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**INTERNATIONAL
CONFERENCE ON**

**DECISION MAKING FOR SMALL AND
MEDIUM-SIZED ENTERPRISES**

CONFERENCE PROCEEDINGS

International scientific Conference of Department of Business Economics and Management and Department of Informatics and Mathematics at Silesian university in Opava, School of Business Administration in Karvina.



**SILESIA
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4th International conference on Decision making for Small and Medium-Sized Enterprises

Conference Proceedings



**SILESIA
UNIVERSITY**
SCHOOL OF BUSINESS
ADMINISTRATION IN KARVINA

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Dear readers,

these are the proceedings of the 4th edition of the international scientific conference DEcision Making for Small and Medium-sized Enterprises 2023 (DEMSME 2023, go.slu.cz/demsme), which took place at the Petrovice Castle in Petrovice, Czech Republic. The two-day conference was organised by the Department of Business Economics and Management and the Department of Informatics and Mathematics of the Silesian University in Opava, School of Business Administration in Karvina. DEMSME 2023 was a regular meeting of experts from universities and companies interested in the theory and application of decision making research using methods from the disciplines of business economics, management, marketing, artificial intelligence and mathematics in the current practice of small and medium-sized enterprises (SMEs). In particular, this year's edition reflected on the lessons learned from the Covid-19 pandemic in 2020-21.

We are very pleased to have received 43 submissions and to have selected a total of 37 original papers after a rigorous double-blind review process and evaluation. The authors came from 6 countries, namely the Czech Republic, Slovakia, Poland, Romania, Greece and the Netherlands. From the 37 papers, some best papers will be selected for publication in our 15 partner journals (e.g. E&M Economics and Management, Journal of Entrepreneurship, Management and Innovation, Scientific Annals of Economics and Business, Organizacija, Central European Business Review, etc.). The total number of articles from the above-mentioned fields shows that these fields are interesting from a scientific point of view and that there are generally a lot of problems that require a specific scientific approach to solve them and to strengthen the competitive advantages of SMEs. You will find 28 selected papers in these proceedings.

The papers combine scientific activities with current practice dedicated in SMEs and beyond. The focus of this issue of DEMSME is on the response of the business environment to the challenges of the coronavirus pandemic and changes in managerial decision making. In particular, the papers reflected on working from home and its impact on business performance, the impact of changes in the global business environment on SMEs, supply chains, e-commerce, consumer preferences and management strategy during the pandemic, creativity in decision making, human resource management and communication, statistical evaluation of SME development, customer loyalty, process mining analysis, ICT tools and their use in Industry 4.0, business process automation, statistical models, exchange rates in foreign trade, consumer behaviour and business performance measurement, and more. Most of the presentations provided up-to-date knowledge that could be immediately implemented in the practice of SMEs. The conference was enriched by keynote speakers Prof. Yu-Wang Chen (University of Manchester, UK) with a presentation on "Business Analytics: A Brief Overview of Teaching and Research at Alliance Manchester Business School", Prof. Anna Ujwary-Gil (Polish Academy of Sciences, Poland) with her topic "Technology and Services Provided by Digital Innovation Hubs in Poland and the Czech Republic: Digital Transformation of Small and Medium Enterprises" and Kristýna Pochvalitová (New Dimension, Czech Republic) with the topic "What has changed in business management after Covid-19?"

We would like to thank the scientific committee of the conference, the organisers and partners, first of all the European Structural and Investment Funds (Operational Programme Research, Development and Education) and the Ministry of Education, Youth and Sports of the Czech Republic as the exclusive financial supporters of the conference within the project CZ.02.2.69/0.0/0.0/18_054/0014696 entitled Development of R&D capacities of the Silesian University in Opava. We believe that the fourth edition of the DEMSME conference was again successful and we are looking forward to the next meeting after two years together with other traditional scientific conferences organised at the Silesian University in Opava, School of Business Administration in Karvina, Czech Republic.

Roman Šperka, Petr Suchánek
Executive Co-Chairs, DEMSME 2023

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OBSERVING SMES WITH TECHNOLOGY ADOPTION GLASSES THROUGH SYSTEMS ENGINEERING LENS

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Abstract

Hi-tech small and medium enterprises (SMEs) are facing many organizational challenges such as lack of resources including knowledge, competent workforce, managerial training, and experiences. Additionally, SMEs encounter engineering management challenges including inefficient decision-making, inability to adapt changes and lack of customers understanding. Technical support is required to cope with these challenges. Systems engineering (SE) can contribute to resolve growing challenges of complexity and enhance organizational efficiency in this context, although SE adoption is a challenge itself. Primarily SE is employed by large enterprises to manage complexities. The main objective of this study is to investigate the relations among the challenges faced by hi-tech SMEs, the expected benefits and barriers while trying to solve these challenges by adopting SE, and the existing best practices that can facilitate this adoption. Three mind-maps were developed a) challenges faced by hi-tech SMEs, b) potential benefits and challenges to adopt and implement SE, and c) ways to facilitate adoption. These maps converge into an impact model that highlights the important factors to be improved with SE knowledge and tries to overcome barriers associated with adoption processes. Authors argue that technology adoption theories and techniques can provide support to make SE more adoptable in the case of hi-tech SMEs. Therefore, the presented impact model can help hi-tech SMEs to decide on strategies to use SE to solve some of their engineering management challenges.

Keywords: decision support, engineering management, organizational challenges, small and medium enterprises, systems engineering, technology adoption

JEL codes: M15, 014

1. Introduction

Small and medium enterprises (SMEs) are considered a pillar of a country's economic growth. They contribute to the economic development and provide support in regional, cultural and developmental aspects as well (Palmieri, 2007). The European Union (EU) define SMEs as firms

employing fewer than 250 employees with the annual turn over less than or equal to 50 million euros or 43 million euro in the balance sheets (European Commission, 2003). SMEs represent approximately 99.8% of Europeans businesses (Alessandrini *et al.*, 2019) and has the employment share up to 65% in 2020 (Hope *et al.*, 2021). SMEs contributes to the economic value addition, growth, and sustainability of society. Along with economic and social benefits, hi-tech SMEs are facing a unique set of issues, that requires assistance as compared to large enterprises. Some of the identified issues in SMEs are market failure, and structural fields such as finances, research, innovation, and environmental regulations (Antoniuk *et al.*, 2017). Rigidity in labor market, lack of management and technical skills, and limited knowledge of opportunities are the kind of structural barriers that may appear at SMEs, as well (Yoshino, 2016). Moreover, these challenges may contribute to issues related to organizational decision-making at SMEs. SMEs are under pressure to adopt and use modern ways to overcome these hurdles more intensively. Systems Engineering (SE) is a potential way forward in this perspective, that can provide tools, techniques, processes, and methodologies to provide better decision support to overcome these challenges. This paper examines issues and challenges faced by SMEs and potential of SE implementation highlight possible hindrance in SE implementation by considering technology adoption challenges.

To address the growing challenges of complexity and enhance organizational efficiency, there is a widely accepted belief that the concept of Systems Engineering (SE) has expanded to encompass a more comprehensive approach. Hi-tech SMEs require access to sophisticated technical solutions that support various technical system-level functions. These include concept creation, performance assessment, architecture development and risk assessments etc. Moreover, SMEs need to address organizational functions related to design and development phases from conception to retirement along with effective stakeholder communication and record management. It includes both external stakeholders such as customers and users, as well as internal cross-disciplinary engineering teams. According to INCOSE (Walden *et al.*, 2015) SE is defined as

“a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”

SE aims to fulfill customer needs and requirements by defining them early in the development cycle, documenting them, and ensuring their integration into the design and validation process of the system. It spans both technical and business needs of stakeholders to ensure the end-product is of high quality and meets user needs and specifications. Additionally, SE offers necessary competencies for effective project management. i.e. “shared leadership, social competence and emotional intelligence, communication, skills in organizational politics and the importance of visions, values, and beliefs have emerged as competencies that are required from project managers in complex environments” (Thomas and Mengel, 2008).

The foundations of SE can be traced back to 1930s, but it saw considerable growth in the 1950s when the Department of Defense DoD¹ required the delivery of military projects on time, within budget, and these critical aspects; 1) achieve long term objectives and 2) effective stakeholder management (Locatelli, Mancini and Romano, 2014).

According to (Honour, 2004) SE implementation requires about 15-20% of total project effort for optimal results. This approach has been adopted by large industries such as automobile and aerospace, as well as complex organizations like the DoD, to address organizational complexities. However, there is a basic difference between SMEs and large industries in terms of finances and human resources. Furthermore, SE is often regarded as an expensive solution in SMEs.

Despite the benefits of SE to manage complexities, there has been limited discussion in literature on SE adoption and challenges faced by SMEs in the adoption process. Researchers have investigated the behavior of stakeholders such as end-users and customers and identified three key challenges: entrepreneurial, technological, and administrative (Yanes-Estévez, García-Pérez and Oreja-Rodríguez,

¹ The Department of Defense (DoD) is an Executive Department of the United States government responsible for overseeing and coordinating all agencies and functions of the government relating to national security and Armed Forces. DoD has played a significant role in developing various management practices and tools, such as the SE, which are primarily used both in military and civil settings. These techniques can be traced back to the DoD's original research and development efforts.

