confirm existence of U-shape. We can see that increased ICT was always connected with higher ED, while this relationship was more intense in LIC. ICT tends to be a more crucial factor in ED for LIC than AM due to its potential to rapidly address various developmental challenges. In LIC, ICT can act as catalyst to bridge developmental gaps. It offers opportunities for leapfrogging traditional development stages by providing access to information, education, healthcare, and financial services that might otherwise be limited or absent. ICT can jumpstart economic transformation by enabling new business models, improving efficiency, and facilitating trade and access to global markets, even in regions with limited physical infrastructure. It can overcome geographical barriers, providing access to essential services like healthcare and banking in remote areas where physical infrastructure might be lacking. ICT infrastructure can enhance country's resilience to external shocks by enabling remote work, digital transactions, and communication during crises, contributing to economic stability. In AM, while ICT remains crucial for economic growth and innovation, relative impact might differ due to existing infrastructure, higher levels of development, and saturation of specific ICT markets. However, even in AM, continuous advancements in ICT play significant role in maintaining competitiveness, driving innovation, and enhancing various sectors of economy.

We found that countries' GDP per capita and ICT are heterogeneous, but positive development could be seen in all groups mentioned. The use of ICT worldwide has seen significant development in recent years. The highest boom could be seen in LIC. Looking at primary indicators of ICT, we can see that share of Individuals using Internet increased by 36901% between 1997 and 2021, and value of Mobile cellular subscriptions increased by 48459%. It can be attributed to several factors. Some LIC without infrastructure have adopted newer technologies without replacing existing systems. They

have skipped traditional development stages and have quickly adopted mobile phones and internet technologies. Mobile phones are essential in LIC due to their affordability and accessibility. They have enabled communication and access to banking services and information, thus supporting growth of ICTs. Also, some governments have introduced policies and initiatives to promote ICT infrastructure development, recognising its potential to support ED and improve various sectors such as health, education and commerce. In summary, confluence of factors such as innovative technologies, affordability, entrepreneurial efforts, supportive policies and international initiatives has enabled significant growth of ICTs in LIC, allowing them to use technology for development.

Although LIC experienced the most remarkable boom, we can see that level of ICT was higher in countries with higher ED. The reason could be that advanced countries tend to have well-established infrastructure, including robust telecommunications networks and internet connectivity. Also, citizens in these countries have greater purchasing power, making ICT devices and services more affordable and accessible. These countries also often prioritise education and digital literacy, leading to population which is more technologically adept and inclined to adopt and use ICT tools effectively. ED is often accompanied by robust innovation ecosystem and research institutions, which leads to development of high technology, fostering culture of innovation and adopting new ICT solutions. Advanced countries often have policies and investments to advance ICT infrastructure and foster technological innovation, including initiatives to promote research, development, and digital infrastructure expansion. These factors create environment where technology adoption becomes more widespread and deeply integrated into various aspects of life and economy.

The increasing ICT opens up opportunities for new companies in new industries. However, future of doing business in digital age will mainly depend on outlook of digital progress and business climate and how policy and regulatory challenges are addressed simultaneously. Given disparities in ICT, ED, and other indicators' points of view, we can conclude that applying uniform policy and approach is not desirable to ensure higher economic growth. The dedicated digitalisation policies should be adapted to regional specificities of each country. Each country's economic, cultural, and digital behaviour characteristics can influence success of political decisions. However, in general, we can conclude that policymakers could make concerted effort to exploit inherent benefits of ICT use, which includes reducing rising costs associated with use of communication technologies, such as cost of buying mobile phone, price of internet connection, cost of subscription and others.

As mentioned in paper, other indicators of ICT also exist. The application of only traditional indicators can be considered research limitation. As more data becomes available, empirical analysis and comparison between ICT would help depict which policies are the most effective. The suggestion for future research could be to analyse role of ICT in the growth and competitiveness of companies, examine the contribution of smart infrastructure, e-government and fintech innovations in enhancing economic resilience to crises and promoting economic development in rapidly evolving environment.

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Primary Paper Section: A

Secondary Paper Section: AH

NURSES' ENGAGEMENT AND ORGANIZATIONAL COMMITMENT: THE ROLE OF JOB ATTITUDES TO THEIR JOB ROLE AND INTENTIONS TO STAY

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Abstract: The main purpose is to assess the level of organizational commitment of hospital nurses in terms of their job role and level of engagement. In the study, the factor analysis of the engagement variable is applied. In addition, the scoring method is used to evaluate the variable of job satisfaction, in which nurses' attitudes towards their job role were assessed. Next, the variable of sustainability is utilized to assess hospital nurses' intentions to stay. The first variable examined was job satisfaction to assess nurses' attitudes toward their job role. It has been found that hospital nurses see their work as a mission. The results of the study show that the mean score is the highest in nurses' professional pride in their work. Factor analysis identified 3 main work engagement subfactors in hospital nurses. Factor 1 contains the variables as follows: At my work, I feel bursting with energy; At my job, I feel strong and vigorous; I am enthusiastic about my job; When I get up in the morning, I feel like going to work. Factor 2: I get carried away when I'm working; It is difficult to detach myself from my job. Factor 3: At my work I always persevere, even when things do not go well. The variable of sustainability reveals that hospital nurses have developed a strong organizational commitment to their hospital. The analysis has also revealed turnover considerations of hospital nurses. It was found that nurses are considering leaving their current job and/or working abroad. Despite the high engagement of nurses, it is essential to identify and understand the factors that may enhance retention of nurses in hospital settings.

Keywords: job satisfaction, work engagement, sustainability, organizational commitment

1 Introduction

Recently, the factor of job engagement representing the individual aspect of nurses' work and affecting the quality of nursing services has emerged (Kim & Seo, 2021). Work engagement is a positive and fulfilling work-related mental state characterized by energy, dedication, and absorption. Nurses with high levels of energy and work engagement exhibit superior performance and enhanced well-being (Mahiro et al., 2014; Mukaihata et al., 2020; Yue et al., 2024; Ren et al., 2024). In general, engaged employees have high energy levels and better mental health (Kato et al., 2023). Work engagement is seen as the positive antipode of job burnout, with burnout turning energy into exhaustion, involvement into cynicism, and efficacy into ineffectiveness (Schaufeli & Bakker, 2004; Shahpouri et al., 2016). Work engagement is crucial to achieve effective and efficient healthcare delivery, and nurses, as the backbone of the healthcare system, play an important role in ensuring this (Cabrera-Aguilar et al., 2023). Work engagement is defined as a stable and positive emotional activation state of employees including three dimensions of vigor, dedication and absorption. Individual characteristics such as emotional intelligence and achievement striving are considered to be antecedent variables that affect nurses' work involvement and attitudes towards work (Zhang et al., 2018). Work engagement in nursing is a focused, engaging, and dynamic nursing practice that stems from an environment of autonomy and trust and leads to safer, more cost-effective patient outcomes (Zhou et al., 2023). To solve the problem of the lingering shortage of nurses, it may be effective to increase nurses' work engagement. (Hara et al., 2023). Relational leadership practices should be encouraged and supported by hospitals and medical facilities to enhance nursing job satisfaction, retention, and individual productivity. Supportive leadership and management styles can improve nurses' job satisfaction, organizational commitment, and intent to stay in their position (Sulosaari et al., 2023). Understanding different patterns of work engagement in frontline nurses can help nursing managers provide emotional, material and organizational support based on the features of each latent profile, which may improve the quality of care (Yin et al., 2022). Organisational Commitment is the emotional link between the employee and their organisation (Christopher et al., 2018). Organisational Commitment is also considered as a predictor that reduces a worker's voluntary turnover intention (Arslan Yürümezoğlu et al., 2019).

Nurses' attitudes towards their job role are closely linked to professionalism which refers expertise, knowledge, qualifications, attitudes, and behaviors in line with professional standards which should be possessed by all individuals responsible for performing the roles and responsibilities of a particular profession (Gönel & Sezgin, 2023). The relationship between professional identity and work engagement indicates that professional identity can increase work engagement of nurses (Zhang, et al., 2022). Factors affecting job attitudes include support from co-workers, workload, access to material resources, access to information, patient rapport and nurses' personal resilience (Adynski et al., 2022). Workplace belonging refers to the sense of connection, acceptance, and inclusion that individuals experience within their work environment. Affective commitment, on the other hand, reflects an employee's emotional attachment and identification with their organization, leading to greater loyalty and engagement. Both factors are crucial to promote a positive organizational environment (Saleh et al., 2024). An employee exemplifying vigor, dedication, and absorption demonstrates high energy levels, mental resilience, and a commitment to exerting an effort at work, while also being deeply engaged and experiencing a sense of significance, enthusiasm, inspiration, pride, and challenge. A work-engaged employee is also characterized by complete concentration and a joyful immersion in their job, resulting in the rapid passage of time and difficulty in disengaging from tasks (Moisoglou, et al., 2025). The effective utilization of the nursing taskforce, among other healthcare professionals, can bring sustainable and competitive advantages to the organization. An important way in which such utilization of human resources could be delivered is by engaging them in their work. In this context, an integrative review pointed out that healthcare bodies should offer working conditions that nurture work engagement to ensure that nurses remain engaged in their work (Alkorashy & Alanazi, 2023). In addition, it has been found that engaged employees have less job stress and depression than nonengaged employees and that a high level of work engagement can enhance nurses' job performance, job satisfaction, and emotional health and reduce turnover intention (Wang et al., 2021; Ren et al., 2024). Deficiencies in the working conditions of health- and social care have weakened the sector's attraction and retention. Demand for a future health- and social care workforce may fuel global competition for skilled professionals requiring change and effort from organisations and management to retain current employees (Kuha et al., 2024). Components of job satisfaction associated with turnover intention involving many aspects and those frequently assessed include income, supervisors, colleagues, organizational factors and work environment (Zhang et al., 2018). Factors related to the work environment rather than individual or demographic factors are still of most importance to nurses' turnover intentions (Coomber & Louise Barriball, 2007). Given the high turnover rate of the nursing occupation, meaningful work may be the very reason why many nurses choose to stay in health care (Meng et al., 2023). Nurse turnover is one of the major reasons for the global nurse shortage. Thus, turnover intention is a strong predictor of actual turnover (Feng et al., 2017). Retention of healthcare staff in an organization helps to maintain the quality of care and it protects the financial balance of overall costs of healthcare services. Turnover may be due to the individual characteristics of the nurses and organizational reasons (Alan et al., 2022). Nurses' organizational turnover intention or professional turnover intention can be interpreted as a reaction to the negative aspects of the organization and/or the profession. For example, in nursing, the

process starts with nurses leaving the clinical unit, then the organization, and finally the profession (Arslan Yürümezoğlu et al., 2019).

2 Materials and methods

Research goal: The main purpose is to assess the level of organizational commitment of hospital nurses in terms of their job role and level of engagement.

Partial goals and tasks:

1. to analyse papers from Web of Science and Scopus databases;
2. to identify variables and research methods;
3. to analyse relationships and measure variables - job satisfaction (nurses' attitudes towards their job role), nurses' engagement and sustainability;
4. to evaluate results.

Methods applied:

The Kaiser-Meyer-Olkin Measure and Bartlett's Test are used to assess the suitability of the data for factor analysis. KMO values range from 0 to 1, with higher values indicating better fit of the data for factor analysis. A significant Bartlett's test value (usually $p < 0.05$) indicates that the variables are sufficiently correlated, and it is justifiable to perform factor analysis.

Factor analysis is a multivariate statistical method designed to analyse correlations among many observed variables. Factor analysis explains the level of engagement factors that have an impact on nurses.

The scoring method and the calculation of the mean score represent a quantitative procedure used to objectify and standardize the evaluation of a larger number of variables. Likert scale variables are assigned points, an average score is calculated and ranking of importance is determined based on the results of the average score. This approach was applied to assess the variables of job satisfaction (nurses' attitudes towards their job role) and sustainability.

3 Results

The research section interprets the findings from the questionnaire survey. The survey sample consists of a total of 500 respondents (hospital nurses). Of these, 94.2% are female and 5.8% are male. Their average age is 49.8 years. The subject of the study are hospital nurses and their attitudes towards work, level of work engagement and intentions to stay in their current job are examined.

Table 1: The role of hospital nurses to their job role

Variables	Average score	Ranking
Sometimes I feel that my work is meaningless	2.93	3
I enjoy my work	3.93	2
I'm proud of my job	3.96	1

Source: Elaborated by the authors in Excel, 2025

To analyse job satisfaction, 3 variables were selected. The three variables are related to nurses' job attitudes, and thus to the level of organizational commitment and sustainability (Zhang, et al., 2022; Saleh et al., 2024). The scoring results showed that nurses are generally satisfied with their career choice, as evidenced by the high mean scores for the statements "I enjoy my job" and "I am proud of my job". Lower mean score, however, was received for the statement "Sometimes I feel that my work is not meaningful". 38.8% nurses agree they sometimes feel their job is not meaningful.

Before performing factor analysis, KMO test and Bartle's test of sphericity to check the appropriateness of the variables were used. The test values were appropriate to apply factor analysis.

Table 2. KMO & Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.924
Bartlett's Test of Sphericity	Approx. Chi-Square	3705.01
	df	136
	Sig.	0.000

Source: Elaborated by the authors in Statistica, 2025

3 factors of hospital nurses' engagement were extracted performing principal component extraction. To determine the number of common explanatory factors underlying the model, an eigenvalue correlation matrix was implemented. Based on the Kaiser criterion (R), the eigenvalue must be greater than one. Based on the correlation matrix of the dataset with 17 variables (engagement), three common factors that cumulatively explain 56.29% of the total variance were extracted through principal component factor extraction – Table 3.

Table 3. Correlation matrix – Kaiser criterion (R)

Values	Eigenvalues Extraction: Principal Component			
	Eigenvalue	% total variance	Cumul. eigenvalue	Cumul. %
1	6.959056	40.93562	6.959056	40.93562
2	1.455399	8.56117	8.414455	49.49680
3	1.156018	6.80010	9.570473	56.29690

Source: Elaborated by the authors in Statistica, 2025

UWES 17 standardized questionnaire was employed to analyse the level of engagement of hospital nurses. Table 4 identifies the variables that were subjected to factor analysis.

Table 4. Identification of variables: Engagement (UWES 17)

Variable 1	At my work, I feel bursting with energy.
Variable 2	I find the work that I do full of meaning and purpose.
Variable 3	Time flies when I'm working.
Variable 4	At my job, I feel strong and vigorous.
Variable 5	I am enthusiastic about my job.
Variable 6	When I am working, I forget everything else around me.
Variable 7	My job inspires me.
Variable 8	When I get up in the morning, I feel like going to work.
Variable 9	I feel happy when I am working intensely.
Variable 10	I am proud of the work that I do.
Variable 11	I am immersed in my work.
Variable 12	I can continue working for very long periods at a time.
Variable 13	To me, my job is challenging.
Variable 14	I get carried away when I'm working.
Variable 15	At my job, I am very resilient, mentally.
Variable 16	It is difficult to detach myself from my job.
Variable 17	At my work I always persevere, even when things do not go well.