2018). The adoption process of new technology at hi-tech SMEs can be influenced by the role of human resources and can present numerous challenges.

The aim of this paper is to investigate the challenges faced by SMEs and explore the field of systems engineering, to mitigate/overcome these challenges. This includes challenges may be inflicting by SE adoption/implementation at SMEs.

The structure of this paper is as follows: Initially, we describe the research methodology used for data collection. This is followed by an overview of existing literature on the challenges faced by SMEs, systems engineering competencies, and the challenges related to technology adoption. Subsequently, the findings are presented in Section 3, to highlight the gap in existing literature. Finally, we conclude by addressing the limitations of this study and providing recommendations for future research.

2. Methodology

This study employs an inductive approach (Jebreen, 2012) to investigate the challenges faced by SMEs through analysis of multiple secondary sources. The sources of information include scholarly articles, conference papers, theses, government and institutional reports, and websites.

We intend to focus on technical aspects such as: requirement elicitation and management, information management, and risk analysis to support decision making process in SMEs by considering challenges faced in design and development process. The objective is to help SMEs effectively adopt SE by considering their constraints and needs. For comprehensive understanding of challenges faced by SMEs, a study was performed by collecting and critically evaluating the sources of information to identify the most relevant and common challenges. This information is presented in the form of Mind Maps (Davies, 2011). Mind maps present visual information which is processed by humans more efficiently and effectively as compared to knowledge presented in other forms. The collected information is then subjected to an in-depth analysis using critical content analysis to find gaps in existing literature. The analysis results in the synthesis of findings into a reference model (Blessing and Chakrabarti, 2009), that highlights the most important information derived from the sources.

This paper aims to contribute to the literature on SMEs by providing insightful information on the challenges faced by SMEs and making recommendations for future research.

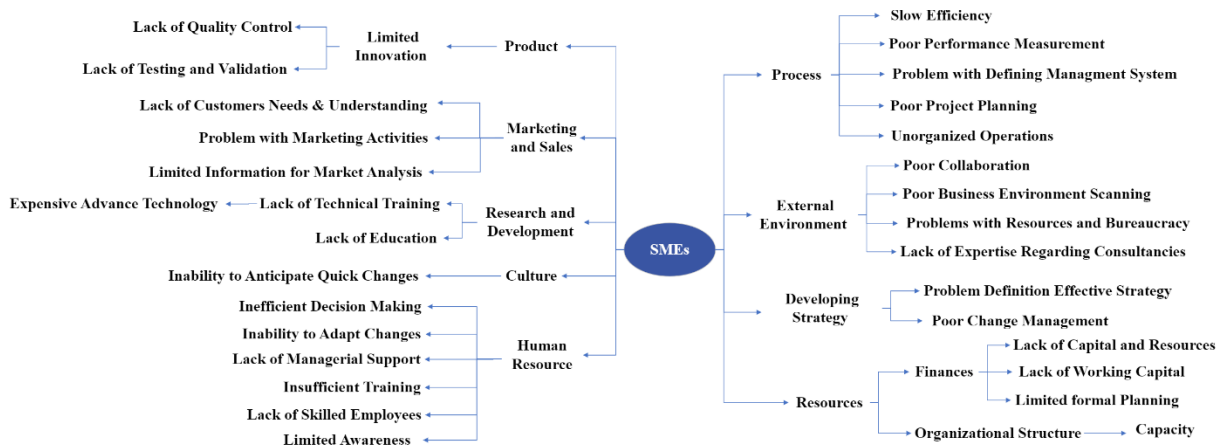
3. Research Background

3.1. Small and Medium Enterprises (SMEs)

SMEs play a key role in a country's economic and societal development. They provide employment, contribute to economic growth, and enhance competition in the market. Furthermore, added value of small and medium enterprises includes innovation, and community development (Bahri, St-Pierre and Sakka, 2011). The importance of SMEs to EU and global economic development along with wealth generation is well known (OECD, 2017).

Along with the added value, SMEs also encounter a range of challenges. These include intensified competition, swift need to adjust with market needs and requirements, increasing technological advancement, and capacity limitations regarding creativity, innovation and knowledge (Chien *et al.*, 2022). Despite the ability, SMEs often fail to achieve their full potential due to the range of factors associated with their small scale. These factors include insufficient resources such as limited finances, access to technology, shortage of skilled and experienced labor. Moreover, these enterprises also suffer from the absence of scale and scope compared to large enterprises and suffer from insufficient networks that can contribute to lack of knowledge and information, know-how and experience related to both national and international markets. The increase in globalization and economic expansion has led to increased market competition and concentration by large industries. Furthermore, SMEs find it challenging to compete with large enterprises in terms of research and development expenditure and innovation regarding organizational processes and products. Lack of entrepreneurial enthusiasm, also presents a significant obstruction to SMEs' ability to achieve full potential (Yoshino, 2016). Figure 1 represents some of these challenges related to SMEs and shows how these may lead to other aspects.

Figure:1 Challenges faced by Small and Medium Enterprises



Source: Representation by authors based on (Tiwari and Buse, 2007; Yoshino, 2016; Alessandrini *et al.*, 2019; Pelletier and Martin Cloutier, 2019; Ghobakhloo *et al.*, 2022)

3.2. Systems Engineering

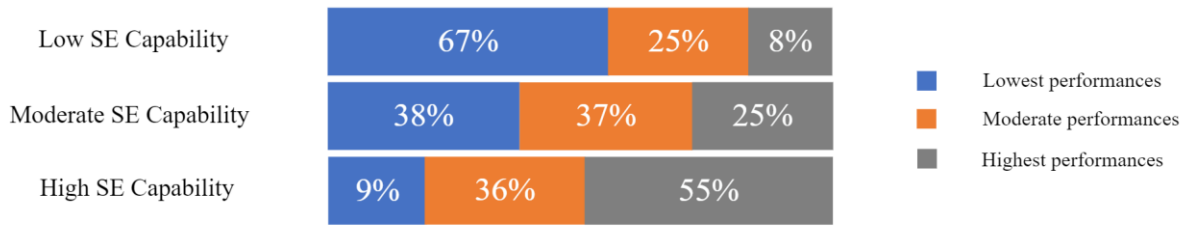
Modern organizations are threatened by a variety of challenges, including increased competition, complexity, limited time to react to changing market dynamics, scarcity of essential and skilled resources, requests for cost reductions, and a constant search for optimization. These challenges can hinder organization's ability to operate effectively and efficiently, as these require significant investment of time, money, and human resources. Therefore, organizations need to formulate strategies to address these challenges to remain competitive and sustainable in the long run. This requires an ongoing commitment to innovation, adaptability, and continuous improvement.

SE is an established field of study, and has been developed to facilitate the successful delivery of projects and systems in complex organizations and environments such as ground control stations, cockpits (Walden *et al.*, 2015). SE deals with technical aspects of system development including design, development, testing and maintenance. It provides a fundamental approach that is closely aligned with project management as it promotes a systematic and structured approach to the development process. SE emphasizes early definition of customers needs and requirements, managing requirements and information, design synthesis, and systems verification and validation. It encompasses the entirety of a systems' lifespan, from conception to retirement with an objective to optimize.

SE facilitates integration among diverse disciplines and specialized groups, leading to a collaborative team effort that establish a structured development process. Moreover, it takes into account business and technical requirements of all the customers and stakeholders with the aim of delivering high quality product that satisfy their needs and specifications (Hall, 2018). SE can be described as “big picture thinking and the application of common sense to projects” through “a structured and auditable approach to identifying requirements, managing interfaces and controlling risks throughout the project life cycle” (Cusk *et al.*, 2009). Systems engineering processes consists of two main objectives, 1) build the right system and 2) build the system right. This refers that SE focuses on the design of a system as specified and verification of the system to ensure that it effectively fulfil specifications and requirements of customers and stakeholders (Boehm, 1984).

Successful application of SE presents considerable positive impact to several segments of the organizations' effort while developing a new system. (Elm and Goldenson, 2014) and (Balslev, 2017) showed that the projects having participants with strong SE knowledge and capabilities are significantly more likely to deliver high level performance. This is achieved by a systematic and iterative approach that involves identifying and analyzing system requirements, designing, and implementing solutions, testing, and validating performance, and system optimization. Figure 2 shows that projects with high SE capabilities achieve highest performance of 55 percent as compared to just 8 percent for project with low SE capabilities.

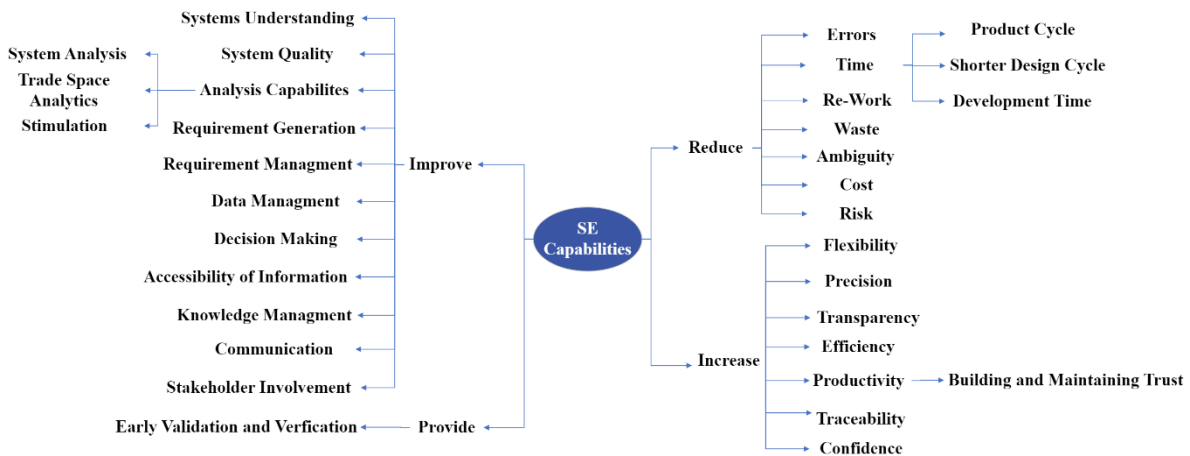
Figure 2: Impact of Systems Engineering Implementation



Source: (Elm and Goldenson, 2014; Balslev, 2017)

Systems engineering capabilities bring a number of benefits and advantages. These capabilities can help to improve organizational abilities, decrease challenges, and increase competencies in SMEs. Figure 3 represents a few SE capabilities that can be beneficial to overcome the challenges faced by SMEs.

Figure 3: Systems Engineering Capabilities



Source: Representation by authors based on (Beasley, 2017; Henderson and Salado, 2021)

Regardless of the widely acknowledged benefits of systems engineering in enhancing complexity management, small and medium-sized organizations (SMEs) have struggled to implement this approach. One of the major reasons for this is the expected significant cost associated with effective systems engineering. Along with this there are other barriers that can affect the adaptation and adoption process in SMEs such as a steep learning curve.

3.3. Adoption (Human Factors) Barriers

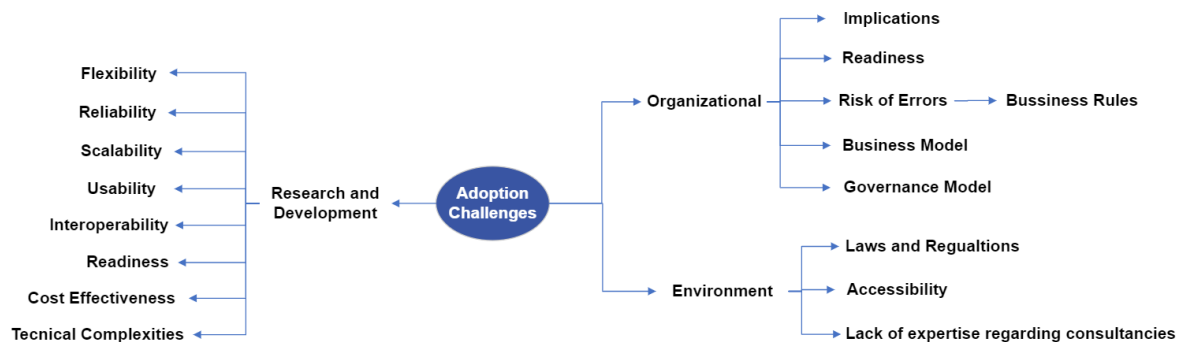
SMEs frequently experience insufficient access to financial and human resources which may hinder their ability to adopt modern technologies or solutions. Implementation of any innovative technology/solution or change in the environment brings a number of concerns for the enterprise and stakeholder involved in the adoption process. A review on organizational study observed over 20 different definitions of adoption and extracted four core characteristics: 1) adoption is generally understood to refer to introduction of a new innovation, 2) distinguish between adoption and invention, 3) adoption is both process and outcome, about a range of activities aimed at incorporating innovation and 4) often requires discontinuous change (Osborne, 1998). According to a study conducted by (Damanpour and Schneider, 2006) various researchers have categorized the innovation adoption process into multiple phases. For instance, (Hage and Aiken, 1967) identified evaluation, initiation, implementation and routinization as the stages of the adoption process. (Klein and Sorra 1996) characterized the adoption process as awareness, selection, adoption and routinization. (Zaltman *et al.*, 1973) described the adoption stages as knowledge awareness, attitude formation, decision, initial

implementation, and sustained implementation. Furthermore, study conducted by (Van de Ven *et al.*, 2000) distinguished adoption process into four stages including initiation, development, implementation and termination. Systems engineering involves a wide range of tools, techniques, processes, practices, and actions, which can be daunting for organizations with limited resources (Kossiakoff *et al.*, 2020). Furthermore, it requires a steep learning curve which can affect the adoption at SMEs.

There are several challenges to be considered while introducing a new way of working, especially if this requires changing the working environment. Most prominent challenges are environmental, technological, and organizational. Technological challenges are cited as the most significant barrier to the technology adoption at SMEs (Ghobakhloo *et al.*, 2022). Figure 4 presents a few adoption barriers that may hinder SE adoption process.

These challenges focus on the following human factors that are considered significant in research on information systems and technology. 1) perceived relative advantage of the innovation, 2) personal beliefs and values about technology, 3) perceived complexity, 4) previous experiences, 5) exposure to the technology, 6) attitude towards change and 7) communication behavior. Individual acceptance and rejections are based on these factors (Nedovic-Budic and Godschalk, 1996).

Figure 4: Adoption Hindrance in Small and Medium Enterprises



Source: Representation by authors based on (Del Aguila-Obra and Padilla-Meléndez, 2006; Khan and Qudrat-Ullah, 2021; Ghobakhloo *et al.*, 2022)

4. Discussion

In this work we present the challenges that may appear at SMEs at various levels and phases of the product or systems life cycle. To demonstrate this, we used the mind map technique (Guerrero and Ramos, 2015), that helps to visualize relations among various aspect of a factor. This way, the objectives of the study can be seen better. The perspectives presented here are derived from researchers' viewpoint based on analysis of existing literature and identification of gaps within the problem and solution domains. Figure 5 shows the concept map related to impact of SE introduction to the challenges faced by SMEs and why SE support needs adoption perspective in this context.

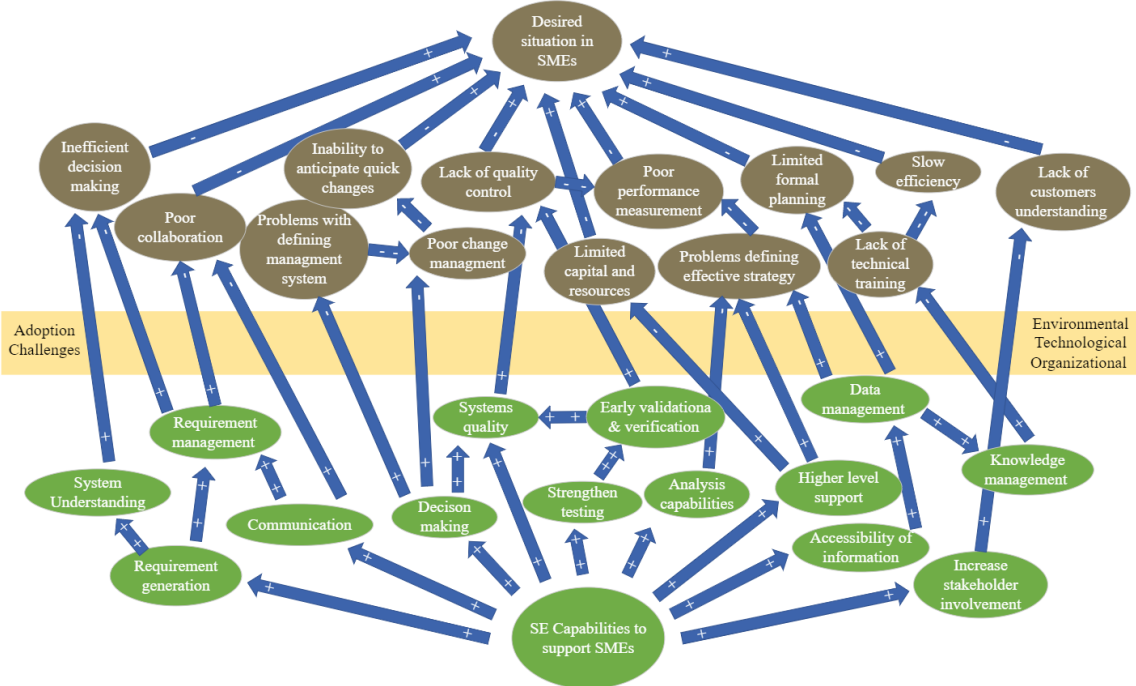
For better understanding of the situation and working conditions related to SMEs, literature exploration was done, and the extracted information shows the challenges that are faced by these enterprises and how these challenges are impacting the working environment of SMEs. Figure 1 presents these challenges and categorized into different sections such as challenges faced by external environment factors, research and development, related to product and organizational processes etc. For example, *resources*: due to limited finances of SMEs has less capital which has a negative effect on the working capital, and this leads to the scarcity of skilled employees. This affects the decisions capability in organization or on-going project. SMEs are not the only businesses who faces this problem, some of these problems are common in large industries as well. Due to limited resources and other constraints, these challenges are becoming more prominent and require a systematic solution to the problem as failure of one project can be fatal in context of SMEs.