Source: Elaborated by the authors in Excel, 2025

Table 5 extracts the 3 main factors that determine the level of nurses' engagement. Factor loadings - Vearimax normalized; The highlighted loadings are significant in factor analysis if the values are greater than > 0.700000.

Table 5. Factor loadings

Variable	Factor 1	Factor 2	Factor 3
Variable 1	**0.834562**	0.028554	0.073303

Variable 2	0.667495	0.184334	0.377582
Variable 3	0.257796	0.220009	0.393131
Variable 4	**0.799416**	0.134839	0.107328
Variable 5	**0.702169**	0.256469	0.264125
Variable 6	0.202180	0.598912	0.114810
Variable 7	0.669964	0.371838	0.238679
Variable 8	**0.742607**	0.184833	0.085008
Variable 9	0.658495	0.324306	0.191555
Variable 10	0.552678	0.232809	0.423198
Variable 11	0.312076	0.439613	0.534030
Variable 12	0.201579	0.496135	0.425692
Variable 13	0.431337	0.523100	0.324435
Variable 14	0.287916	**0.706612**	0.053155
Variable 15	0.237326	-0.048876	0.650446
Variable 16	0.013768	**0.738956**	0.039624
Variable 17	-0.008236	0.125082	**0.822125**
Total variance	4.584424	2.634087	2.351962
% total	0.269672	0.154946	0.138351

Source: Elaborated by the authors in Statistica, 2025

Factor 1 (Vigour) contains the highest number of extracted variables: At my work, I feel bursting with energy (0.834562); At my job, I feel strong and vigorous (0.799416); I am enthusiastic about my job (0.702169); When I get up in the morning, I feel like going to work (0.742607). The results of factor rotation show that factor 1 accounts for 4.584424 of the total variance explaining 26.96% for the 17 variables. Factor 2 (Absorption) contains two main variables, such as I get carried away when I'm working (0.706612); It is difficult to detach myself from my job. (0.738956). Factor rotation results indicate factor 2 accounting for 2.634087 of the total variance explaining 15.49% for the 17 variables. Factor 3 (Perseverance) contains the following variable: At my work I always persevere, even when things do not go well (0.822125). The results of factor rotation show that factor 3 accounts for 2.351962 of the total variance explaining 13.83% for the 17 variables. Vigor means high levels of energy and mental resilience during work. Dedication refers to a sense of significance, enthusiasm, and pride. Absorption means complete concentration in one's work (Kato et al., 2023).

Table 6. Nurses' intentions to stay (level of organizational commitment)

Variables	Average score	Ranking
Changing jobs is not the key problem	3.35	1
I tell my friends that this hospital is a great place to work.	2.69	2
I want to leave my current workplace for an outpatient clinic within a year.	2.23	3
I want to change my health care field (pharmacy, nursing) within a year.	1.936	5
In the future I want to work abroad.	2.112	4

Source: Elaborated by the authors in Excel, 2025

Hospital nurses are quite satisfied with their employer's choice. The variables with the highest mean and point scores include "Changing jobs is not a key problem" (3.35) and "I tell my friends that this hospital is a great place to work" (2.69). The results indicate that nurses are relatively sustainable, although in some cases they are thinking about changing their workplace or labour migration. In this case, the importance of the link among the attitude towards the job role, work engagement and sustainability can be underscored.

Despite relatively positive results regarding sustainability of hospital nurses, other research findings suggest that 10% of hospital nurses are thinking about changing their workplace by moving to outpatient clinics and 13% of respondents are considering labour migration.

The findings give a warning as nurses aged 44 to 60 years are mainly thinking about changing their hospital job for an outpatient clinic. Mainly nurses under 30 years of age are considering labour migration. Thinking about leaving their hospital jobs might have resulted from excessive workload in the hospital, and leaving for outpatient clinics could partly solve the problem of nurses aged 44-60. Nurses under the age of 30 need to be paid special attention. Their decisions on and attitudes towards labour migration may significantly impact the health sector in the future in terms of lowering interest among young people in studying nursing and increasing interest in seeking new job opportunities abroad.

4 Discussion

Meaningful work is the subjective experience in which one can understand and realize the significance of one's work and have a sense of purpose from work, which widely exists in many occupations while varies in its levels among individuals (Meng et al., 2023). The analysis revealed a comprehensive interaction among job attitudes, work engagement and sustainability. The results of the scoring method indicate nurses' general satisfaction with their choice of occupation (professional identity), as demonstrated in high mean scores for statements on job enjoyment and professional pride. A significant share of nurses (38.8%) expressed feeling a lack of meaningfulness in their work, suggesting potential risks to their long-term motivation and commitment. Zhang et al. (2023) maintain professional identity be formed as an individual's perception of his or her own profession, including the recognition of its value and the development of personal competencies. When a person recognizes the value of his or her work and develops his or her competencies, he or she feels more engaged and motivated. Adynski et al. (2022) found that nurses' job attitudes affect their ability to do their jobs well. Positive work attitudes increase work efficiency, while negative attitudes do the contrary. The findings support investment in factors to promote positive nurse attitudes and job performance such as a healthy work environment and self-efficacy.

Factor analysis extracted three key dimensions of work engagement: vigour, absorption and dedication. Vigour, characterized by high levels of energy and mental resilience, explains most of the variability in the data. Absorption defined as being focused on one's work, and high level of energy and mental resilience to the work and persevering even in the face of difficulties also contribute greatly to overal work engagment of nurses. Tang et al. (2022) highlight the important relationship between organisational commitment and work engagement among nurses. The resulst of the study by Cao et al. (2019) conclude that employees with high level of organizational commitment had a strong belief and acceptance of the organization's goals and values and were willing to make considerable efforts and sacrifice to their organization. The findings by Orgambídez et al. (2019) give empirical support to the Job Demands-Resources Model, which raises the mediating role of work engagement between self-efficacy (personal resource) and affective organizational commitment.

Despite general satisfaction with employer choice and positive perceptions of the hospital as a workplace, the analysis revealed worrying trends in staff sustainability. Large share of hospital nurses are thinking about leaving for outpatient clinics (10%) or leaving to work abroad (13%). This phenomenon is particularly pronounced in two age groups: nurses aged 44-60 who are thinking of changing their job in a hospital for a job in outpatient clinics due to excessive workload, and nurses under 30 who are interested in a job abroad. Tussing et al. (2024) argue that recruitment, onboarding, and retention strategies of the youngest working generation, Generation Z, need to be personalized,

digitally based, and aligned with their lifestyle choices. The issue of nurse sustainability is also examined by (Moscelli et al., 2025) who say that retention of skilled workers is essential for labour-intensive organizations like hospitals, where an excessive turnover of doctors and nurses can reduce the quality and quantity of services provided to patients. Similarly, BowenXue et al. (2024) claim that by focusing on measures such as supporting nurses' work engagement, providing resources, creating a positive work environment, offering motivation and recognition, promoting work-life balance, and fostering a sense of participation, nursing turnover rates can be reduced.

5 Conclusion

Despite high levels of positive job attitudes, organisational commitment and work engagement, hospital nurses are thinking about changing their place of work or leaving Slovakia for employment purposes. These findings are a warning sign for the health sector. Experienced nurses leaving to outpatient clinics and the outflow of young talent abroad may lead to a shortage of skilled staff and jeopardise the quality of healthcare provided. It is crucial that healthcare institutions and competent authorities pay close attention to the needs and expectations of nurses, especially in the areas of meaningful work, workload and opportunities for professional development.

Human resource management in hospitals should apply a comprehensive approach to improving working conditions and nurse engagement. A priority is to increase nurses' perception regarding the meaningufulness of their work. Although nurses report high levels of professional pride and satisfaction with their career choice, a large share of them do not perceive their daily activities as meaningful. Therefore, management should implement strategies that would emphasize the value of nurses' work to patients and the entire organization. Nurses should be acknowledged for their work and the positive impact on the patients on a daily basis. In addition, hospitals should organize programmes to promote nurses' work engagement. Moreover, hospital management should invest in schemes to reduce workload, improve work environment and promote work-life balance. It is also crucial to strengthen nurses' self-efficacy through training and competence development as these have a strong effect on their work performance and organisational commitment.

With regard to alarming trends in hospital nurse sustainability, turnover and migration trends are prevalent in younger aged nurses. In contrast, older nurses plan transition from the hospital to outpatient clinics. Therefore, it is crucial to implement focused retention strategies, with a particular emphasis on Age Management. Age management is a strategic approach to human resource management that acknowledges the age diversity within the workforce and adapts working conditions, development opportunities, and motivation strategies to suit different age groups.

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THE INFLUENCE OF WORKING MEMORY AND INHIBITORY CONTROL ON EDUCATIONAL CURRICULUM IN SCHOOL CHILDREN

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Abstract: In the present paper, we examine executive functions in primary school children. In particular, we focus on working memory and inhibitory control and their relevance to the design of curriculum content in the educational process. The research was conducted by administering the Behaviour Rating Inventory of Executive Function - BRIEF and the Cognitive Coping Strategies Questionnaire - CERQ in schools. We received responses from 258 primary school children, their parents and teachers. The results show us the relationships between the quality of executive functions and emotion regulation, which are essential for the successful adaptation of pupils to the educational process. We point out the need to modify educational curriculum and educational content.

Keywords: working memory, inhibitory control, educational curriculum, school age

1 Introduction

Executive functions are higher-level cognitive processes that, through their influence on lower-level processes, allow individuals to regulate their thoughts and actions during goal-directed behaviour (Friedman, Myiake, 2017). They allow us to control our behaviour and coordinate other cognitive functions, such as planning or organizing.

Executive functions and self-regulation are most often associated with students' academic performance, but to what extent is not entirely clear and proven. The relationships of associations related to self-regulation remain unexplored (Zorza et al., 2017).

As peer relationships begin to deteriorate and become unstable in early adolescence, adolescents with adequate self-regulation and empathy can rely on their ability to regulate and balance their relationships. Self-regulation develops during childhood and adolescence, and its development (as well as the development of executive functions) is influenced by life experiences (Berthelsen et. al., 2017).

It is therefore necessary to focus on strengthening individual sources of self-regulation and supporting the development of executive functions, including through curriculum content in the educational process.

1.1 Working memory and inhibitory control

In solving various difficulties, problems and cognitive operations, it is often necessary to focus attention on the necessary information. One of the executive functions that serves this purpose is the ability to monitor and update representations in working memory - working memory updating (Missier, Mäntylä, & de Bruin, 2010). We understand working memory updating as "the ability to monitor incoming information, assess its relevance to the goal, and then revise the contents of working memory so that older and outdated contents are replaced by newer, relevant ones" (Miyake et al., 2000, p. 57).

According to Morris and collective (2017), memory updating is the ability to modify current representations and schemas so that they adapt to new input. Several authors (Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000; Lenartowicz, Escobedo-Quiroz, & Cohen, 2010) emphasise that updating working memory is a function that requires dynamic and active manipulation of content.

However, working memory is a complex and multifaceted faculty that encompasses a variety of functions (Oberauer et al., 2000). It plays a key role in storing, equipping and adapting knowledge that is essential for navigating situations, understanding instructions and making decisions when solving tasks.

The child needs to remember important information and be able to use it actively. While memorisation is quite fast, the ability to work with this knowledge and use it effectively develops much more slowly (Vágnerová, 2020).

With the help of working memory, we divide a task into smaller, manageable parts, solve one of them, memorise it and continue solving the next one at the same time. In addition, working memory also supports the understanding of language - both spoken and written. Its effective functioning is essential for successful learning, because in learning we manipulate information, plan, solve tasks step by step and link new information with that stored in long-term memory (Izdenczyová, 2017).

Pennington & Ozonoff, (1996) define working memory as the ability of the learner to store information and keep it unchanged until mental operations are performed. The working memory function is essential for effective learning because it manipulates information and organises the sequence of steps in specific tasks. It works with long-term memory and has the ability to store and process information simultaneously (Gathercole & Alloway, 2008). This means that learning success is strongly influenced by the efficiency and capacity of working memory.

As defined by Clark (cited in Friedman and Miyake, 2004), inhibition is any mechanism that dampens neural, mental or behavioural activity. However, it should be emphasised that the term inhibition is used to refer to a variety of complex processes (Miyake, et. al. 2000).

Nigg (2000) distinguishes two types of inhibition, depending on whether they are consciously controlled or occur automatically without conscious control. The author calls the former conscious inhibition of a motor or cognitive response and the latter automatic inhibition. Within conscious inhibition, he distinguishes four subtypes:

1. Interference control - this is the ability to maintain performance in the presence and action of distractors that interfere by evoking an alternative response that is inappropriate to the intended behavioural goal.
2. Cognitive inhibition - the active inhibition of mental content. It is used to suppress inappropriate or irrelevant thoughts in order to maintain attention and promote working memory activity.
3. Behavioural inhibition - the suppression of automatic responses or socially inappropriate behaviour.
4. Oculomotor inhibition - deliberate suppression of automatic reflexive movements.

According to several studies, the ability to control inhibitions contributes significantly to successful performance in a variety of tasks. According to DeBeni, Palladino, Pazzaglia and Cornoldi (1998), the ability to inhibit irrelevant information has a significant impact on working memory performance.

In addition, McNab et al. (2008) found that some functional areas involved in inhibitory control are also activated during working memory engagement. Inhibitory control, like the ability to update working memory, is another executive function that contributes to reading comprehension (Gernsbacher, 1993).

An important part of the executive system in the developmental process is the regulation of attention. Its regulation and maintenance "interacts with memory processes to form the cognitive structures necessary for executive control and behavioural control" (Akyurek, 2018).

1.2 A developmental perspective on working memory and inhibitory control

Working memory begins to form at an early age and develops during the preschool years as part of a child's overall cognitive development. It is closely linked to the development of attention, reasoning and language skills. It plays an important role in the understanding of spoken language. It is necessary for successful socialisation - children with a well-developed working memory find it easier to remember rules and are better at activities that require them to be followed (Cowan, 2016; Garon et al., 2008).

Wagner (2020) states that working memory capacity is limited in pre-schoolers, with younger children having difficulty linking and effectively using more knowledge. Both executive functions, working memory and inhibitory control, depend on brain capacity that is still limited at this age. Therefore, increased demands on one of these functions may negatively affect the use of the other (Diamond, 2013).

According to Zelazo and Carlson (2012), behavioural research has shown that the development of rule use follows a predictable pattern: children first acquire the ability to follow one rule, and then learn to switch flexibly between two rules, and finally are able to switch flexibly between two incompatible pairs of rules.

When a child has to remember a larger amount of information, a more complex rule or a rule change, the capacity of their working memory can significantly affect their performance. Processing information more efficiently also improves retention. Since it is not just a matter of mechanically retaining knowledge, but also of understanding it, the child's level of thinking also plays a very important role.

Accelerated processing of information also contributes to the development of working memory, which reduces the likelihood of forgetting information between the processing and storage phases (Vágnerová, 2020).

Working memory and inhibitory control support self-regulatory mechanisms. Hofmann, Schmeichel, and Baddeley (2012) argue that self-regulation is a fundamental aspect of human behaviour.

2 Research part

2.1 Objective and methods of research

The main aim of the research study was to investigate how memory and inhibitory control influence the structure of educational content and to make recommendations for teachers in the development of educational curricular content.

The selection of respondents for our research was oriented towards a group of school-aged students; the age range of the respondents was between 11 and 13 years (M = 12.65; SD = 0.78). 258 respondents from primary schools in Slovakia took part in the study. The administration took place in the school.

We used the Behaviour Rating Inventory of Executive Function (BRIEF), a questionnaire for parents and teachers of school-aged children that allows the assessment and rating of children's executive functions in the home and school environment. The method is used to assess children between the ages of 5 and 18. Each version of the questionnaire, for both parents and teachers, contains 86 items in eight scales that assess different aspects of executive functioning: inhibition, shifting of attention, emotional control, and initiative, working memory, planning and organisation, organisation of tools, behavioural control.

The second was the CERQ multidimensional questionnaire (Garnefski et al., 2001), which consists of 36 items that examine an individual's general cognitive style and nine emotion regulation strategies after experiencing a stressful situation. Four questionnaire items assess each strategy, with five strategies falling under the category of adaptation: acceptance, positive reappraisal, planning, positive refocusing, putting things in perspective; other regulation strategies assessed in the questionnaire: self-blame, rumination, catastrophizing, blaming others. The respondent answers on a five-point Likert scale. The questionnaire is designed to identify cognitive emotion regulation strategies (or cognitive coping strategies) that someone uses after experiencing negative events or situations.

The results of the questionnaires were analysed using the SPSS statistical programme. The distribution of the data according to the Kolmogorov-Smirnov test met the normality criterion.

2.2 Research results

From our comparisons, we can confirm that the individual relationships between the variables studied are complementary. In the following, we mainly present the results that showed significant co-relations and relationships.

The higher the children's initiative, the more independent they are in solving problems, the higher and richer the level of working memory (M = 1.85; SD = 0.42). There is a positive correlation at the 0.05 level, suggesting that in this case there is less need for adult supervision, and the children in our sample are also more likely to remember information in the longer term (p = 0.020, r = 0.205*). This is also related to the completion of homework, which they do not forget and complete without help from parents or teachers.

It is also worth noting the positive correlation with planning/organising (M = 1.78; SD = 0.37), which gains significantly in structure and precision when children's working memory is accurate and unproblematic (p = .000, r = .305**) when working memory is effective. These two factors influence each other, and if an individual is able to organise their activities without confusion and chaos, if they can navigate the schedule and timetable of activities, then their working memory is likely to be working at an appropriate level. Adequate time management also contributes to this, which motivates respondents to perform better.

Working memory is also positively correlated with shifting attention (M = 1.84; SD = 0.39), which is an important part of executive functioning. If respondents in our sample are working effectively with their working memory, it is possible that this is reflected in attention shifting and its effectiveness (p = .000, r = .310**).

We believe that school-age children who can remember both information and activities to be carried out over a longer period can shift their attention more easily from one activity to another without the need for external cues to shift their attention. They are more likely to shift attention away from negative emotions and situations, and are less likely to be distracted by changes in plans or different factors during the lesson.

Another variable was inhibitory control, which is the respondent's ability to control their attention, behaviour, thoughts and emotions. It involves suppressing internal predispositions and choosing what is more appropriate or necessary (Diamond, 2013).

The significant relationship between the two variables was perspective taking, which influences students' inhibition (M = 1.72; SD = 0.38). A positive correlation was found at the 0.05 level, indicating that the more respondents think prospectively and positively about challenging situations, the more we can observe an increase in the frequency of behavioural inhibition of individuals (p = .018, r = .210*). In this case, respondents are able to control their behaviour and adapt it to the situation they find themselves in. When individuals are able to view the situation with detachment and perceive it as something that can be overcome, their behaviour is under their own control.

However, behavioural inhibition also shows a negative relationship with suppression (M = 4.28; SD = 1.56) at the 0.01 level, as indicated by the associations confirmed so far (p=.009,

r=-.279**). In this significant correlation, we can observe a phenomenon that suggests that the sample of respondents who use a suppression strategy in problem solving are likely to have lower levels of inhibition and behavioural control. Intractability, impulsivity and lack of control tend to increase with increased use of the suppression strategy, which is also reflected in our sample. Respondents try to suppress and not express their emotions; this strategy may induce the opposite behaviour, which is likely to manifest itself later in specific situations.

Based on the following correlation, which examines the relationship between inhibition and blaming others (M = 3.14; SD = 0.82), we can hypothesise at the 0.01 level that as the score on the variable blaming others increases, so does the difficulty with inhibition and behavioural control (p=.007, r=.274**). Respondents who cannot take responsibility for their actions and blame all their problems and their consequences on other people are also more likely to engage in impulsive and uncontrollable behaviour.

3 Discussion

An important formative factor of executive function is working memory, which plays an important role in our paper. Hofmann, Schmeichel, and Baddeley (2012) support the idea that working memory, as a 'cold' executive function, controls and regulates emotions, which is one reason why it is essential to work with and develop it.

They argue that working memory is also a kind of drive for goal achievement, which our research has shown to be true, supported by correlations with organisation and planning. When working memory is at a higher level, it can lead to mobilisation and the setting of achievable goals.

If people are still thinking about the situations they have experienced and are unable to get away from them and change their way of thinking, this will be reflected in the way they organise the tools they need to carry out tasks and everyday situations. It increases forgetfulness, lack of independence and impatience, and affects other executive functions such as planning, organising, working memory or shifting attention.

Our research does not allow us to assess whether good school performance is a consequence of good executive functioning. The behaviour regulation index, which consists of emotional control, inhibition as well as attention shifting, is inseparable with the metacognition index.

The activity of the behavioral regulation index and metacognition is reflected in the performance of common everyday situations, planning the day, overall functioning as well as in academic activities and in the decision-making process (Miller & Byrnes, 2001).

If the respondent has, problems with inhibition and control of emotions, their decision-making abilities are limited and their decisions are mostly ineffective. If their emotional regulation and behavioral regulation index are normal, the achievement of goals in life and the development and activity of executive functions are higher (Vancu, Jonášová, 2024).

4 Recommendations and conclusion

From our comparisons, we can confirm that working memory is "an active memory system responsible for the temporary storage and concurrent processing of information" (Bayliss et al., 2005, p. 580). It integrates the products of other cognitive processes and is involved in a range of complex mental activities.

One of the aims of this approach is precisely to ensure that learning does not overload the child's working memory, otherwise it will be ineffective (Kester, Paas, & van Merriënboer, 2010).

Students with poor working memory often get 'lost' when solving more tasks that are complex, need to repeat instructions more often, skip steps in problem solving, and are often unable to complete given tasks (Alloway et al., 2005). There is widespread consensus that a poorly functioning working memory system has a devastating effect on the functioning of higher mental processes in reading, arithmetic or the organisation of intentional behaviour in general (McDonald & Day, 2010).

Working memory is arguably a prerequisite for effective learning, as the learning process requires the manipulation of information, planning and a series of problem-solving steps, interaction with long-term memory, and simultaneous memorization and processing of information (Gathercole & Alloway, 2008).

Working memory is not significantly more involved in already routine activities. All this implies that teachers should try to optimize the demands on working memory, especially in the initial stages of learning. The content of the classroom is full of information that is new to the pupils.

The limitations of working memory apply particularly to this information, and for this reason, the structure of this learning content needs to be carefully considered, particularly for pupils. The implications of these claims are elaborated further within the educational theory of cognitive load (Paas, van Gog, & Sweller, 2010).

Literature:

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Primary Paper Section: A

Secondary Paper Section: AM, AN

B PHYSICS AND MATHEMATICS

BA GENERAL MATHEMATICS
BB APPLIED STATISTICS, OPERATIONAL RESEARCH
BC THEORY AND MANAGEMENT SYSTEMS
BD INFORMATION THEORY
BE THEORETICAL PHYSICS
BF ELEMENTARY PARTICLE THEORY AND HIGH ENERGY PHYSICS
BG NUCLEAR, ATOMIC AND MOLECULAR PHYSICS, ACCELERATORS
BH OPTICS, MASERS AND LASERS
BI ACOUSTICS AND OSCILLATION
BJ THERMODYNAMICS
BK LIQUID MECHANICS
BL PLASMA PHYSICS AND DISCHARGE THROUGH GASES
BM SOLID-STATE PHYSICS AND MAGNETISM
BN ASTRONOMY AND CELESTIAL MECHANICS, ASTROPHYSICS
BO BIOPHYSICS

NONLINEAR DIFFERENTIAL EQUATION AND SIS EPIDEMIOLOGICAL MODEL WITH A TIME DELAY BOUNDED BY TWO POSITIVE FUNCTIONS

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Abstract: In this paper, we consider an epidemiological SIS model. We use a nonlinear differential system with time delay as a mathematical formulation of this model. It is examined by the existence of a positive solution that is bounded by two functions k1, k2 ∈ C([t0,∞), (0,∞)) with constants λ1 > 0, λ2 > 0, where 0 < λ1 ≤ λ2. The conditions are put in place for the existence of a positive solution that approaches zero in infinity if t → ∞. There is a lot of ambiguity concerning the time span and final spread of the epidemic, thus making it very demanding for the governing bodies, healthcare institutions, and economic sector to precisely judge the future development. Several examples are shown at the end of this paper.

Keywords: mathematical modelling, epidemiological model, nonlinear differential equations, time delay bounded, SIS model, positive solution, COVID-19, spread model, pandemic

1 Introduction

Mathematical modelling spans many fields of study thanks to its versatility. It is useful in biology, economics, or medicine. It is very popular today thanks to big advances in computing technology, which allow us to analyse many models and visualize the results in a short period of time. One of the very important areas where differential equations can be applied is the epidemiological modelling that can be used to forecast the occurrence or spread of the infection. Modelling infectious diseases is always a very real topic, with new types of infections appearing and old infections reappearing, bacteria becoming resistant to antibiotics, and globalization supporting the spreading of diseases worldwide [[5]]. Mathematical modelling is a very good tool for understanding the spread of the many infectious diseases, including the most recent COVID-19 pandemic, and exploring different scenarios. We are aware, though, that "one model cannot answer it all" and that more models are necessary to answer all outstanding questions and paint the whole picture. What we aimed to achieve was to connect the mathematical results we acquired with a real infectious disease problem. The plague in the first half of the 6th century BC killed tens of millions of people, and several centuries later, the total number of victims grew several times. After the first wave of infection receded, it periodically reappeared in waves. Other notable pandemics in history were the Spanish flu, HIV/AIDS, SARS, and MERS, up to the COVID-19 pandemic. The infectious diseases, including the most recent COVID-19 illness, which is induced by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), have not only caused a large number of deaths worldwide but also led to economic stagnation or even decline in the standard of living. Several published studies have shown the negative financial effect the restricted movement has on the economy, especially in the manufacturing and services sectors (such as tourism or retail) [[5],[6],[19],[20]]. We describe the spread of the infectious diseases, including the most recent COVID-19 illness, by choosing the SIS model over the SIR model, and we use a nonlinear differential system with time delay as a mathematical formulation of this model.

2 Nonlinear differential equation with time delay

Chronic diseases like cancer or heart disease today receive more attention, especially in third-world countries, when compared to infectious diseases, which are still the most prominent cause of deaths worldwide.

The mechanisms of transfer from an infected individual to susceptible subjects and interactions within the population are very complex and, therefore, very difficult to completely describe the dynamics of the infection spread without a kind of formal structure of the mathematical model.

Modelling can often be used to compare the behaviour of different kinds of diseases in the same group of people, of the same kind of disease in different groups, or of the same kind of disease in different time periods. Epidemiological models can also be used to forecast disease occurrence and spread. There has been a revival of interest in the study of differential equations with delays recently, which has been motivated by its many applications [[1], [4], [9], [10], [13], [14], [15], [16]].

We first consider a nonlinear differential equation with time delay [[18]].

$$\dot{x}(t) = p(t)(t) - q(t)x(t)x\big(\tau(t)\big), t \geq t_0, \qquad (1)$$

where $p \in C([t_0, \infty), R)$, $q, \tau \in C([t_0,\infty), [0,\infty))$, $q(t) \neq 0$, τ is a non-decreasing function, $\tau(t) < t$, and $\lim_{t\to\infty} \tau(t) = \infty$.

Using this equation, we describe the SIS model in section 3 that represents the Covid-19 virus spread. Time delay is the time period between getting infected and the appearance of symptoms. The solution x(t) of the equation (1) is considered a function $x \in C([t_1 - \tau(t_1), \infty), R)$ for some $t_1 \geq t_0$ and such that the equation (1) is valid for $\geq t_1$. In the next section, we set some of the sufficient conditions that allow the existence of a positive solution of (1) bounded by two positive functions. We will also study the conditions for the existence of a positive solution that tends to zero in infinity as $\to \infty$. Next, we use a nonlinear differential system with time delay as a mathematical formulation for the SIS model. It is examined by the existence of a positive solution that is bound by two functions $k_1, k_2 \in C([t_0,\infty), (0,\infty))$ with constants $\lambda_1 > 0$ and $\lambda_2 > 0$, where $0 < \lambda_1 \leq \lambda_2$. In the next part, we make use of this lemma:

Lemma 2.1. [[4], [9]] (Schauder fixed-point theorem). Let Ω be a closed, convex, and non-empty subset of the Banach space X. Let $S:\Omega \to \Omega$ be a continuous mapping such that $S\Omega$ is a relatively compact subset of X. Then S has at least one fixed point in Ω. That means that $x \in \Omega$ exists for which $Sx = x$.

2.1 Existence of positive solutions

In the following section we set sufficient conditions necessary for the existence of a positive solution of equation (1).

Theorem 2.1. Let constants $c>0$, $0 < \lambda_1 \leq \lambda_2$ and bounded functions $k_1, k_2 \in C([t_0,\infty),(0,\infty))$ exist such that

$$k_1(t) = k_2(t) = c, \quad t_0 \leq t \leq t_1, \tau(t_1) \geq t_0,$$
$$k_1(t) \leq k_2(t), \quad t \geq t_1,$$

$$\ln\frac{1}{c}k_2(t) \geq \int_{t_1}^{t} |p(s) - \lambda_1 q(s)k_1(s)|\, ds, t \geq t_1, \qquad (2)$$

$$\ln\frac{1}{c}k_1(t) \leq \int_{t_1}^{t} |p(s) - \lambda_2 q(s)k_2(s)|\, ds, t \geq t_1, \qquad (3)$$

$$\ln \lambda_2 \geq \int_{\tau(t)}^{t} [-p(s) + \lambda_2 q(s) k_2(s)]\, ds, \tau(t) \geq t_1, \quad (4)$$

$$\ln \lambda_1 \leq \int_{\tau(t)}^{t} [-p(s) + \lambda_1 q(s) k_2(s)]\, ds, \tau(t) \geq t_1. \quad (5)$$

Then the equation (1) has a positive solution bounded by functions $k_1(t)$ a $k_2(t)$.