Systems engineering is employed by large industries to manage complexities and we propose to introduce it in SMEs to overcome the challenges faced by them. Figure 3 presents some of the

capabilities that may be helpful to overcome the challenges appearing in these enterprises. To demonstrate a potential impact of SE solution, we select a challenge from SMEs for instance *poor performance measurement*. SE capabilities offer enhanced testing protocol that enables early validation and verification during product life cycle. Similarly, with the dominos effect of same problem, if a firm faces a challenge regarding increase in poor performance that may lead to problems with quality control, SE offers better product quality and better analysis capabilities to maintain good product quality.

The review of literature reveals that systems engineering implementation can provide SMEs with numerous benefits. Regardless of the evident benefits SE can offer to SMEs, there are only a few examples where SMEs are adopting SE. Authors believe that the steep learning curve of SE at very initial phases and expected high investment are some of the few factors that make it difficult.

Figure 5: Impact of Systems Engineering to SMEs Challenges



Source: Authors own representation

This study took into consideration the limitations of SMEs and looked at this problem from a different perspective. We proposed to include the adopters (human at SMEs) perspective to the problem definition and potential solution support that may lower the adoption learning curve and minimize the initial investment cost as given by (Honour, 2010). Studies mentioned in adoption challenges highlight several adoption challenges regarding new technologies and innovations that can hinder the SE implementation in the working environment. These challenges are divided into three categories, see figure 4, those may need to be considered while introducing solution support by considering problem domain. Figure 5 represents a concept map that will be used as reference model. This was developed on the basis of most important challenges and the reflection of SE capabilities to minimize SMEs challenges. The model also refers towards the adoption challenges as noise which may present as hurdles in SE adoption process. This study proposes a further investigation to design a support to overcome SMEs contemporary situations, by considering the adoption perspective related to human aspect in both problem and solution domain.

5. Conclusion & Future Work

This study brings insights on the challenges faced by SMEs and presents systems engineering as a potential solution to overcome these obstacles. We presented the potential benefits from literature towards SE introduction in SMEs. A further investigation was conducted to explore potential hindrances to the possible solution in this context. Three mind maps were developed for each aspect: SMEs challenges, SE capabilities and adoption challenges. These mind maps converge into a concept map that highlights the impact of potential solution and shows how SE adoption may have promising influence on SMEs working environment. It shows that systems engineering adoption in SMEs impact positively and will help to overcome number of challenges including requirement and knowledge management, and testing and validation related to design and development processes.

The study presents certain limitations, it is based on secondary sources and shows our position in this regard. Future work will present how SMEs potentially see systems engineering as a solution to their problems and hurdles. We will evaluate the findings from SMEs to cover both perspectives; systems engineering as a solution and to overcome adoption challenges from human factors context. Our goal is to complete the first task and develop support to introduce systems engineering. SMEs from different technical capabilities (such as electronic and medical device development and food processing) will be recruited to evaluate the results on a broad range of enterprises.

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ERP SYSTEM AS A SOURCE OF DATA FOR PREDICTING OPERATIONAL INDICATORS USING ARTIFICIAL INTELLIGENCE METHODS

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Abstract

The article shows an overview of the standard functions of the ERP (Enterprise Resource Planning) information system in manufacturing companies and deals with the ERP system data for the optimization of reliability, management and product quality process. A comprehensive approach to data collection, processing and their storage in the ERP system (cloud storage, data warehouses) is necessary for successful management of the production process. By using advanced statistical and artificial intelligence methods (neural networks, trees, logistic regression), it is possible to analyze the data and obtain additional knowledge and dependencies in the data. The application part of the article presents the prediction of reliability indicators. From the ERP system database, the data set of a time to failure has been obtained. This data for the creation of a parametric model, based on Weibull distribution, has been used. The article demonstrates the application of artificial neural networks for the prediction of reliability indicators, and a parametric model based on the Weibull distribution has been created from the input data.

Keywords: Clouds, Enterprise Resource Planning, Neural Networks, Operational Indicator, Weibull Distribution. Reliability

JEL codes: C14, C15, C45, C63, C67

1. ERP system as a data source for operational indicators prediction

Every organization, manufacturing company or state institution produces a large amount of data in its information systems, mostly as a result of economic, logistical, operational or production processes. The effectiveness of the operation and provision of information to different company levels determines the effectiveness of the entire information system in the company. Efforts to increase the efficiency is usually the reason for the introduction or innovation of a corporate ERP system (Vymětal

2009). The ERP system (Enterprise Resource Planning) is an integrated software system to support the planning and management of all the main processes of the company (Slaninová, Vymětal 2023).

Figure 1: ERP system (Enterprise Resource Planning)



Source: Author

In the recent past, ERP systems and information systems were generally deployed exclusively on their own equipment (own hardware, own servers - solution called: on-premise). This means that not only the own system, but also the databases were operated locally at the customer, which meant own responsibility for security, service, licenses. Currently, with the development of the Internet and remote access to applications, cloud access has become widespread. The ERP system itself is usually managed by the provider on its devices, and the customer only remotely connects to this system via the Internet (usually via a web interface). The cloud services can be provided at different levels, e.g., IaaS (Infrastructure as a Service), PaaS (Platform as a Service), or SaaS (Software as a Service). It is also possible to use a public cloud (shared by several users) or a private cloud (a more common variant for ERP systems). These ERP application methods can be combined in various ways by deploying part of the system at the customer with private/public cloud access. In this case, we talk about a hybrid cloud. Often, the customer deploys a cloud solution on their own servers to, for example, have more control over sensitive data, and shares access with other branches of the company through cloud access. Companies also often pay to host their cloud environment. After the rapid onset of cloud solutions, the situation on the market is now stabilized and, according to Panorama Consulting (2022), cloud solutions already occupy approximately 65% of the market, compared to on-premise data storage solutions of ERP systems (Slaninová, Vymětal 2023).

The mentioned method of data storage in the centralized database of the ERP system is advantageous for various analyzes of the collected data. The data in the database is cleaned, structured and quickly available in the form of reports. For example, production planning, production management, reliability and maintenance management systems are implemented in the ERP system in manufacturing companies.

The system should provide information of repair planning, equipment revisions, repair and preventive maintenance costs. An effective reliability and maintenance management system is based on feedback. The feedback function can be performed by a data collection system that provides information to control of reliability at all stages of the life cycle, supplemented by a diagnostic system. The system

must allow access to stored reliability data, effective statistical prediction, other quantitative and qualitative methods, and models suitable for prediction, analysis, and estimation of reliability indicators (David, et al, 2013).

Determining, modeling and prediction of reliability indicators, requires operational field data of tasks, errors, downtimes, or failures. Typical reliability indicators as failure rate, probability of failure or repair time from the field data will be calculated (David, et al, 2012).

From the ERP system database, the data set of a time to failure has been obtained. This data for the creation of a parametric model, based on Weibull distribution, has been used. The Weibull distribution has a large variability, and due this reason is very often used as a theoretical model for statistic modeling of reliability of mechanical and electronic components or entire systems. The Weibull distribution probability density is described by equation (1) and distribution function by equation (2).

$$f(t) = \frac{m}{t_0} \cdot \left(\frac{t}{t_0}\right)^{m-1} \cdot \exp\left[-\left(\frac{t}{t_0}\right)^m\right] \quad (1)$$

$$F(t) = 1 - e^{-\left(\frac{t}{t_0}\right)^m} \quad (2)$$

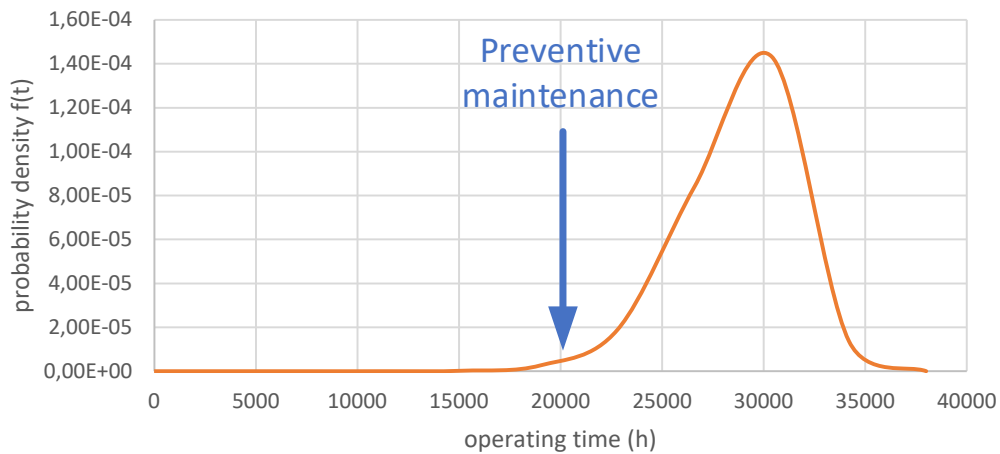
$$v_k = \frac{s}{\bar{x}} \quad (3)$$

Where:

t	–	operational time [h],
m	–	shape parameter [-],
t ₀	–	scale parameter [h],
\bar{x}	–	mean [h],
s	–	standard deviation [-],

The utilization of the Weibull probability distribution is conditioned by the estimation of both parameters, the shape parameter and the scale parameter. The parameters estimation is based on the operating time between failures of the monitored device or component, obtained from the ERP system. If both parameters are known, it is possible to model the course of reliability, for example, of a rolling bearing (see Figure 2).