Proof. [[1],[3]] Let $C([t_0,\infty),R)$ be a set of all continuous bounded functions with a norm $\|x\| = \sup_{t\geq t0} |x(t)|$. Then the $C([t_0,\infty), R)$ is a Banach space. We define a closed, bounded and convex subset Ω of the space $C([t_0,\infty) ,R)$ as follows:

$$\begin{aligned}\Omega = \{&k_1(t) \leq x(t) \leq k_2(t), t \geq t_1,\\ &k_1(t) = k_2(t) = x(t) = c, t_0 \leq t \leq t_1,\\ &x(\tau(t)) < \lambda_2 x(t), t \geq t_1,\\ &x(\tau(t)) \geq \lambda_1 x(t), t \geq t_1\}.\end{aligned}$$

We define a mapping $S : \Omega \to C([t_0,\infty),R)$ this way:

$$(Sx)(t) = \begin{cases} c\, exp\left(\int_{t_1}^{t} [p(s) - q(s)x(\tau(s))]\, ds\right), t \geq t_1 \\ c, \quad t_0 \leq t \leq t_1. \end{cases}$$

We will show that for an arbitrary $x \in \Omega$ we have $Sx \in \Omega$. For each $x \in \Omega$ and $t \geq t_1$ we get

$$\begin{aligned}(Sx)(t) &= c\, exp\left(\int_{t_1}^{t} [p(s) - q(s)x(\tau(s))]\, ds\right)\\ &\geq c\, exp\left(\int_{t_1}^{t} [p(s) - \lambda_2 q(s)x(s)]\, ds\right)\\ &\geq c\, exp\left(\int_{t_1}^{t} [p(s) - \lambda_2 q(s)k_2(s)]\, ds\right)\\ &\geq k_1(t).\end{aligned}$$

$$\begin{aligned}(Sx)(t) &= c\, exp\left(\int_{t_1}^{t} [p(s) - q(s)x(\tau(s))]\, ds\right)\\ &\leq c\, exp\left(\int_{t_1}^{t} [p(s) - \lambda_1 q(s)x(s)]\, ds\right)\\ &\leq c\, exp\left(\int_{t_1}^{t} [p(s) - \lambda_1 q(s)k_1(s)]\, ds\right)\\ &\leq k_2(t).\end{aligned}$$

For $t_0 \leq t \leq t_1$ we get $(Sx)(t) = c$, and so $(Sx)(t) \in \Omega$.
Additionally, for $\tau(t) \geq t_1$ we have

$$\begin{aligned}(Sx)(\tau(t)) &= c\, exp\left(\int_{t_1}^{\tau(t)} [p(s) - q(s)x(\tau(s))]\, ds\right)\\ &= (Sx)(t)\, exp\left(-\int_{\tau(t)}^{t} [p(s) - q(s)x(\tau(s))]\, ds\right). \quad (6)\end{aligned}$$

With regards to previously inequalities for each $x \in \Omega$ and $\tau(t) \geq t_1$ we get

$$\begin{aligned}&(Sx)(\tau(t)) =\\ &= (Sx)(t)\, exp\left(\int_{\tau(t)}^{t} [-p(s) + q(s)x(\tau(s))]\, ds\right)\\ &\leq (Sx)(t)\, exp\left(\int_{\tau(t)}^{t} [-p(s) + \lambda_2 q(s)x(s)]\, ds\right)\\ &\leq (Sx)(t)\, exp\left(\int_{\tau(t)}^{t} [-p(s) + \lambda_2 q(s)k_2(s)]\, ds\right)\\ &\leq \lambda_2 (Sx)(t),\end{aligned}$$

$$\begin{aligned}(Sx)(\tau(t)) &\geq (Sx)(t)\, exp\left(\int_{\tau(t)}^{t} [-p(s) + \lambda_1 q(s)k_1(s)]\, ds\right)\\ &\geq \lambda_1 (Sx)(t).\end{aligned}$$

For $t_0 \leq \tau(t) \leq t_1$ we get $(Sx)(\tau(t)) = c$, and so $(Sx)(\tau(t)) \in \Omega$. This way we have proven that $Sx \in \Omega$ for an arbitrary $x \in \Omega$.

We will now show that S is continuous. Let $x_i = x_i(t) \in \Omega$ be such, that $x_i(t) \to x(t)$ for $i \to \infty$. Since Ω is closed then $x = x(t) \in \Omega$.

For $t \geq t_1$ we have

$$|(Sx_i)(t) - (Sx)(t)| =$$

$$= \left|c\left[exp\left(\int_{t_1}^{t} [p(s) - q(s)x_i(\tau(s))]\, ds\right) - exp\left(\int_{t_1}^{t} [p(s) - -q(s)x(\tau(s))]\, ds\right)\right]\right|.$$

Since

$$\left|exp\left(\int_{t_1}^{t} [p(s) - q(s)x_i(\tau(s))]\, ds\right) - exp\left(\int_{t_1}^{t} [p(s) - -q(s)x(\tau(s))]\, ds\right)\right| \to 0,$$

for $i \to \infty$, we conclude that

$$\lim_{i\to\infty} \left|(Sx_i)(t) - (Sx)(t)\right| = 0.$$

This means that S is a continuous mapping. The set of functions $\{Sx : x \in \Omega\}$ is uniformly bounded in $[t_0,\infty)$. This results from the definition of Ω. This subset is also uniformly continuous in $[t_0,\infty)$. Then according to the Arzel-Ascoli theorem the $S\Omega$ is a relatively compact subset of $C([t_0,\infty),R)$. According to the lemma 2.1 there exists such $x_0 \in \Omega$ that $Sx_0 = x_0$. We can see that $x_0(t)$ is a positive solution of the equation (1). The proof is now complete.

Now we will present two simple examples that prove the theorem 2.1 validity.

Example 2.1. Consider a nonlinear differential equation with delayed argument\

$$\dot{x}(t) = -\frac{1}{2}x(t) - \frac{1}{10}x(t)x(t-1), t \geq t_0 \quad (7)$$

If we take
$k_1(t) = e^{1-t}, k_2(t) = 1, t \geq t_1 = 1,$
$k_1(t) = k_2(t) = c = 1, 0 \leq t \leq 1,$
$\lambda_1 = 1,$
$\lambda_2 = 5,$
then we have

$$\ln k_2(t) = 0 \geq \int_1^t \left(-\frac{1}{2} - \frac{1}{10}e^{1-s}\right) ds = -\frac{t}{2} + \frac{1}{10}e^{1-t} + \frac{2}{5},$$

for $t \geq 1$,

$$\ln k_1(t) = 1 - t \leq -\int_1^t ds = 1 - t, t \geq 1,$$

$$\ln \lambda_2 = \ln 5 \geq \int_{t-1}^{t} ds = 1, t \geq 2,$$

$$\ln \lambda_1 = 0 \leq \int_{t-1}^{t} \left(\frac{1}{2} + \frac{1}{10}e^{1-s}\right) ds = \frac{1}{2} + \frac{e-1}{10}e^{1-t},$$

for $t \geq 2$.

Since all the conditions from theorem 2.1 are satisfied, the equation (7) has a positive solution.

Corollary 2.1. We assume the existence of such constants $c,\lambda \in (0,\infty)$ and such bounded function $k \in C([t_0,\infty),(0,\infty))$, that

$$k(t) = c > 0, t_0 \leq t \leq t_1, \tau(t_1) \geq t_0$$

$$\ln\frac{1}{c}k(t) = \int_{t_1}^{t}[p(s) - \lambda q(s)k(s)]ds, t \geq t_1,$$

$$\ln\lambda = \int_{\tau(t)}^{t}[-p(s) + \lambda q(s)k(s)]ds, \tau(t) \geq t_1,$$

then the equation (1) has a positive solution

$$x(t) = c\,exp\left(\int_{t_1}^{t}[p(s) - \lambda q(s)k(s)]ds\right), \tau(t) \geq t_1.$$

Proof. We set $k_1(t) = k_2(t) = k(t)$, $t \geq t_0$ and apply theorem 2.1.

Example 2.2. Consider a nonlinear differential equation with delayed argument

$$\dot{x}(t) = (e^{2\tau} - 1)x(t) - e^{t}x(t)x(t - \delta), \quad t \geq t_0, \qquad (8)$$

where $\delta \in (0,\infty)$. If we take $k(t) = c$ for $-\delta \leq t \leq t_1 = 0$, $k(t) = ce^{-t}$ for $t \geq 0$ and $\lambda = e^{\delta} = c$, we then get

$$\ln\frac{1}{c}k(t) = -t = \int_0^t\left(e^{2\delta} - 1 - e^{\delta}e^{s}ce^{-s}\right)ds = -t, t \geq 0,$$

$$\ln\lambda = \delta = \int_{1-\delta}^{t}\left(1 - e^{2\delta} + e^{\delta}e^{s}ce^{-s}\right)ds = \int_{1-\delta}^{t}ds = \delta,$$

for $t \geq \delta$.

Since all the conditions of the corollary 2.1 are satisfied, the equation (8) has a positive solution [[1]]

$$x(t) = c\exp\left(-\int_0^t ds\right) = ce^{-t}, t \geq \delta.$$

Corollary 2.2. Let's assume the existence of such constants $c > 0$, $0 < \lambda_1 \leq \lambda_2$ and such bounded functions $k_1, k_2 \in C([t_0,\infty),(0,\infty))$, that the conditions of theorem 2.1 are satisfied and $\int_{t_1}^{\infty}[p(t) - \lambda_1 q(t)k_1(t)]dt = -\infty$. Then the equation (1) has a positive solution which converges to zero.

3 SIS model

Population is considered to be divided into disjunct classes that change in time t. The susceptible class consists of individuals who can contract the disease but were not infected yet. The infected class consists of individuals spreading the infection to others. Parts of the total population in these classes are designated S(t) and I(t) respectively.[[11]]

Our epidemiological model also takes into consideration the following assumptions [[6]]:

1. The observed population has a constant size N, which is sufficiently large for each of the set classes to be considered a continuous variable. We assume that births and natural deaths are in equal amount and all newborns are susceptible. Individuals from both classes are removed by death at a rate proportional to the class size with a constant μ called daily death rate.
2. The population is homogeneously intermixed. The number of daily contacts β is a number of average contacts of one infected individual per day. The adequate contact of the infected is defined as an interaction leading to infecting other subject who is not immune. Thus we define βS as the average number of susceptible subjects infected by the infectious individual per day and βSNI as the average number of susceptible subjects infected by the infectious class with size NI per day. The kind of direct or indirect contact necessary for passing on the virus is subject to a particular type of infection.[[12]]
3. The subjects are considered recovered and taken out of the infected class at a rate in proportion to the number of infected using proportional constant γ named rate of daily recoveries. The number removed from the infected class either by death or recovery equals γ + μ. If the recovery does not lead to immunity then we call the model an SIS due to the fact that the individuals are transferred from the susceptible class S to the infected class I and back to the susceptible class S after recovery.[11]

The SIS models in general are applicable for certain bacterial diseases like meningitis, plague, sexual diseases, protozoic diseases like malaria or for virus diseases like common flu or the current SARS-COV-2 coronavirus with documented cases of a repeated infections. The medical institutions are investigating the possible reasons for repeated positive tests including virus reactivation or possible errors in testing. In this paper we consider the SIS model valid for the diseases that do not lead to gaining immunity. Natural births and deaths and model history dependent-time delay argument are part of the system. SIS model is represented by the following differential system with time delay argument and these initial conditions:

$$\begin{aligned}
&\dot{S}(t) = -\beta I(t)S\big(\tau(t)\big) + \gamma I(t) + \mu - \mu S(t),\\
&\dot{I}(t) = \beta I(t)S\big(\tau(t)\big) - \gamma I(t) - \mu I(t), t \geq t_0,\\
&S(t) = \varphi_1(t),\\
&\tau(t_0) \leq t \leq t_0, \varphi_1 \in C\big([\tau(t_0), t_0], [0,\infty)\big), \varphi_1(t_0) > 0,\\
&I(t_0) > 0,\\
&S(t) + I(t) = 1. \qquad (9)
\end{aligned}$$

Let's assume that $\tau \in C([t_0,\infty),[0,\infty))$ is a nondecreasing function, $\tau(t) \leq t$ and $\lim_{\tau\to\infty}\tau(t) = \infty$. For $\tau(t) = t$ is the model (9) treated in [4]. It is natural to assume that the frequency of contacts β, death rate μ and recovery rate γ change in time t. Thus β, μ and γ in the model (9) will be replaced by variables β(t), μ(t) and γ(t).

Since S(t) can be derived from I(t) by using $S(t) = 1 - I(t)$, where it is sufficient to consider [[11]]

$$\begin{aligned}
&\dot{I}(t) = \big(\beta(t) - \gamma(t) - \mu(t)\big)I(t) - \beta(t)I(t)I\big(\tau(t)\big), \text{ for } t \geq t_0, \qquad (10)\\
&I(t) = \varphi_2(t),\\
&\tau(t_0) \leq t \leq t_0, \varphi_2 \in C\big([\tau(t_0), t_0], [0,\infty)\big), \varphi_2(t_0) > 0.
\end{aligned}$$

We now apply the theorem 2.1 and the corollaries 2.1, 2.2 on the equation (10) and we get the next theorem.

Theorem 3.1. Let constants $c > 0$, $0 < \lambda_1 \leq \lambda_2$ and bounded functions $k_1, k_2 \in C([t_0,\infty),(0,\infty))$ exist such that

$$k_1(t) = k_2(t) = c, t_0 \leq t \leq t_1, \tau(t_1) \geq t_0,$$

$$k_1(t) \leq k_2(t) = c, t \geq t_1,$$

$$\ln\frac{1}{c}k_2(t) \geq \int_{t_1}^{t}[\beta(s) - \gamma(s) - \mu(s) - \lambda_1\beta(s)k_1(s)]ds,$$

for $t \geq t_1$,

$$\ln\frac{1}{c}k_1(t) \leq \int_{t_1}^{t}[\beta(s) - \gamma(s) - \mu(s) - \lambda_2\beta(s)k_2(s)]ds,$$

for $t \geq t_1$,

$$\ln\lambda_2 \geq \int_{\tau(t)}^{t}[-\beta(s) + \gamma(s) + \mu(s) + \lambda_2\beta(s)k_2(s)]ds,$$

for $\tau(t) \geq t_1$,

$$\ln \lambda_1 \le \int_{\tau(t)}^{t} [-\beta(s) + \gamma(s) + \mu(s) + \lambda_1 \beta(s) k_1(s)] ds,$$

for $\tau(t) \ge t_1$.

Then the equation (3) has a positive solution bounded by functions $k_1(t)$ and $k_2(t)$.

Corollary 3.1. Let's assume the existence of a constant c, $\lambda \in (0,\infty)$ and a bounded function $k \in C([t_0,\infty),[0,\infty))$ such that $k(t) = c$, $t_0 \le t \le t_1$, $\tau(t_1) \ge t_0$,

$$\ln \frac{1}{c} k(t) = \int_{t_1}^{t} [\beta(s) - \gamma(s) - \mu(s) - \lambda\beta(s)k(s)] ds,$$

for $t \ge t_1$,

$$\ln \lambda = \int_{\tau(t)}^{t} [-\beta(s) + \gamma(s) + \mu(s) + \lambda\beta(s)k(s)] ds,$$

for $\tau(t) \ge t_1$,

then the equation (10) has a positive result.

$$I(t) = c\, exp\left(\int_{t_1}^{t} [\beta(s) - \gamma(s) - \mu(s) - \lambda\beta(s)k(s)] ds \right),$$

for $\tau(t) \ge t_1$.

Proof. We set $k_1(t) = k_2(t) = k(t)$, $t \ge t_0$, $\lambda_1 = \lambda_2 = \lambda$, and apply theorem 3.1 and corollary 2.1, where

$$p(t) = \beta(t) - \gamma(t) - \mu(t),$$
$$q(t) = \beta(t), \tau(t) \ge t_1.$$

Example 3.1. Let's assume a nonlinear differential function with time delay

$$\dot{I}(t) = \left(e^{b\delta}\, \beta(t) e^{-b(t-\delta)} - b\right) I(t) - \beta(t) I(t) I(t - \delta),$$

for $t \ge 0$, (11)

where $b,\delta \in (0,\infty)$, $\beta(t) > 0$.
This equation is identic with the equation 10, if

$$b = \gamma + \mu$$

When we set the $k(t) = c$ for $-\delta \le t \le t_1 = 0$, $k(t) = ce^{-bt}$ for $t \ge t_1 = 0$ and $c = \lambda = e^{b\delta}$, we then get

$$\ln \frac{1}{c} k(t) = \int_0^t \left[e^{b\delta} \beta(s) e^{-b(s-\delta)} - b - e^{b\delta} \beta(s) c e^{-bs} \right] =$$

$$= \int_0^t (-b) ds = -bt, \quad t \ge 0,$$

$$ln\, \lambda = \int_{1-\delta}^{t} b\, ds = b\delta, \quad t \ge \delta.$$

Since all conditions of the corollary 3.1 are satisfied, the equation (11) has a positive result

$$I(t) = ce^{-bt}, t \ge \delta.$$

Corollary 3.2. Let's assume the existence of constants $c>0$, $0<\lambda_1 \le \lambda_2$ and bounded functions $k_1, k_2 \in C([t_0,\infty),(0,\infty))$ such that the conditions of theorem 3.1 are satisfied and

$$\int_{t_1}^{\infty} [\beta(t) - \gamma(t) - \mu(t) - \lambda_1 \beta(t) k_1(t)] dt = -\infty.$$

Then the equation (10) has a positive solution converging to zero.

Proof. We apply theorem 3.1 and corollary 2.2, where

$$p(t) = \beta(t) - \gamma(t) - \mu(t),$$

$$q(t) = \beta(t), \tau(t) \ge t_1.$$

4 Conclusion

Differential delay equations successfully model the actual delay cycles in the physical nature of the model to be solved. The spread of infection becomes uncontrollable without mitigation measures such as quarantine or social distancing. It is recommended to purify the air through air purifying filters inside offices, enclosed spaces and hospitals which will help reduce the percentage of viruses; leaving the virus trapped in the filter and reduces the condition to people who work in these spaces. COVID-19 has caught the world unprepared and the fact that it is highly contagious causes unpredictable complications. We see its impact everywhere, whether it is hospital overcrowding, education or tourism. Unpredictable future development of the pandemic is even more worrying. In this precarious situation, modelling infectious diseases is a very hot topic. Many different theoretically valid mathematical models that have been experimentally validated in the past are used to predict the development of the epidemic. We have considered the SIS epidemiological model in our work. We used a nonlinear differential system with time delay as a mathematical formulation of this model. We searched for the existence of a positive solution bounded by two functions k_1, k_2 with constants $\lambda_1 > 0$, $\lambda_2 > 0$ where $0 < \lambda_1 \le \lambda_2$.

We suppose that $\beta(t)$, $\gamma(t)$, $\mu(t)$ are nonnegative functions for $t \ge t_1$.

If

$$\beta(t) < \gamma(t) + \mu(t), t \ge t_1,$$

than

$$\beta(t) - \lambda_1 \beta(t) k_1(t) < \beta(t) \le \gamma(t) + \mu(t),$$

$$\beta(t) - \lambda_1 \beta(t) k_1(t) < \gamma(t) + \mu(t),$$

$$\beta(t) - \gamma(t) - \mu(t) - \lambda_1 \beta(t) k_1(t) < 0\,, t \ge t_1.$$

Thus, we have

$$\int_{t_1}^{\infty} [\beta(t) - \gamma(t) - \mu(t) - \lambda_1 \beta(t) k_1(t)] dt = -\infty,$$

or

$$\int_{t_1}^{\infty} [\beta(t) - \gamma(t) - \mu(t) - \lambda_1 \beta(t) k_1(t)] dt = -k,$$

for $k \in (0,\infty)$.

So, if

$$\beta(t) \le \gamma(t) + \mu(t), t \ge t_1.$$

If the number of average contacts for one infected individual per day is less or equal to the number removed from the infected class by recovery or death per day, then the number of infected individuals converges to zero or is less or equal to ce^{-k} (Corollary 3.2). The model we used, especially in relation with the spread of COVID-19, confirms that the measures put in place to slow down the spread of COVID-19, such as covering the upper airways using a respirator in public areas, public transport, taxis or other means of transport, compulsory quarantine (domestic isolation) or contact limitation, are effective.

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I INFORMATICS

IN INFORMATICS

LIVE STREAMING OF CHILD SEXUAL ABUSE AS A 21ST-CENTURY CHALLENGE

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Abstract: This article focuses on some selected aspects of live streaming of child sexual abuse as this phenomenon has generated significant financial profits for perpetrators throughout the years. The paper defines the basic terminology, analyses the current situation worldwide, identifies groups of children most at risk, and discusses the currently effective criminal legislation in the Czech Republic. Last but not least, the article describes some measures for combating this phenomenon that have been introduced in the Republic of the Philippines in this issue. Key areas for further study are then indicated in the conclusion.

Keywords: child pornography, child sexual abuse, cryptocurrency, live streaming, protection of children, statistics

Introduction

The fact that child sexual abuse has become a worldwide pandemic is undisputable at present. With the development of digital technologies and the expansion of the global market, perpetrators now have unprecedented access to children, whereas cyberspace makes the production and dissemination of materials depicting child sexual abuse easier. The enormously escalated demand for new materials causes deepening of the problem.

In child sexual abuse, live streaming represents a phenomenon of these days. Unfortunately, the available statistics, as presented in Chapter 2, show the sad truth as this phenomenon affects a significant part of the child population. Live streaming of child sexual abuse makes it possible for perpetrators to cash huge amounts from customers. From the perspective of technology, the only '*superstructure*' prerequisite for the facilitation or participation in such streaming is the need for a stable and fast connection to the global Internet.

The situation in live streaming of child sexual abuse is alarming also because it involves a highly latent (concealed, hidden) criminal activity, as all the persons involved (customer, facilitator) commit a crime. Of course, except for the abused child. Last but not least, it is a very serious crime activity with a long-term, in many cases even life-long negative impact on the most vulnerable victims – the children.

1 Basic terms and their definitions

Before tackling the definition of live streaming, it is necessary to define the term 'child'. Under Article 1 of the United Nations Convention on the Rights of the Child, a child means every human being below the age of eighteen. Directive 2011/93/EU of the European Parliament and of the Council on combating the sexual abuse and sexual exploitation of children and child pornography and Section 126 of the Czech Criminal Code both use the same definition.

Concerning the concept of live streaming of child sexual abuse, there is still no globally accepted definition at the moment. A historical excursion can search for some existing definitions such as, '*Live streaming of child sexual abuse (CSA) involves broadcasting acts of sexual abuse of children live via webcam to people anywhere in the world*'.[1] Another available definition reads, '*Live child abuse anywhere across the world, and in some of these sites and some of these facilities enables them to direct individuals who are abusing children to abuse them in a way to which they gain some form of satisfaction*'.[2] The latest definition from y. 2024 reads, '*It involves transmitting the sexual abuse of children in 'real time' via a webcam to individuals in any geographical location*'.[3]

The scholarly literature also offers the following definition, '*Child sexual abuse (CSA) features the procurement and viewing of sexual abuse of children across the internet in real time, in exchange for money*'.[4] This definition was deliberately included in the paper because it is the only one that uses the defining feature of 'in exchange for money'. As explained in detail in Chapter 4, there are more reasons for children to take part in live streaming than just money.

Based on the above, only the first three definitions presented here will be analysed in the next part of the paper. Three basic features can be derived from the definitions, namely the existence of a platform on which live streaming will take place, the webcam as a transmission tool for the streaming, the recipient (at least one), and the child. As regards the first feature, i.e. the existence of a platform, it is vital to distinguish between streaming platforms (TikTok, Twitch, YouTube) and platforms allowing a video call (WhatsApp, Webex, Facebook Messenger). Live streaming platforms allow one-way streaming and the possibility for an unspecified number of users to connect. A video call is defined as real-time communication between two or more parties and is usually limited by the number of connected users. For example, the WhatsApp platform currently allows only 32 users to join a video call.[5] Both types of platforms allow users to make requests for the content of the streaming in real time. In live streaming platforms, a chat line will be the means of how to communicate requests, while in video calls, verbal requests will predominate. It should be noted that under the legislation in force in the United States of America, namely 18 U.S. Code § 2258A, the platforms send reports of suspected sexually explicit live streaming involving children to the National Center for Missing and Exploited Children, abbreviated as NCMEC.[6]

Child abuse for live streaming can be divided into three categories as follows:

- Voluntary, self-generated
- Coercive (under threat)
- Organised

The first category of live streaming includes cases in which the child creates the live streaming him-/herself quite voluntarily, i.e. without coercion from another person. The request for voluntariness is quite obligatory; otherwise, the material would fall into the second category. Voluntary live streaming usually takes place in the environment of social media, especially on various social networking sites, such as Instagram Messenger, Webex, TikTok, Snapchat, and others. There are several reasons for this behaviour, e.g. obtaining a higher number of followers, love of life, financial gain, or the child´s sexual satisfaction.

Coercive live streaming includes cases where the child is coerced under various threats to create sex-related live streaming, which has several features in common. The perpetrator's web camera is usually switched off during the live streaming, so their real appearance is neither known to the victim nor the police authorities. The perpetrator already has sensitive

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sex-related material (photographs, video file) at this stage, obtained from the victim during the previous communication. Live streams no longer take place on standard social media, as e.g. TikTok declares in its rules that, '*TikTok shall sanction any content or account which displays a material containing child sexual abuse or juvenile sexual exploitation*'[7], or YouTube says that, '*We shall search for any sexually explicit content depicting juveniles and any content that abuses minors sexually. We shall report any content depicting child sexual abuse to the NCMEC (National Center for Missing and Exploited Children), which cooperates with police and security agencies worldwide*'.[8] The guidelines of these online service providers indicate that such content is detected, blocked, and reported to the NCMEC. In other words, these platforms are not a favourable environment for perpetrators to commit this type of crime.

Live streaming organised by groups is the gravest and most dangerous ever. These organised groups of perpetrators receive huge amounts of money from all over the world from people who prefer children. Each organised group has its hierarchical structure. Moreover, the crimes committed by them are highly sophisticated, using all available so-called protective elements to make it as difficult as possible for the police to detect the groups. Such elements include organising live streaming especially on the darknet and on end-to-end encrypted platforms (Signal, WhatsApp), and strong verification of the identity of members of the organised group or of the consumers in order to prevent infiltration in live streaming by undercover agents. The term undercover agent can mean '*an individual who is placed in a specific setting, such as a warehouse, to gather information covertly. They typically work for a contract service firm and receive a salary from them while maintaining a cover as an employee of the target organizations*'.[9]

2 Analysis of the current situation

The following chapter does not aim to describe the origin and development of the issues of sexually explicit live streaming involving children but to focus on a detailed analysis of the current situation in this area. For this purpose, partial research was carried out by combining a search of publicly accessible websites, periodic annual reports on activities, or press statements of selected organizations working in the field of protection of children from sexual abuse, with subsequent quantitative analyses of the data obtained.

The selected organisations were classified into three groups: law enforcement agencies, international police organisations, organisations that have their database or portal for receiving notifications.

The most important law enforcement agencies undoubtedly include the Federal Bureau of Investigations (FBI) and Homeland Security Investigations (HSI), whose activities influence other law enforcement agencies globally. FBI places violent and sexually motivated acts among its long-term priorities, which include, in particular, an international network of perpetrators organising live streams. FBI regularly shares in the media part of their successful arrests or convictions of life-streaming perpetrators, e.g. '*West Columbia Man Indicted for Directing the Sex Abuse of Children in Brazil by Livestream, Producing Child Sexual Abuse Material*'.[10]

HSI merely makes the general statement in its publicly available annual report that child sexual abuse has been on the rise in the sphere of financial sextortion (especially in connection with male juveniles), cyber grooming, live streaming, and the creation of materials depicting sexual abuse of children by using the artificial intelligence.[11] These authorities have not shared any specific statistical data on live streaming by the research carried out.

The international organisation *Europol* detects an increasing threat in the form of live streaming of sexual performances involving children, known as '*online distant sexual abuse*', and refers to e.g. Operation Sprint, carried out in June 2024 and aimed at perpetrators who consume live child abuse streams in exchange for money. Special investigators from ten countries were working on the case. Operation Sprint resulted in creating information packages that pointed to nearly 197 perpetrators paying for live child abuse streams.[12] The issue of live streaming is hugely latent, and infiltrating such groups is proving to be very challenging from all perspectives. For logical reasons, it is difficult to have any valid statistical data for a subsequent detailed analysis. *Interpol* has 19 available global databases in total.[13] An analysis of periodic reports from 2022, and 2023 and follow-up documents available was conducted but the relevant data is only available to police forces, not to the public.[14]

The non-profit organisation called *Internet Watch Foundation* (IWF) represents an international foundation headquartered in Great Britain, engaged in combating child sexual abuse and removing such materials from cyberspace.[15] The research conducted in 2018 collected worrying data about the involvement of children between the ages of 11 and 13 in live streaming. The research, however, indicated the involvement of even younger children at the age of 7 to 10.[16] Since the research, the age of the children involved has remained relatively constant. Another organisation called *WeProtect* considers sexually explicit live streaming involving children to be the most significant threat in this field, as described in their document titled '*Global Threat Assessment 2023*'. The primary reason is the considerable difficulty for police forces to locate and obtain evidence of such streams, especially if no video footage or photographs are taken.[17]

As part of the partial research, the author further analysed the content of important documents with the following titles, 'Organised Crime Threat Assessment', 'EMPACT 2023 Results Factsheets', 'EU Serious and Organised Crime Threat Assessment', 'Consolidated Annual Activity Report 2023', and 'INHOPE Annual Report 2024'. However, no relevant data applicable to the purpose of the paper was found.

As mentioned in the introduction of this paper, the issue of live streaming is hugely latent, and infiltrating such groups is proving to be quite challenging from all perspectives. The partial research carried out by the author to analyse the current condition of this area, especially backed up by 'hard' data, was not successful as originally intended, especially due to the absence of statistical data. In conclusion, it is necessary to reiterate that, from an objective point of view, it is almost

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unattainable to have meaningful statistics in this area for subsequent research.