Figure 2: Reliability of a rolling bearing (preventive bearing replacement time in graph is indicated)



Source: Author

It is clear from the course of the probability density $f(t)$ in Figure 2, that the number of failures will be very low for a certain period of operation. Due to wear and tear, after approx. 20,000 hours of operation, the number of failures starts to rise steeply, the maximum will be around 30,000 hours. However, if we replace the bearing as a preventive measure, the number of failures will significantly decrease with a positive impact on the reliability of the entire device.

To estimate the parameters, it is possible to use several methods based on different procedures, e.g., the method using linear regression (Famfulik, 2017), the maximum likelihood method (Grencik, 2021). All methods, however, use analytical procedures. The next part of the article describes an innovative parameter estimation method using a neural network.

2. Neural network processing of Weibull data

The data files were processed by machine learning of the neural network, where the processed data was divided into sets and the performance of the network was monitored in the individual stages of data set processing. The goal of performance tracking was not maximizing network performance on training data but a reasonable compromise between training performance and the ability to generalize knowledge on new data. The data must be sensitively divided into three sets, namely the training, test and possibly validation set. In practice, the set ratio is set at 50-25-25 or 70-15-15, respectively. Results are then reported for each of the sets. Subsequently, a network is selected from the network collection, which does not have very large fluctuations between the outputs of the individual sets.

Training Set - Randomly selected part of the data that is used to teach the network. This largest set directly contains patterns for use in the learning process. Depending on these patterns, scales are adjusted and their best configurations are sought. There may be a crash monitoring during training to find the best number of training steps.

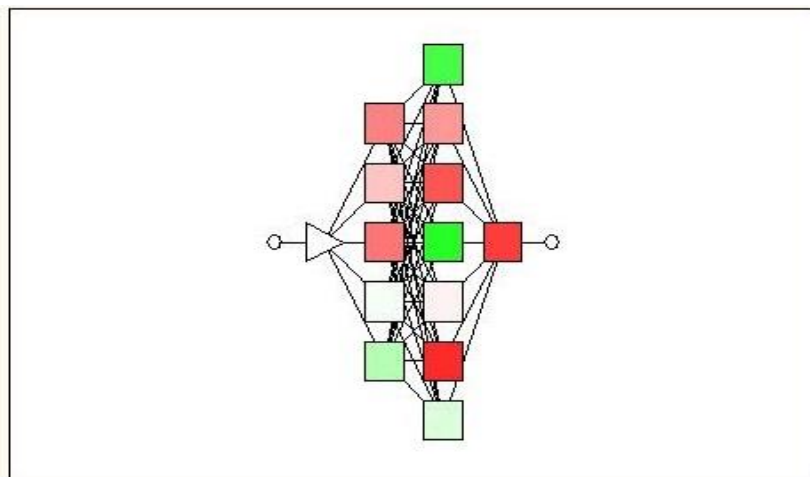
Test set - to verify network traction, including its generalization capability, it stops training to avoid network tracing. The test set does not participate in the learning process.

Validation set - a part of the data on which the neural network verifies the final quality of the neural network model and properties. This data sample has not yet been available for the neural network. The validation set participates in network training, with the test set providing an estimate of network properties on unknown data.

Ideally, the total network error converges to zero, which is considered to be a 100% training result in the training set, while the network error in the test set first decreases and then increases. The state of the minimal error on the test set is the optimal moment for learning termination, since from this point onwards the network loses its ability to generalize and is too fixed to the training set and becomes overlearned.

Figure 3 Topology of the best neural network.

Network type: VVPS 1:1-5-7-1:1, Training performance = 0,139047, validation performance = 0,065299, test performance = 0,215393.



Source: Author, Software STATISTICA

3. Neural network design

The coefficient of variation was selected as input data and the shape parameter as output. With the established minimum data sample of data – 11 data batches of 2 variables, the data was modified in the form of a table of input and output variables. (Barčák, 2016)

The statistical methods and tests are used for validation and evaluation of machine learning models and machine learning algorithms (Witten, 2011). The regression method was chosen as the most appropriate statistical method. Data processing using the regression method makes it possible to predict a continuous output based on continuous predictors. As a training data set, data from an MS Excel spreadsheet was used and this data were transposed in the STATISTICA software. A validation data set also has been defined and similarly a test data set has been defined to verify the learning results of the neural network. The training, validation and test data were used in the proportions 57-27-27, 71-20-20, 81-15-15 for the tested multilayer neural networks.

For each given ratio of sets, the selection of groups for individual trained networks was determined. Two types of data sampling were selected, namely: One random selection, the same for all networks, and repeated sampling, random for each network. The result of unknown sequences of data processing is the output of a neural network, which determines the shape parameters based on the coefficients of variation. The resulting best STATISTICA networks had excellent and very good performance. (Barčák, 2020)

From the offered solutions, the best neural network has been selected. It is a simple multilayer network, a four-layer perceptron neural network with a topology of 1 - 5 - 7 - 1. A graphic representation of the topology of this neural network is shown in Figure 3. This neural network for the prediction of the Weibull distribution parameters has been used. (Barčák, 2016)

Figure 4 Results of the Neuron Network shape prediction results.

	Prom2	Prom2.1	Prom2.2	Prom2.3	Prom2.4	Prom2.5
1	9,74084	9,70205	9,50745	10,39327	9,92164	10,12635
2	10,18896	9,92181	10,63017	10,84436	10,55419	10,71159
3	11,40655	10,00797	10,94669	11,03271	10,87339	10,96120
4	12,84059	10,08418	11,23542	11,20526	11,26351	11,19218
5	11,65127	9,91964	10,62158	10,83969	10,54718	10,70544
6	11,17481	9,88116	10,46240	10,75783	10,42872	10,59790
7	9,74084	9,85487	10,34478	10,70264	10,35226	10,52572
8	9,74084	10,07689	11,20485	11,18850	11,21999	11,16966
9	11,21510	10,13842	11,50492	11,33164	11,64105	11,36261
10	9,52875	9,87661	10,44258	10,74824	10,41527	10,58533
11	10,78435	9,90634	10,56818	10,81124	10,50513	10,66800
12	9,62823	9,90840	10,57657	10,81564	10,51156	10,67379
13	10,97784	9,71176	9,56809	10,41237	9,95003	10,15074
14	14,59499	10,33652	14,41414	11,82077	14,35913	12,02935
15	11,08018	9,99602	10,90431	11,00617	10,82306	10,92586
16	10,89690	9,87304	10,42689	10,74073	10,40480	10,57550
17	14,02597	10,32837	14,17683	11,79974	14,18606	12,00053
18	9,58274	9,78348	9,98592	10,55576	10,15278	10,33497
19	11,14103	10,07457	11,19532	11,18318	11,20645	11,16251
20	11,28644	10,16110	11,64982	11,38541	11,83207	11,43539
21	0,87723	0,91690	0,95416	1,02089	0,91604	0,95605
22	0,58338	0,79044	0,66996	0,76703	0,64466	0,67605
23	0,60853	0,70114	0,75508	0,87822	0,78229	0,76787
24	0,78876	0,91694	0,95360	1,02044	0,91620	0,95530
25	0,39368	0,58224	0,65069	0,70619	0,63349	0,63897
26	5,31105	6,80678	5,17885	6,50063	5,14084	6,00012
27	5,51415	6,48884	5,38527	6,17913	5,44938	5,72818

Source: Author, Software STATISTICA

The Weibull distribution shape parameter values were predicted in the resulting reports., The reliability indicators of the technical object can be successfully predicted by the correct neural network parameters settings. In this way, the neural network application possibility to the given problem has been verified. Figure 4 shows the results of shape parameter prediction by the best neural network, represented by column Prom2.2.

In the next phase, the performance of selected types of neural networks has been monitored. The different input ratio of training, validation and test sets in the two data samples selection and allocation phases have been used. The STATISTICA software provided the best topologies and performances of the different types of networks that have been practicing multi-level training. The performances of the selected best networks have been collected in table and subsequently analyzed and compared. The performance of neural networks is shown in Figure 5. (Barčák, 2016)

Figure 5 Neural network performance.