3 Payment methods for participation in live streaming

As mentioned in the introduction of this paper, the digital world moves fast forward on a daily basis, and the same applies when it comes to consumers paying money to join live streaming. Perpetrators become more sophisticated, and therefore also police forces must focus intensively on the area of payments for illegal content. If police forces gave up on investigating the payments, they would lose quite a sufficient quantity of information that is capable of helping to identify specific perpetrators. From a historical perspective, the following four payment methods for sexually explicit live streaming involving children can be identified:

- Cash payments
- Credit card – bank transfer
- Email payments
- Cryptocurrencies

The first two methods can now be considered outdated. Cash payments were common at a time when current options were not available. Nowadays they are virtually excluded, as the connected consumers are from all over the world, given the nature of cyberspace. Sending cash in envelopes is hard to imagine. From the perpetrators´ point of view, it does not seem appropriate to accept payments for live streaming via standard bank accounts. This method was widely spread in y. 2000.[18] By sharing a person´s bank account number there is a risk, among others, that some of the customers may, for any reason, disclose the bank account to police forces. Nowadays, investigation of this payment method does not cause any significant problems in practice.

E-mail payments represent a method that even nowadays provides perpetrators with room to cover their illegal activities. To use this method, it is 'only' obligatory to register the email address with the payment service provider.[19] For a higher level of anonymousness, perpetrators mostly use encrypted services, such as Tutanota, or Protonmail.

The last alternative is currently cryptocurrencies (virtual currencies), considered the future of the world and technologies.[20] Cryptocurrencies are characterised as '*virtual money*'. These are digital assets that operate on the principle of decentralised technology of blockchain[21], which means that no central entity (such as a bank or government) can control the network. This competence is replaced by transaction management and authentication, which is distributed among a number of independent nodes (computers).[22] In the context of cryptocurrencies, perpetrators take advantage of the possibility of private transactions, i.e. payments are anonymous, which can be used to obtain funds from their criminal activities. Coin mixers (such as Tumbler, Blender, or others) are also an issue, which means '*a service that improves the privacy of cryptocurrency transactions. It hides the connection between sending and receiving addresses by mixing the user's coins with others, breaking the trace on the blockchain. This makes it difficult to track the flow of funds*'.[23]

Foreign partner units of the Czech Financial Analytical Office are active in the field of prevention and detection of illegal payments and provide information about payments for child sexual abuse, including live streaming.[24] Payments for live streaming are frequently made via so-called FinTech companies. The abbreviation defines companies engaged in providing cashless payment processing technology and related services. These companies include Revolut, WesternUnion, PayPal, and others.[25]

The cryptocurrency service Coinbase conducted research in 2022 using data collected from the IWF (this organisation was briefly introduced in Chapter 2). The research resulted in the identification of more than 6,500 individuals suspected of abusing the platform for alleged illegal purposes. This information also helped the platform to identify service providers believed to be selling and distributing child sexual abuse material, with the parallel shutdown of the traders who were accepting sums of money for illegal services.[26]

These financial transactions alone are not sufficient to convict the perpetrator but are nevertheless crucial to linking the consumer to the seller. Perpetrators usually do not plead guilty to this type of crime. Therefore, additional means of evidence must be secured to form an interconnected, unbroken, or closed chain that admits no alternative other than the guilt of the perpetrator.[27]

The situation in the cryptocurrency sector is addressed by the European Union. An agreement was reached between the Parliament and the Council on the Markets in Crypto-Assets Regulation (MiCA) in June 2022. It was formally approved by the Parliament in April 2023. Approval by the EU Member States was given in May 2023, which represented the final step of the legislative process. The new measures are designed to promote the development and use of these technologies, provide legal certainty, encourage innovation, protect consumers and investors, and ensure financial stability.[28]

4 Vulnerable groups of children

Based on research conducted within the project '*Comprehensive Approach to Preventing and Combating Child Trafficking*', funded by the '*Security Research Programme for the Needs of the State 2022-2027*'[29], and taking regard of the author´s expertise, four groups that need to be addressed can currently be identified as regards children engaged in live streaming:

1. Children who come from socially and economically disadvantaged families or low-income areas. These cases involve the so-called 'intra-family' abuse of a child.[30] The primary motive will be financial benefit to cover the basic living needs of the family. However, it is also possible to detect cases in which the financial resources obtained serve to suppress the need for work activity of the parents themselves. In these cases, funds are hardly ever invested in the development of the abused child.

[18] UNIVERSITY OF NOTTINGHAM. Payment methods and investigation of finan cial transactions in online sexual exploitation of children cases. Online. 2023. Available from: https://www.nottingham.ac.uk/research/beacons-of-excellence/rights-lab/resources/reports-and-briefings/2023/october/payment-methods-and-investigation-of-financial-transactions-in-online-sexual-exploitation-of-children-cases.pdf. [quoted 2025-06-03].
[19] Ibid.
[20] PATRICK, Zandl. Mýty a naděje digitálního světa: Vše, co potřebujete vědět o kryptoměnách, umělé inteligenci a dalších převratných technologiích [Myths and Hopes of the Digital World: Everything You Need to Know About Cryptocurrencies, Artificial Intelligence, and Other Disruptive Technologies]. Jan Melvil Publishing, 2022. ISBN 978-80-7555-176-4. p. 17.
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[23] BITCOIN.COM. What is coin mixer? Online. 2025. Available from: https://www.bitcoin.com/cs/get-started/what-is-coin-mixer/. [quoted 2025-06-04].
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[26] INTERNET WATCH FOUNDATION. Websites offering cryptocurrency payment for child sexual abuse images 'doubling every year'. Online. 2022. Available from: https://www.iwf.org.uk/news-media/news/websites-offering-cryptocurrency-payment-for-child-sexual-abuse-images-doubling-every-year/. [quoted 2025-06-02].
[27] FENYK, Jaroslav; CÍSAŘOVÁ, Dagmar and Tomáš GŘIVNA. Trestní právo procesní [Criminal Procedural Law]. 8th edition. Prague: Wolters Kluwer, 2024. ISBN 978-80-7676-898-7. p. 317.
[28] EUROPEAN PARLIAMENT. Cryptocurrency dangers and the benefits of EU legislation. Online. 2022, update 28.9.2023. Available from: https://www.europarl.europa.eu/topics/en/article/20220324STO26154/cryptocurrency-dangers-and-the-benefits-of-eu-legislation. [quoted 2025-06-03].
[29] Information on this project available at https://obchodsdetmi.cz/
[30] WEISS, Petr. Sexuální zneužívání - pachatelé a oběti [Sexual abuse – offenders and victims]. Psyché. Prague: Grada, 2000. ISBN 80-716-9795-8. p.10.

A related aspect is the pattern of behaviour that a child from such a family environment 'carries' to their life. Even from the point of view of value hierarchy, such children are oriented quite differently from children from the stratum described under Paragraph 2 of this chapter, often leading to their delinquent behaviour in adolescence or adulthood.[31]

2. Children who come from socially and economically average or even well-off families and explain the above from two perspectives. The first perspective is the possibility of additional earnings (for example, secondary school students can be included in this group). The trigger for the behaviour is the pressure of society that is currently extremely focused on material values. For children, expensive items are important for the sake of self-esteem or to meet peer group standards.[32] The second view is stepping out of the boredom zone to diversify the existing way of life or as part of a recruitment strategy for variously oriented groups.

3. Children living in or escaping from juvenile rehabilitation institutions or other facilities adapted for this purpose. Such children often look for ways to '*survive*' outside these institutions, at whatever cost. They then find shelter and a certain service from persons who, in return, demand, often not entirely voluntarily, favours that fall into the category of sexual exploitation, especially by showing off in front of a web camera for paying customers. However, it is usually not an organised group, but an individual initiative. There are often situations in which a person provides shelter to several children (for example, if there are three female friends on the run). Both girls and boys are at risk from these perpetrators' activities. It can be noted that consumers have been lately increasingly interested in live streaming engaging young boys.

4. Last but not least, children from other countries, especially from Ukraine, represent a challenge. In the absence of other opportunities to earn a living, coercion to the creation of sexually explicit content, even inside the families, cannot be excluded. A warning from our Slovak partners can be quoted as, '*At the beginning of y. 2025, more than 4,000 children from Ukraine were living in Slovakia, so to speak, outside the system, receiving no social benefits or attending school. These are in many cases unaccompanied minors and this can be seen as a ticking bomb for the future*'.[33] Even *Europol* has been working extensively on this issue, with the digital sprint to disrupt the sexual exploitation of Ukrainian nationals, including children, with a focus on detecting and disrupting trafficking networks that use online platforms to facilitate their criminal activities.[34] In terms of the proportion of persons who have been granted temporary protection about the war in Ukraine in the total population, the Czech Republic ranks second behind the Republic of Moldova with 3.51 percent.[35]

5 Criminal legislation currently valid in the Czech Republic

The strongest and most effective tool to combat behaviour harmful to society is the law and in the case of live streaming, criminal law. In the field of criminal law, live streaming represents two quite different levels. The first includes perpetrators who, by various means, for example, induce, procure, recruit, seduce, or deliver a child to appear on such a live stream for financial gain. Such acts can be legally qualified as an offence of trafficking in human beings under Section 168(1)(a) of the Criminal Code.

In cases when perpetrators act as members of an organised group or commit such offences with the intent to gain for themselves or others at least CZK 1,000,000, they are at risk of being sentenced for up to 12 years. Currently, perpetrators demand approximately between 50 and 100 EUR or USD for making such performances available. It is important to note that the amount will depend on what kind of performance it is. It will differ if the subject of the performance is '*merely*' to show exposed genitals without any further sexual activity or if the sexual activities to be streamed emphasize violence or disrespect towards the child (humiliation, pissing, sexual slavery, and similar). To fulfil the element of financial benefit which is a prerequisite for the imposition of a longer sentence, it will not be necessary to carry out a large number of partial performances, since, based on the premise that one performance is attended by 100 spectators, each of whom paying EUR 100 (CZK 250,000), it will ultimately be necessary to organise four such performances.

As for the offence of trafficking in human beings, a joinder with the offence of exploitation of a child for the production of pornography under Section 193 of the Criminal Code is excluded due to the special nature of the offence.[36]

For the next part of the paper, especially about the detection of groups of children at risk of trafficking, it is necessary to look closely at the obligatory element of the merits of the crime of trafficking in human beings, namely concealment. Concealment is defined as '*placing a child in a hidden place where (s)he is out of reach of his/her legal guardians or public authorities or other authorised entities*'.[37] These will include cases of escape of male/female juveniles from juvenile rehabilitation centres, followed by hiding from a return to such institutions, as described in more detail in Chapter 4.

Another element is the consumers of such content. The provisions of Section 193a of the Criminal Code establish criminal liability for those 'who participate in a pornographic performance or another similar show in which a child performs'. The merits of the crime described above were incorporated into the Criminal Code in 2014 by the implementation of Directive 2011/93/EU of 13 December 2011 on combating the sexual abuse and sexual exploitation of children and child pornography. It declares the social harmfulness of watching a live performance of a child via the Internet or other means of communication that has sexual overtones and is intended for a specific audience.[38]

In order to determine the relevant legal qualification, a pornographic performance that runs in real time, without an option of replay or other repetitive displays, is a significant element.[39] Unfortunately, even nowadays it is possible to encounter cases of subsumption of such conduct under the second paragraph of Section 192 which reads, '*Whoever, by employing information or communication technology, gains access to child pornography*'. The provision, however, presumes access to child pornography (pornographic work) and therefore does not apply to pornographic performances. This was also the reason for the introduction of the separate Section 193a of the Criminal Code, as mentioned above.

As for finances, it is most beneficial for perpetrators when the highest possible number of customers joins the performance. However, criminal liability can also be deduced about a single viewer, provided the performance was originally intended for an

[31] MATOUŠEK, Oldřich and MATOUŠKOVÁ, Andrea. Mládež a delikvence: možné příčiny, struktura, programy prevence kriminality mládeže [Youth and delinquency: possible causes, structure, juvenile crime prevention programmes]. 3rd edition, updated. Prague: Portál, 2011. ISBN 978-80-7367-825-8. p. 99.
[32] GŘIVNA, Tomáš, Miroslav SCHEINOST and Ivana ZOUBKOVÁ. Kriminologie [Criminology]. 5th updated ed.. Prague: Wolters Kluwer.2019 ISBN 978-80-7598-554-5.
[33] Information on this project available at https://obchodsdetmi.cz/
[34] EUROPOL. Digital sprint to disrupt sexual exploitation of Ukrainian nationals. Online. 2025. Available from: https://www.europol.europa.eu/mediapress/newsroom/news/digital-sprint-to-disrupt-sexual-exploitation-of-ukrainian-nationals.[quoted 2025-05-24].
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[37] ŠČERBA, Filip a kolektiv. Trestní zákoník. Komentář [Criminal Code. Comment]. 1st edition (3rd update). Prague: C. H. Beck, 2024. ISBN: p. 41.
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[39] ŠÁMAL, Pavel. Trestní zákoník: komentář. III [Criminal Code: Comments], 3rd edition. Velké komentáře. Prague: C.H. Beck, 2023. ISBN 978-80-7400-893-1. p. 2214.

audience.[40] It is a different situation if a perpetrator agrees with a child bilaterally on a video chat for his/her pleasure. From the viewpoint of legal qualification, there is also another significant circumstance in whether a recording of such a video chat is made. If the video chat is not recorded, in other words, if no recording is available, in whatever format, the case will be a suspected crime of trafficking in human beings under Section 168(1)(a) of the Criminal Code.

In the event a recording is made as a sexually motivated pornographic work with child abuse, the provisions of Section 193, which read, '*Whoever induces, procures, recruits, entices, seduces or exploits a child to produce a pornographic work or to profit from the participation of a child in such a pornographic work*' are applied. With a view to the above, the provisions of Section 193a are not applied in these cases. The aforementioned offences are excluded from a joinder on the ground of subsidiarity.[41]

6 Options and tools to combat live streaming

With regard to the defined scope of the article, the Republic of the Philippines has been chosen as it is globally considered a '*hotspot*' of child live streaming. The local police forces have the most experience with the detection and investigation of this crime. The legal and technological aspects of this issue must be compatible. Otherwise, the fight against this phenomenon will not be effective.

From the perspective of law enforcement bodies and justice, the effective detection of such live streaming represents a cornerstone.[42] As mentioned in the introduction of this paper, this type of criminal activity is highly latent, primarily because all the parties involved (customer, facilitator) commit a criminal offence, except for the abused child.

According to Sharon Pursey, co-founder of safety tech firm SafeToNet, '*Technology exists that can detect and block child sexual abuse from being digitally created or consumed via images, video or live stream. Artificial intelligence and machine learning tools can detect new abusive content and be dropped onto applications, networks, or Operating Systems (OS) of smart devices, preventing devices from rendering illegal sexual images of children*'.[43]

The Philippine government adopted Act No. 11930, also known as 'Anti-Online Sexual Abuse or Exploitation of Children (OSAEC) and Anti-Child Sexual Abuse or Exploitation Materials (CSAEM) Act' in July 2022, which has brought effective elements of combating sexual abuse of children online. Among other things, it requires service providers to install in their services such advanced technologies, mechanisms, or measures that are designed to prevent, detect, or report materials relating to sexual abuse and exploitation of children and simultaneously ensure that distribution and streaming are removed or blocked.[44] The success rate of detection is directly proportional to the quality of cooperation between law enforcement authorities and Internet service providers. In a significant number of cases, the service providers are the only ones who can detect abuse and make a report to law enforcement authorities, as the child him/herself is afraid or too young to report the incident, and the parents or custodians know nothing about the abuse.

From this point of view, the Czech Republic is lagging, as the legislation establishes that a Czech provider of a service that entails storing information provided by the user (e.g. web hosting or social networks) does not have an obligation to monitor the content of its network or to actively search for illegal content, according to the provisions of Section 6(a), (b) of Act No. 480/2004 Coll., on certain information company services.[45]

As another measure, the Republic of the Philippines Act introduces a '*register of perpetrators*', which includes both Philippine citizens and foreigners. The register is further connected with the competent government bodies and international police agencies.[46] Similar registers already exist in the United States and the United Kingdom. In the Czech Republic, however, such a register has not been created yet.

Last but not least, effective combat requires strong and rapid international cooperation between law enforcement agencies, technology companies, and NGOs. Even *Europol*[47] and *Interpol*[48] agree with this statement in their documents.

Conclusion

The article describes the issues of live streaming of child sexual abuse. Its goal is to provide the reader with sufficient information about the phenomenon, namely about the basic terminology, to present the current situation worldwide, and the relevant criminal law in the Czech Republic. The analysis conducted shows that even though the current criminal legislation in the Czech Republic allows for sentencing these offences, due to the dynamics and technical complexity of this type of crime, it is, however, necessary to continue to improve it - especially in the area of international cooperation, early detection, and sufficient deterrence of perpetrators from committing this crime.

The article identifies key areas for further review. They specifically include:

- The absence of a legal definition of the term 'sexually explicit live streaming involving children', preferably accepted globally.
- Live streams operated on encrypted platforms and in the darknet environment, and the possibilities of detection also on ClearWeb from the technological point of view.[49]
- Payments for participation in live streaming in cryptocurrency, including the identification of metadata to support more effective detection of payments related to live streaming.
- '*False positive*' designation of live streaming or video calls in which children are depicted, but which are not of a harmful (sexual) nature.
- The absence of relevant legislation about live streaming at the level of the European Union.

It must be stated here that the author intends to explore these topics more, either in the form of further papers for the following years of the QUAERE conference or as part of the author's

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[43] Ibid.
[44] Ibid.
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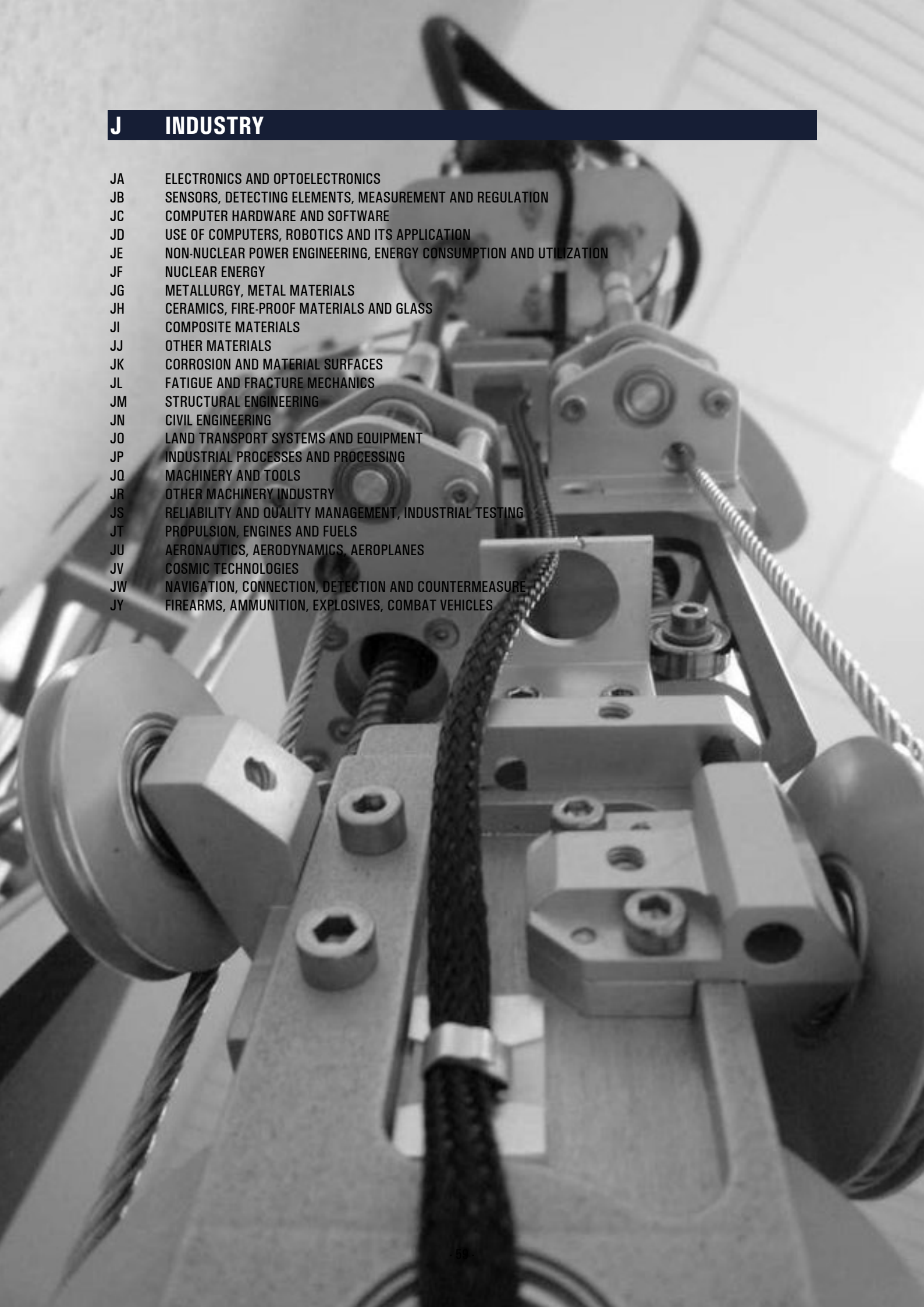

J INDUSTRY

JA ELECTRONICS AND OPTOELECTRONICS
JB SENSORS, DETECTING ELEMENTS, MEASUREMENT AND REGULATION
JC COMPUTER HARDWARE AND SOFTWARE
JD USE OF COMPUTERS, ROBOTICS AND ITS APPLICATION
JE NON-NUCLEAR POWER ENGINEERING, ENERGY CONSUMPTION AND UTILIZATION
JF NUCLEAR ENERGY
JG METALLURGY, METAL MATERIALS
JH CERAMICS, FIRE-PROOF MATERIALS AND GLASS
JI COMPOSITE MATERIALS
JJ OTHER MATERIALS
JK CORROSION AND MATERIAL SURFACES
JL FATIGUE AND FRACTURE MECHANICS
JM STRUCTURAL ENGINEERING
JN CIVIL ENGINEERING
JO LAND TRANSPORT SYSTEMS AND EQUIPMENT
JP INDUSTRIAL PROCESSES AND PROCESSING
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JY FIREARMS, AMMUNITION, EXPLOSIVES, COMBAT VEHICLES

RESEARCH INTO FAILURE RATES OF TRACTIVE ROLLING STOCKS

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Abstract: Failures of means of transport significantly affect the reliability and availability of the individual modes of transport. This paper presents a study of failure rates of powered railway vehicles. The frequency of failures in 69 powered locomotives was monitored. Bathtub curves were drawn for individual railway vehicles and the probabilities of their failure-free operation were identified. The most reliable powered locomotives, as well as locomotives with the highest failure rates, were identified based on the risk matrix by applying the Risk Based Inspection (RBI) method. The work brings new results from the point of view of the failure rate of tractive rolling stocks. The intensity of failures was determined to assess the reliability. Graphical dependences on the instantaneous values of the failure rate on time, i.e. the vehicle life indicators, were constructed. The contribution of this work is the research of the failure rate of rolling stock used in railway transport. Based on the risk matrix according to the RBI method, the most reliable electric locomotives were identified.

Keywords: Failure rate, locomotives, RBI, bathtub curve.

1 Introduction

In practice, reliability is typically evaluated based on a failure rate λ, which expresses the number of failures that occur over a time unit throughout the vehicle life cycle. Instantaneous values of failure rates may be calculated as a quotient of the value of the slope of the tangent line to the curve of probability of a failure F(t) and the respective value of probability of a trouble-free operation, i.e. reliability R(t) at a particular moment in time t_0 (Raschman & Pačaiová, 2002):

$$\lambda(t_0) = \frac{\left(\frac{dF}{dt}\right) t_0}{R(t_0)} \quad (1)$$

The failure rates of the railway rolling stock can be estimated using age values and the railway stock maintenance manual (Park et al., 2017).

A graphical representation of the correlation between the instantaneous values of failure rates and the time is a curve of the vehicle life indicators. The curve of the vehicle life indicators, i.e. the bathtub curve, is an analogue to the wear curve, which is comprised of three distinguishable phases (early use, normal use, wear-out). Since the failure rates are highest during the early life and at the wear-out, the bath curve (Figure 1) suggests 3 areas of failure rates (Roesch, 2012):

- I – early use phase;
- II – normal use phase;
- III – wear-out phase.

The period of early failures is referred to as the infant mortality period. Immediately after the vehicle is put in use, early failures may occur. Causes of such failures may be internal (faulty design, manufacture or assembly) or external (impermissible overloading of a vehicle, violation of rules for operation, maintenance or repair, etc.).

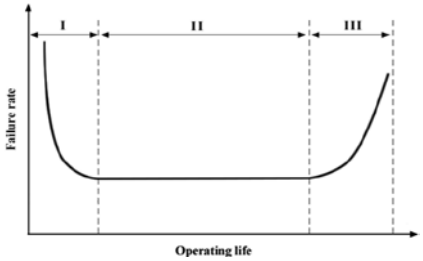


Figure 1. Curve of the vehicle life indicators (bathtub curve)

However, the curve is only typical for certain types of simple equipment and for certain more complex objects with a dominant mechanism of failures. The course of the failure period by wearing out is often affected by the wear, for example, by fatigue, corrosion and abrasion. In general, contemporary equipment is much more complex and the shapes of the curves of life indicators are therefore different. Fig. 2 shows the bathtub curves of various electric and mechanical components based on their use times (Raschman and Pačaiová, 2002; Moubray, 1997):

Pattern A (Figure 2a) represents a typical bathtub curve – it begins with a high failure rate period, which changes into the period of approximately a constant failure rate and ends with the wear-out zone.

Pattern B (Figure 2b) exhibits a prolonged period of a constant failure rate or a failure rate with a slowly increasing intensity, eventually followed by the wear-out zone.

Pattern C (Figure 2c) – the failure rate gradually and slowly increases, but the curve does not end with the wear-out zone.

Pattern D (Figure 2d) – typically low failure rates of new products, which shortly afterwards sharply increase to a constant level.

Pattern E (Figure 2e) represents a constant failure rate throughout the whole operating life.

Pattern F (Figure 2f) begins with a high failure rate, which later sharply decreases down to a constant value.

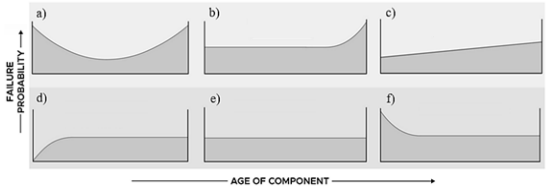


Figure 2. Curves of the vehicle life indicators, a) pattern A, b) pattern B, c) pattern C, d) pattern D, e) pattern E, f) pattern F (Christiansen, 2023)

Even though Patterns A, B and C can be monitored, it is impractical to monitor Patterns D, E and F as there is no or only a little change that could be used to justify the diagnosis of a maintenance need (Baglee, 2014).

Studies in the field of civil aviation have shown that Pattern A describes behaviour of approximately 4% of objects, while Pattern B describes 2%, C 5%, D 7%, E 14% and Pattern F describes 68% of objects (Pačaiová, 2006).

Despite the fact that relative proportions of objects with different behaviours (Patterns A to F) in the aviation sector and various industries are not identical, in general, the patterns of equipment failure rates increasingly approach the shapes of Patterns E and F as the complexity of the equipment increases (Pačaiová, 2011).

The bathtub curve model with a finite support can better conform the sharp change in the failure rate, which usually increases very fast in the wear-out phase (Jiang, 2013).

Increasing the proportion of railway transport is crucial for reducing the environmental pollution caused by road transport (Frisch et al., 2021). Maintenance of the railway infrastructure plays a key role in the railway transport sector. Its purpose is to ensure safety of operation and availability of railway lines, as well as related equipment, for the purpose of transport regulation. Competition on the transport market requires the improvement of vehicle maintenance with the aim of reducing the maintenance cost while maintaining the operation safety (Macchi et al., 2012) railway companies must comply with the determined safety regulations (Roberts et al., 2002) that define maintenance procedures, as well as frequencies of preventive

measures, primarily aimed at providing high-level safety (Carretero et al., 2003). In the European Railway Transport, great efforts are exerted in the field of Condition-Based Maintenance (CBM) with the aim of collecting, processing and evaluating data using respective sensor systems for the online monitoring of the condition of lubricated components of locomotives and wagons in order to increase their safety and availability while reducing the maintenance costs and unplanned downtimes (Schneidhofer, Dubek & Dörr, 2023).

The paper (Ambriško, Šaderová & Antal, 2023) deals with the evaluation of parameters of reliability of railway transport vehicles and presents the methods for railway vehicle maintenance. Authors of the paper (Nedeliaková, Valla & Masár, 2024) assessed the efficiency of modernisation of wagons intended for the passenger transport; according to their opinion, modernisation is an important step towards safer and more efficient operation of railways. When idle, wagons are mostly kept in workshops and subjected to maintenance and repairs, and that increases the costs of, for example, lease and storage. Train fleets remain idle on average 70% of time; as a result, additional storage costs are incurred. Moreover, maintenance operations that are intended for larger train fleets become inefficient, while it is expected that they will be adjusted to the servicing and inspection of multiple idle wagons (Bigi et al., 2024). When organising maintenance of wagons, experts must take into consideration two main challenges: (i) which of the wagons of an arriving train must be parked for maintenance required under relevant regulations or which wagons must be replaced; (ii) how to implement a traffic schedule that will ensure traffic safety (Zagorskikh, Alsova & Gavrilov, 2020). The purpose of the paper (Bigi et al., 2024) was to investigate into long-term effects of mileage-based maintenance on the management of freight trains, as well as its impact on the fleet idle rate and management.

The challenges related to the support of required professional skills of staff performing the maintenance of railway wagons were discussed in the paper (Nikitin et al., 2020), authors of which designed a virtual-reality-based simulator for the purpose of testing the skills of maintenance staff according to the instructions.