Network type	Performance			Error			Training /Networks	TRAIN-VAL-TEST	Select groups for individual trained networks
	Training	Validation	Testing	Training	Validation	Testing			
ZRNS 1:1-57-2-1:1	0.2558	0.1312	0.1715	0.0635	0.0293	0.0364	SS	57-27-27	One random selection is the same for all networks
RBF 1:1-16-1:1	0.0953	0.1016	0.0633	0.0236	0.0226	0.0125	KM.KN.PI	57-27-27	One random selection is the same for all networks
VVPS 1:1-3-1:1	0.1714	0.0948	0.1186	0.0386	0.0191	0.0214	ZŠ100.SG43b	57-27-27	One random selection is the same for all networks
RBF 1:1-19-1:1	0.0967	0.0838	0.0709	0.0240	0.0186	0.0140	KM.KN.PI	57-27-27	One random selection is the same for all networks
VVPS 1:1-5-4-1:1	0.1516	0.0824	0.0674	0.0341	0.0171	0.0140	ZŠ100.SG50b	57-27-27	One random selection is the same for all networks
RBF 1:1-7-1:1	0.1075	0.1172	0.1930	0.0339	0.0473	0.0906	KM.KN.PI	71-20-20	One random selection is the same for all networks
RBF 1:1-8-1:1	0.0872	0.0968	0.1798	0.0275	0.0398	0.0840	KM.KN.PI	71-20-20	One random selection is the same for all networks
ZRNS 1:1-71-2-1:1	0.1021	0.0539	0.2584	0.0322	0.0219	0.1209	SS	71-20-20	One random selection is the same for all networks
VVPS 1:1-5-1:1	0.1251	0.0854	0.2117	0.0253	0.0213	0.0630	ZŠ100.SG64b	71-20-20	One random selection is the same for all networks
VVPS 1:1-5-7-1:1	0.1390	0.0652	0.2153	0.0294	0.0199	0.0638	ZŠ100.SG21b	71-20-20	One random selection is the same for all networks
ZRNS 1:1-81-2-1:1	0.1017	0.1038	0.2716	0.0313	0.0390	0.1485	SS	81-15-15	One random selection is the same for all networks
RBF 1:1-10-1:1	0.0816	0.0923	0.1726	0.0251	0.0355	0.0970	KM.KN.PI	81-15-15	One random selection is the same for all networks
RBF 1:1-11-1:1	0.0820	0.0907	0.1663	0.0252	0.0348	0.0927	KM.KN.PI	81-15-15	One random selection is the same for all networks
VVPS 1:1-8-4-1:1	0.1116	0.1047	0.2356	0.0256	0.0288	0.0967	ZŠ100.SG55b	81-15-15	One random selection is the same for all networks
VVPS 1:1-8-7-1:1	0.1013	0.0973	0.2273	0.0231	0.0270	0.0937	ZŠ100.SG36b	81-15-15	Repeated. for each network random selection
ZRNS 1:1-57-2-1:1	0.6996	0.6962	0.7293	0.1582	0.1236	0.1284	SS	57-27-27	Repeated. for each network random selection
VVPS 1:1-4-1:1	0.1629	0.1350	0.1258	0.0371	0.0240	0.0244	ZŠ100.SG31b	57-27-27	Repeated. for each network random selection
VVPS 1:1-5-1:1	0.1604	0.1247	0.1748	0.0343	0.0239	0.0366	ZŠ100.SG99b	57-27-27	Repeated. for each network random selection
RBF 1:1-13-1:1	0.1010	0.0977	0.1130	0.0242	0.0191	0.0192	KM.KN.PI	57-27-27	Repeated. for each network random selection
RBF 1:1-14-1:1	0.0775	0.0518	0.1474	0.0190	0.0066	0.0366	KM.KN.PI	57-27-27	Repeated. for each network random selection
ZRNS 1:1-71-2-1:1	0.6286	0.5389	0.6234	0.1628	0.1090	0.1654	SS	71-20-20	Repeated. for each network random selection
RBF 1:1-5-1:1	0.2436	0.1637	0.1936	0.0702	0.0611	0.0698	KM.KN.PI	71-20-20	Repeated. for each network random selection
RBF 1:1-6-1:1	0.1915	0.1682	0.1647	0.0473	0.0285	0.0320	KM.KN.PI	71-20-20	Repeated. for each network random selection
VVPS 1:1-3-1:1	0.1504	0.1320	0.1253	0.0343	0.0252	0.0216	ZŠ100.SG48b	71-20-20	Repeated. for each network random selection
VVPS 1:1-4-1:1	0.1365	0.0763	0.1751	0.0382	0.0189	0.0327	ZŠ100.SG124b	71-20-20	Repeated. for each network random selection
RBF 1:1-8-1:1	0.1313	0.0761	1.8655	0.0346	0.0221	0.3206	KM.KN.PI	81-15-15	Repeated. for each network random selection
VVPS 1:1-6-1:1	0.1471	0.1048	0.1536	0.0398	0.0219	0.0395	ZŠ100.SG202b	81-15-15	Repeated. for each network random selection
VVPS 1:1-4-3-1:1	0.1273	0.0614	0.2190	0.0248	0.0151	0.0621	ZŠ100.SG53b	81-15-15	Repeated. for each network random selection
ZRNS 1:1-81-2-1:1	0.1747	0.0713	0.1158	0.0445	0.0134	0.0284	SS	81-15-15	Repeated. for each network random selection
RBF 1:1-10-1:1	0.0925	0.1083	0.1488	0.0245	0.0126	0.0461	KM.KN.PI	81-15-15	Repeated. for each network random selection

Source: Author, Software STATISTICA

The evaluation of the performance of neural networks and evaluation of the best resulting errors of the processed data sample, shows that the best results were obtained when the average ratio of the data to the set has been used. In this specific case, the ratio was 71 - 20 - 20. (Barčák, 2016)

4. Conclusion

The aim of this article is to introduce ERP system as a data source for prediction of the reliability indicators using neural network The intention was to verify the possibility of predicting the Weibull distribution parameters with satisfactory accuracy. Furthermore, it was verified that on a particular data set it is possible to determine the optimal topology of the neural network, suitable for processing of large data samples with the same structured data.

This conclusion provides a new possibility of using neural networks in the field of reliability and maintenance of technical objects.

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AN ALGORITHM TO COMPUTE A JOINT PRIORITY VECTOR OF PAIRWISE COMPARISON MATRICES WITH FUZZY ELEMENTS IN GROUP DECISION MAKING

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Abstract

We study the problem how to aggregate different opinions of m decision makers who evaluate n objects with respect to a criterion into a single opinion of the group. In particular, each of the m decision makers evaluates the n objects pairwise with respect to the given criterion. In order to unify various approaches, we assume that the decision makers use the elements of an Abelian linearly ordered group (alo-group) to assess the relative importance of the two items in each pair of the n objects. Moreover, a decision maker (DM) can use a fuzzy subset of the alo-group to assess the relative importance whenever the DM is uncertain about the exact value of the assessment. Thus, the task is to compute a joint priority vector of m given $n \times n$ reciprocal pairwise comparison matrices with fuzzy elements, i.e. fuzzy subsets of an alo-group. In this paper, we consider several desirable properties of the priority vector – consistency, intensity, and coherence – and we propose a new algorithm to compute priority vectors satisfying these desirable properties.

Keywords: multi-criteria group decision making, fuzzy pairwise comparison matrix, joint priority vector, consistency, intensity, coherence, alo-group, Analytic Hierarchy Process (AHP)

JEL codes: C60, C65, D79

1. Introduction

Entrepreneurs, as well as small and medium-sized enterprises (SMEs), frequently need to deal with various multi-criteria decision making (MCDM) problems, e.g., when acquiring new equipment (such as cars, machines, furniture, etc.), assessing investment opportunities, evaluating and improving the services they provide, and so on. Popular methods to solve such MCDM problems include the Analytic Hierarchy Process (AHP) and pairwise comparisons. Moreover, the computers, tablets, smartphones and other computing devices have spread among entrepreneurs and SMEs during the past two decades. Consequently, the popular methods are implemented on computers and the software has become easily available, see Górecki (2023) in these proceedings.

The Analytic Hierarchy Process (AHP) is a popular and powerful tool to solve multi-criteria decision making problems (Saaty, 1980). We consider the following main subproblem of the AHP, which is to be solved in every internal node of the hierarchy; that is, a node having some subnodes. Let n denote the number of these subnodes, which correspond to n objects c_1, c_2, \dots, c_n , i.e. criteria, subcriteria, and/or alternatives (variants). Notice that the internal node corresponds to some criterion, subcriterion, and/or the goal of the hierarchy. Henceforth, we shall use the single term criterion for simplicity. Given the information on the relative importance of the two items in each pair of the objects

with respect to the given criterion (subcriterion, and/or the goal) in the form of an $n \times n$ pairwise comparison matrix A , the purpose is to calculate the priority vector, which is a vector of n weights v_1, v_2, \dots, v_n assigned to the n objects c_1, c_2, \dots, c_n , respectively. The prominent methods to calculate the priority vector include Saaty's Eigenvector Method (EVM) and the Geometric Mean Method (GMM), see Saaty (1980) and Ramík (2020). The priority vector provided by these methods, however, usually do not satisfy desirable properties – consistency, intensity, and/or coherence, in particular – see Saaty and Vargas (1984), D'Apuzzo et al. (2007), and Bana e Costa and Vansnick (2008).