The purpose of this paper was to investigate into failure rates of railway vehicles used in the railway transport. Bathtub curves were drawn for the monitored locomotives and the values of probability of their reliable operation were identified. The most reliable powered locomotives were identified based on the risk matrix by applying the RBI method.

2 Experimental part

The research described in this paper included the monitoring of failure rates of 69 electric tractive railway vehicles over the period of years 2018 and 2019: (i) Series 350 – 18 double -system electric locomotives; (ii) Series 361 – 26 double -system electric locomotives; and (iii) Series 757 – 25 engine -powered locomotives. The parameters of the locomotives of those three series are listed in Tab. 1.

Tab. 1. Basic technical data of engine-powered locomotives (Series 350, 361, 757 locomotive)

Series	350	361	757
Gauge [mm]	1,435	1,435	1,435
Continuous horsepower [kW] (*total)	4,000	3,600	1,550*
Length over buffers [mm]	16,740	16,800	16,540
Total wheelbase [mm]	11,700	11,500	11,400
Bogie wheelbase [mm]	3,200	3,200	2,400
Max. speed [km.h^{-1}]	160	140	100
Locomotive weight [t]	87.6	86	75.4

2.1 Description of the methods used

During the use of a vehicle, the failure intensity λ is approximately constant; that means that the percentage of vehicles in which a failure occurs over the same time interval during the use period is the same. In such a case, the probability of a failure is distributed exponentially. For many real-world objects, such a result may be identified by calculating a mathematical equation, but also confirmed empirically in an analysis. The failure probability density for the operating time t is calculated using the following equation (Pačaiová, 2011):

$$f(t) = \lambda e^{-\lambda t}, \quad t \geq 0 (\lambda = k = const.) \tag{2}$$

Failure probability in the (0, t) interval is determined by the probability density function F(t):

$$F(t) = 1 - e^{-\lambda t} \tag{3}$$

Reliability as the probability of reliable operation R(t) is then calculated using the following equation:

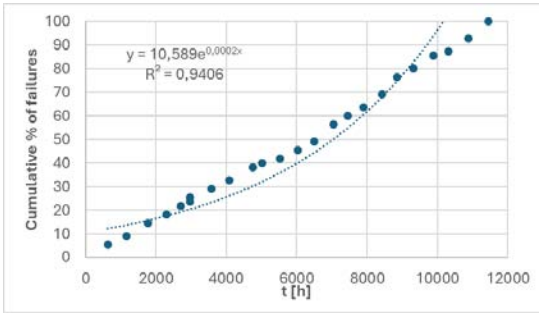
$$R(t) = 1 - F(t) = e^{-\lambda t} \tag{4}$$

The R(t) function expresses the probability that an object will withstand t hours of operation without a failure. For the reliability of railway transport vehicles with failure rates that change over time, the Weibull probability distribution was applied.

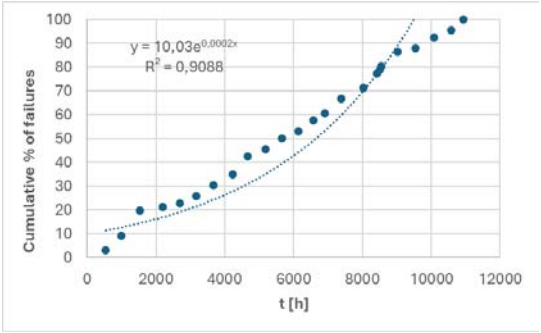
The Risk-Based Inspection (RBI) method is used to identify and understand the factors affecting the risks while considering the equipment lifespan (Petronic et al., 2024). RBI, i.e. the process of creating an inspection schedule based on the knowledge of the risk of equipment failure, is typically used in multiple industries (Mohamed. Hassan & Mahar, 2018). In this paper, the most reliable engine-powered railway transport vehicles, in particular locomotives, were identified based on the risk matrix (Čabaníková, Ambriško & Ďuriška, 2024).

3 Results

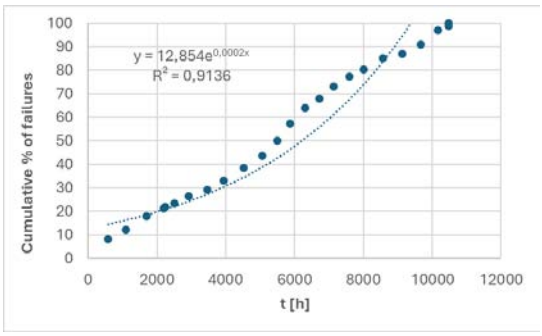
Failure probability distribution curves represent the correlations between the total number of locomotive failures in cumulative percentage and the operating time t. Figure 3 shows particular examples for the individual locomotive series. The least squares method was applied to approximate the curves using exponential functions. The values of the failure probability and of the probability of reliable operation (reliability) of the locomotives were identified (Figure 4). The sum of the failure probability F(t) and the reliability R(t) equals 1 in every moment in time (Ben-Daya et al., 2009).



a) Series 350 locomotive



b) Series 361 locomotive



c) Series 757 locomotive

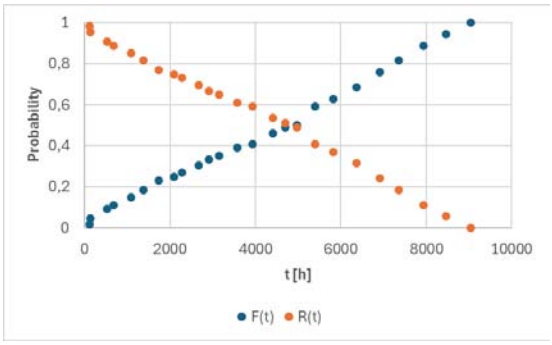
Figure 2. Failure probability distribution curves

The shapes of the curves of the F(t) functions for the 350 Series locomotives indicate that in the time interval of 0–3,500 hours, a failure may be expected in 35% of locomotives, while after 7,000 hours of operation, as much as 75% of them will exhibit a failure. The data shows that out of the locomotives that are put in use after 3,500 hours, 65 out of 100 will probably be functioning (i.e. 12 out of the monitored number), while after 7,000 hours, only 25 out of 100 will continue to be functioning (i.e. 4 locomotives of the 350 Series).

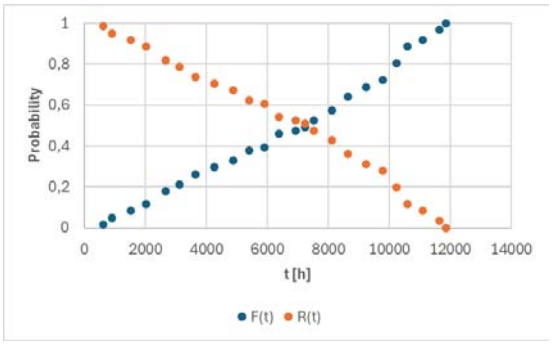
The shapes of the curves of the F(t) functions for the 361 Series locomotives indicate that in the time interval of 0–5,200 hours, a failure may be expected in 35% of locomotives, while after 11,000 hours of operation, 75% of locomotives will be malfunctioning. Out of the locomotives put in use after 5,200 hours, 17 out of the monitored locomotives will probably be functioning, while after 11,000 hours, only 6 locomotives of that series will continue to be functioning.

The shapes of the curves of the F(t) function for the locomotives of Series 757 clearly show that in the interval of 0–4,100 hours, a failure is likely to occur in 35% of locomotives, while after 8,100 hours of operation, 75% of locomotives will exhibit a failure. Based on the analysed data, after 4,100 hours of operation, 65 out of 100 locomotives will probably be functioning (i.e. 16 out of the monitored number), while after 8,100 hours, only 25 out of 100 locomotives will be functioning – 6 locomotives of the 757 Series.

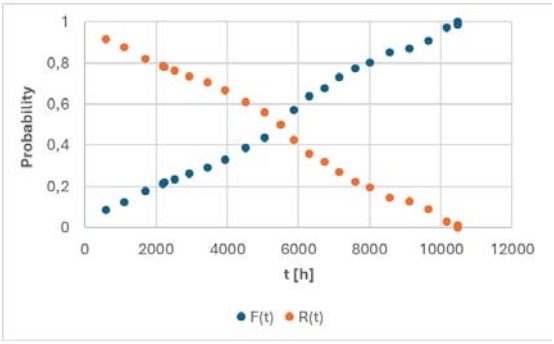
Data on failure probability may be used to determine reliability of an analysed object (Ben-Daya et al., 2009). The probability of reliable operation R(t) decreases over time. After 4,900; 7,250; and 5,500 hours of operation (Series 350; 361; and 757), the locomotive reliability value decreases to 0.5. The failure probability F(t) increases over the operating time: the initial value is 0 when the locomotive is put in use, then the value is 0.5 after approximately 5,880 hours of operation, and eventually 1 at the time of a failure occurrence.



a) Series 350 locomotive



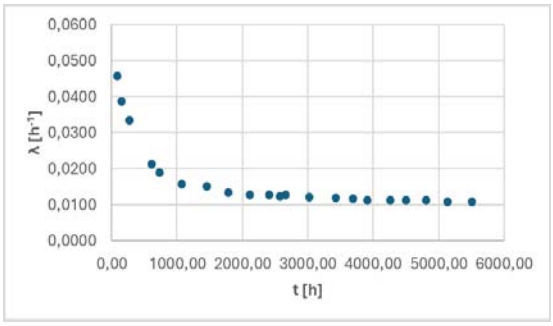
b) Series 361 locomotive



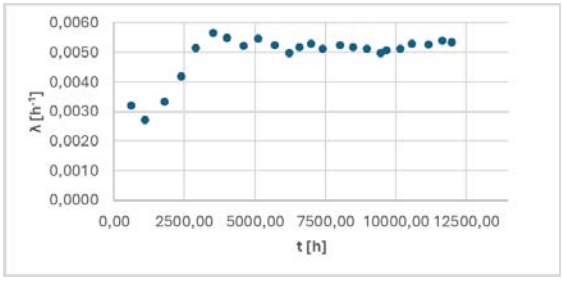
c) Series 757 locomotive

Figure 3. Curves of the failure probability F(t) and the reliable operation R(t)

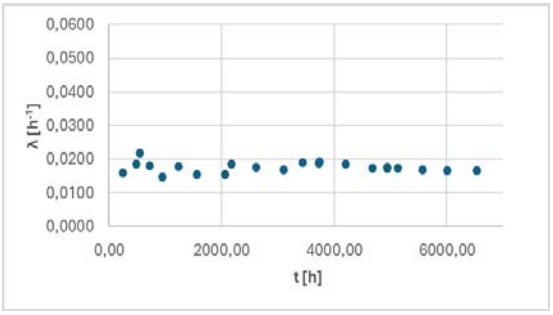
A graphical representation of the correlation between the instantaneous values of a failure rate λ and time t represents the curve of the locomotive life indicators – a bathtub curve (Figure 5). Immediately after the beginning of operation, early failures occur. After a certain time of operation, the period of low and approximately constant failure rates follows. Even though this period of standard operation is designated on the bathtub curve with a horizontal line, it is actually of a slightly bent shape (Pačaiová, 2006).



a) Pattern F for the Series 350 locomotive



b) Pattern D for the Series 361 locomotive



c) Pattern E for the Series 757 locomotive
Figure 4. Bathtub curves

Analysis of the bathtub curves for the analysed locomotives showed that Pattern D describes behaviour of 30.3% of locomotives, while Pattern E of 39.4% of locomotives and Pattern F of 30.3% of locomotives. Although relative proportions of the individual locomotives are not identical, the shapes of the curves of failure rates of the locomotives of the Series 350 are similar to Patterns E and F, while the shapes of the curves for the locomotives of Series 361 and 757 are similar to Patterns D and E.

The input data required for creating the risk matrix was the data on failure rates of the locomotives (in particular the duration and number of failures). Based on the performed analysis and subsequent data categorisation into 3 levels (I, II, III), the locomotives with short-lasting failures and of low failure frequency were identified, i.e. the locomotives with a lower risk of failure. By contrast, locomotives with long-lasting failures and of a high failure frequency were identified as the locomotives with a significantly higher risk of failure. The risk matrix (Figure 6) facilitated the identification of the locomotives that are excellent or problematic, as well as those that require the following:

- Applying the TPM (Total Productive Maintenance) in order to improve their efficiency and reduce the maintenance costs and losses caused by downtimes (Sharma, Chandra & Singh, 2019), based on good communication between the operator and the maintenance staff – the key principle of the TPM strategy (Valenčík and Stejskal, 2009) which emphasises active engagement of employees in maintenance;
- Applying the Reliability-Centred Maintenance (RCM) – a methodical approach to the creation of a planned maintenance programme consisting of cost-effective tasks while ensuring the performance of the critical functions of the equipment (Roberts et al., 2002); RCM is aimed at the identification of critical components of locomotives and creates maintenance plans based on the risks related to those components and their importance;
- Preventive repairs, i.e. a set of activities of various natures that are performed as the prevention against failures;
- Trainings for maintenance staff or equipment operators are aimed to ensure that the employees engaged in the operation and maintenance of locomotives posses the knowledge, skills and information required for the efficient and safe performance of their tasks;
- General repairs and improvements, i.e. extensive adjustments and renovation of locomotives that will improve their reliability, performance and safety, and will extend their lifespan.

The matrix contains colour-coded locomotives of three different series (350, 361 and 757), divided into 9 cells. The risk matrix clearly shows that the majority of locomotives of the Series 757 were identified as those with the highest risk. In order to increase reliability of those locomotives, TPM and RCM methods should be applied, and general repairs should be performed on the locomotives with the highest failure rates. Three colour-coded cells contain the locomotives that require radical repairs.

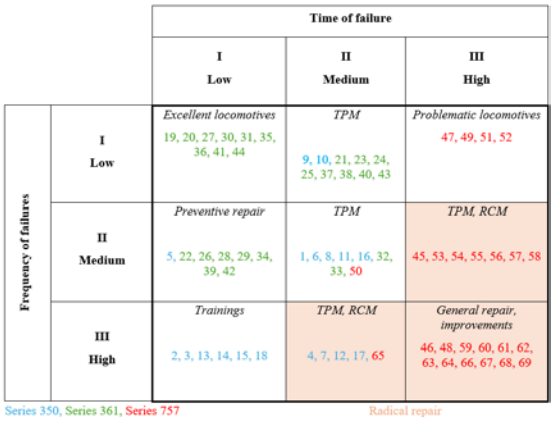


Figure 6. Risk matrix for engine-powered locomotives

4 Conclusion

Research into failure rates of tractive rolling stock provides the options how to improve the management of maintenance in railway transport. Shapes of the bathtub curves drawn for the monitored engine-powered locomotives approach the shapes of Patterns D, E and F.

The failure probability distribution curves for the ribution were approximated using exponential functions. The curves of failure probability clearly show that the locomotive of Series 361 exhibited the longest operation times to failure occurs in 35% and 75% of locomotives. Their reliability, i.e. probability of reliable operation, for the value of 0.5 reaches the maximum operation time out of all 3 locomotive series. The risk matrix confirmed the lowest risk of failures, particularly for the series 361.

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