Additionally, the decision maker may not be sure about the exact value of the relative importance of objects c_i and c_j with respect to the given criterion for $i, j = 1, 2, \dots, n$. It is then appropriate, instead of the exact, i.e. crisp, value a_{ij} , to use fuzzy value \tilde{a}_{ij} , which captures the decision maker's uncertainty and represents the decision maker's (fuzzy) opinion how many times c_i is better or more important than c_j with respect to the given criterion for $i, j = 1, 2, \dots, n$.

Based on these premises, the authors have proposed a new algorithm for computing priority vectors, satisfying desirable properties, of an $n \times n$ fuzzy pairwise comparison matrix \tilde{A} , see Bartl and Ramík (2022).

In this paper, we consider the above main subproblem extended as follows. There are m decision makers (evaluators), and each of them assesses the relative importance of the two items in each pair of the objects with respect to the given criterion in a fuzzy way to capture the decision makers' uncertainty. The fuzzy element \tilde{a}_{ij}^k represents the k -th decision maker's (fuzzy) opinion how many times c_i is better or more important than c_j with respect to the given criterion for $i, j = 1, 2, \dots, n$ and for $k = 1, 2, \dots, m$. We obtain $n \times n$ fuzzy pairwise comparison matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ thus. Our purpose is to improve and extend the authors' new algorithm (Bartl and Ramík, 2022) to this case; that is, our purpose is to compute the priority vector of n weights v_1, v_2, \dots, v_n assigned to the n objects c_1, c_2, \dots, c_n , respectively, yet satisfying the aforementioned desirable properties.

2. Preliminaries and notation

In order to unify and generalize various approaches known from the literature, we use the elements of an Abelian linearly ordered group to evaluate the relative importance of the two items in each pair of the objects with respect to the given criterion, see Cavallo and D'Apuzzo (2009) and Ramík (2015). Recall that an *Abelian group* is a pair (G, \odot) where G is a non-empty set and \odot is a commutative and associative binary operation on G satisfying also the existence of the identity element $e \in G$ and the existence of the inverse element $a^{(-1)} \in G$ for each $a \in G$. We then have $a \odot e = a$ and $a \odot a^{(-1)} = e$ for every $a \in G$. We also put $a \div b = a \odot b^{(-1)}$ for all $a, b \in G$. An *Abelian linearly ordered group (alo-group)* is a triple (G, \odot, \leq) such that (G, \odot) is an Abelian group and \leq is a binary relation of linear ordering on G such that $a \leq b$ implies $a \odot c \leq b \odot c$ for all $a, b, c \in G$. The well-known examples of alo-groups are the Multiplicative alo-group $\mathcal{R}_+ = (\mathbb{R}_+, \cdot, \leq)$ with the usual multiplication and the neutral element $e = 1$, the Additive alo-group $\mathcal{R} = (\mathbb{R}, +, \leq)$ with the usual addition and the neutral element $e = 0$, and the Fuzzy Multiplicative alo-group $\mathcal{F}_{]0;1[} = (]0; 1[, \odot, \leq)$ with $a \odot b = ab / (ab + (1 - a)(1 - b))$ for $a, b \in]0; 1[$ and the neutral element $e = \frac{1}{2}$, see Cavallo and D'Apuzzo (2009), Ramík (2015), and Ramík (2020).

A *fuzzy subset* S of the non-empty set G (or a *fuzzy set* on G) is a family $\{S_\alpha\}_{\alpha \in]0;1]}$ of subsets of G such that $S_0 = G$, and $S_\beta \subseteq S_\alpha$ whenever $0 \leq \alpha \leq \beta \leq 1$, and also $S_\beta = \bigcap_{0 \leq \alpha < \beta} S_\alpha$ whenever $0 < \beta \leq 1$. The *membership function* of S is the function μ_S from G into the unit interval $]0; 1]$ defined by $\mu_S(x) = \sup\{\alpha \mid x \in S_\alpha\}$. Given an $\alpha \in]0; 1]$, the set $[S]_\alpha = \{x \in G \mid \mu_S(x) \geq \alpha\}$ is called the *α -cut of the fuzzy set S* . We say that a fuzzy subset S of G is a *fuzzy interval* whenever S is normal, closed, bounded, and convex; that is, for every $\alpha \in]0; 1]$, there exist two elements $a^L(\alpha), a^R(\alpha) \in G$ such that $a^L(\alpha) \leq a^R(\alpha)$ and the α -cut $[S]_\alpha = \{x \in G \mid a^L(\alpha) \leq x \leq a^R(\alpha)\}$. We refer the reader to Ramík (2020) for further details.

3. Desirable properties of the priority vector

Let us consider an alo-group $\mathcal{G} = (G, \odot, \leq)$ and let us denote the set of the first n positive

natural numbers by \mathcal{N} ; that is, we put $\mathcal{N} = \{1, 2, \dots, n\}$. Considering the set $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$, let $\tilde{A} = \{\tilde{a}_{ij}\}$ be an $n \times n$ matrix such that each of its element \tilde{a}_{ij} is a fuzzy interval of G and evaluates the relative importance of the objects c_i and c_j with respect to the given criterion. Let $\alpha \in [0; 1]$, and let $[\tilde{a}_{ij}]_\alpha = [a_{ij}^L(\alpha); a_{ij}^R(\alpha)]$, with $a_{ij}^L(\alpha), a_{ij}^R(\alpha) \in G$ and $a_{ij}^L(\alpha) \leq a_{ij}^R(\alpha)$, be the α -cut of \tilde{a}_{ij} for $i, j \in \mathcal{N}$. The matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ is said to be α -reciprocal if the following two conditions hold for each $i, j \in \mathcal{N}$:

$$a_{ii}^L(\alpha) = a_{ii}^R(\alpha) = e, \quad \text{and} \quad a_{ij}^L(\alpha) \odot a_{ji}^R(\alpha) = e. \quad (1)$$

If $\tilde{A} = \{\tilde{a}_{ij}\}$ is α -reciprocal for every $\alpha \in [0; 1]$, then it is called *reciprocal*. If $\tilde{A} = \{\tilde{a}_{ij}\}$ is reciprocal, then $\tilde{A} = \{\tilde{a}_{ij}\}$ is called a *fuzzy pairwise comparison matrix*, or *FPC matrix* for short.

Then the result of a pairwise comparison method based on the FPC matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ is a vector $v = (v_1, v_2, \dots, v_n)$ of the weights $v_1, v_2, \dots, v_n \in G$ of the objects $c_1, c_2, \dots, c_n \in \mathcal{C}$, respectively. In other words, the i -th component v_i of the priority vector v is the weight of the object c_i for $i \in \mathcal{N}$. We say the priority vector $v = (v_1, v_2, \dots, v_n)$ is *normalized* if $\odot_{i=1}^n v_i = e$.

Based upon the ideas that have already appeared in the literature (Saaty and Vargas, 1984, Bana e Costa and Vansnick, 2008, D'Apuzzo et al., 2007, and Kułakowski, 2015), we extend the notions of desirable properties to the fuzzy case as follows, cf. Bartl and Ramík (2022, Definition 6.1).

Definition 1. Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, be a priority vector, let $\alpha \in [0; 1]$, and let $[\tilde{a}_{ij}]_\alpha = [a_{ij}^L(\alpha); a_{ij}^R(\alpha)]$ be the α -cut of \tilde{a}_{ij} .

- (i) We say that the vector v is an α -consistent vector (α -CsV) of the FPC matrix \tilde{A} if the following condition holds:

$$a_{ij}^L(\alpha) \leq v_i \div v_j \quad \text{for all } i, j \in \mathcal{N}. \quad (2)$$

Moreover, the vector v is a *consistent vector* (CsV) of the FPC matrix \tilde{A} if condition (2) holds for all $\alpha \in [0; 1]$. If there exists an α -consistent vector or consistent vector of the FPC matrix \tilde{A} , then \tilde{A} is called an α -consistent FPC matrix or consistent FPC matrix, respectively.

- (ii) We say that the vector v is an α -intensity vector (α -InV) of the FPC matrix \tilde{A} if the following condition holds:

$$a_{ij}^L(\alpha) > a_{kl}^R(\alpha) \quad \text{implies} \quad v_i \div v_j > v_k \div v_l \quad \text{for all } i, j, k, l \in \mathcal{N}. \quad (3)$$

Moreover, the vector v is an *intensity vector* (InV) of the FPC matrix \tilde{A} if condition (3) holds for all $\alpha \in [0; 1]$. If there exists an α -intensity vector or intensity vector of the FPC matrix \tilde{A} , then \tilde{A} is called an α -intensity FPC matrix or intensity FPC matrix, respectively.

- (iii) We say that the vector v is an α -coherent vector (α -CoV) of the FPC matrix \tilde{A} if the following condition holds:

$$a_{ij}^L(\alpha) > e \quad \text{implies} \quad v_i > v_j \quad \text{for all } i, j \in \mathcal{N}. \quad (4)$$

Moreover, the vector v is a *coherent vector* (CoV) of the FPC matrix \tilde{A} if condition (4) holds for all $\alpha \in [0; 1]$. If there exists an α -coherent vector or coherent vector of the FPC matrix \tilde{A} , then \tilde{A} is called an α -coherent FPC matrix or coherent FPC matrix, respectively.

Remark 1. Notice that by the reciprocity property (1) it is easy to see that $v = (v_1, v_2, \dots, v_n)$ is an α -consistent vector of the FPC matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ if and only if

$$a_{ij}^L(\alpha) \leq v_i \div v_j \leq a_{ij}^R(\alpha) \quad \text{for all } i, j \in \mathcal{N}. \quad (5)$$

The following result, the proof of which can be found in Bartl and Ramík (2022, Proposition 6.4), turns out to be useful.

Proposition 1. Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $\alpha \in [0; 1]$, and let $[\tilde{a}_{ij}]_\alpha = [a_{ij}^L(\alpha); a_{ij}^R(\alpha)]$ be the α -cut of \tilde{a}_{ij} . A priority vector $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, satisfies

$$a_{ij}^L(\alpha) \div a_{kl}^R(\alpha) \leq (v_i \div v_j) \div (v_k \div v_l) \quad \text{for all } i, j, k, l \in \mathcal{N} \quad (6)$$

if and only if v is an α -consistent vector of the FPC matrix \tilde{A} .

4. Measuring desirable properties of priority vectors

Given an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $\bar{G} = G \cup \{-\infty, +\infty\}$ be the set G extended by adding the two infinity elements $+\infty$ and $-\infty$, and let us extend the ordering \leq of the alo-group \mathcal{G} by defining that $-\infty < x < +\infty$ for every $x \in G$.

Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, be a vector, and let $\alpha \in [0; 1]$. Notice that, if v is an α -consistent priority vector of the FPC matrix \tilde{A} , then it is an α -intensity priority vector of \tilde{A} , yet, if v is an α -intensity priority vector of the FPC matrix \tilde{A} , then it is an α -coherent priority vector of \tilde{A} , see Bartl and Ramík (2022, Remark 6.5). In practice, FPC matrices are often inconsistent, even more, the intensity condition is not satisfied and/or the FPC matrices are incoherent. Therefore, it is useful to know “how much” these desirable properties of the priority vector are violated. This is why we measure the inconsistency, non-intensity, and incoherence of the given FPC matrix \tilde{A} and priority vector v by special grades, see, e.g., Saaty (1980) and Ramík (2020); the following definition improves the earlier one given by Bartl and Ramík (2022, Definition 7.1).

Definition 2. Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$. For every $i, j, k, l \in \mathcal{N}$, for a priority vector $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, and for $\alpha \in [0; 1]$, define:

- (i) The local α -inconsistency grade of two elements of FPC matrix \tilde{A} and vector v

$$\varepsilon_{ijkl}^{\text{Cs}}(\tilde{A}, v, \alpha) = \left(a_{ij}^L(\alpha) \div (v_i \div v_j) \right) \odot \left((v_k \div v_l) \div a_{kl}^R(\alpha) \right), \quad (7)$$

and the global α -inconsistency grade of FPC matrix \tilde{A} and vector v

$$E^{\text{Cs}}(\tilde{A}, v, \alpha) = \max\{ \varepsilon_{ijkl}^{\text{Cs}}(\tilde{A}, v, \alpha) \mid i, j, k, l \in \mathcal{N} \}. \quad (8)$$

- (ii) The local α -non-intensity grade of two elements of FPC matrix \tilde{A} and vector v

$$\varepsilon_{ijkl}^{\text{In}}(\tilde{A}, v, \alpha) = \begin{cases} (v_k \div v_l) \div (v_i \div v_j) & \text{if } a_{ij}^L(\alpha) > a_{kl}^R(\alpha), \\ -\infty & \text{otherwise,} \end{cases} \quad (9)$$

and the global α -non-intensity grade of FPC matrix \tilde{A} and vector v

$$E^{\text{In}}(\tilde{A}, v, \alpha) = \max\{ \varepsilon_{ijkl}^{\text{In}}(\tilde{A}, v, \alpha) \mid i, j, k, l \in \mathcal{N} \}. \quad (10)$$

- (iii) The local α -incoherence grade of an element of FPC matrix \tilde{A} and vector v

$$\varepsilon_{ij}^{\text{Co}}(\tilde{A}, v, \alpha) = \begin{cases} v_j \div v_i & \text{if } a_{ij}^L(\alpha) > e, \\ -\infty & \text{otherwise,} \end{cases} \quad (11)$$

and the global α -incoherence grade of FPC matrix \tilde{A} and vector v

$$E^{\text{Co}}(\tilde{A}, v, \alpha) = \max\{ \varepsilon_{ij}^{\text{Co}}(\tilde{A}, v, \alpha) \mid i, j \in \mathcal{N} \}. \quad (12)$$

Remark 2. The local α -inconsistency grade $\varepsilon_{ijkl}^{\text{Cs}}(\tilde{A}, v, \alpha)$, defined by (7), can equivalently be written as

$$\varepsilon_{ijkl}^{\text{Cs}}(\tilde{A}, v, \alpha) = \left(a_{ij}^{\text{L}}(\alpha) \div a_{kl}^{\text{R}}(\alpha) \right) \div \left((v_i \div v_j) \div (v_k \div v_l) \right), \quad (13)$$

cf. inequality (6) in Proposition 1, by using which it is easy to see that v is an α -consistent vector of \tilde{A} if and only if $\varepsilon_{ijkl}^{\text{Cs}}(\tilde{A}, v, \alpha) \leq e$ for all $i, j, k, l \in \mathcal{N}$, where e is the neutral element of the alo-group \mathcal{G} .

The following proposition is a direct consequence of Definitions 1 and 2 and Remark 2. A detailed proof can be found in Bartl and Ramík (2022, Proposition 7.3).

Proposition 2. Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, be a vector, and let $\alpha \in [0; 1]$. Then:

- (i) $E^{\text{Co}}(\tilde{A}, v, \alpha) \leq e$ if and only if the vector v is α -consistent,
- (ii) $E^{\text{In}}(\tilde{A}, v, \alpha) < e$ if and only if the vector v is an α -intensity vector,
- (iii) $E^{\text{Cs}}(\tilde{A}, v, \alpha) < e$ if and only if the vector v is α -coherent.

The subsequent relations (14) reflect the fact that, if v is an α -consistent priority vector of the FPC matrix \tilde{A} , then it is an α -intensity priority vector of \tilde{A} , yet, if v is an α -intensity priority vector of the FPC matrix \tilde{A} , then it is an α -coherent priority vector of \tilde{A} , which we have already remarked above. A detailed proof of the next proposition can be found in Bartl and Ramík (2022, Proposition 7.3).

Proposition 3. Let $\tilde{A} = \{\tilde{a}_{ij}\}$ be a FPC matrix on an alo-group $\mathcal{G} = (G, \odot, \leq)$, let $v = (v_1, v_2, \dots, v_n)$, with $v_j \in G$, be a vector, and let $\alpha \in [0; 1]$. Then:

$$E^{\text{Co}}(\tilde{A}, v, \alpha) \leq E^{\text{In}}(\tilde{A}, v, \alpha) < E^{\text{Cs}}(\tilde{A}, v, \alpha). \quad (14)$$

5. An algorithm to generate a joint priority vectors of FPC matrices in group decision making

In this paper, we consider the main subproblem of the AHP extended as follows. There are n objects c_1, c_2, \dots, c_n that are to be judged with respect to the given criterion by m independent decision makers (evaluators). Given an alo-group $\mathcal{G} = (G, \odot, \leq)$, each of the decision makers assesses the relative importance of the two items in each pair of the objects with respect to the given criterion by using a fuzzy interval on the alo-group \mathcal{G} ; that is, let the fuzzy subset \tilde{a}_{ij}^k of G be a fuzzy interval and represent the k -th decision maker's (fuzzy) opinion how many times c_i is better or more important than c_j with respect to the given criterion for $i, j = 1, 2, \dots, n$ and for $k = 1, 2, \dots, m$. We are thus given $n \times n$ fuzzy pairwise comparison matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. The purpose is to find a single (joint) priority vector $v = (v_1, v_2, \dots, v_n) \in G^n$ having the aforedefined desirable properties – consistency, intensity, and coherence – with respect to the FPC matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. To this end, we improve and extend the authors' new algorithm (Bartl and Ramík, 2022) to this case. Our enhanced Algorithm consists of the following six steps:

STEP 1. Set $\alpha := 0$. Find an optimal solution v^α to PROBLEM 1:

$$\max\{E^{\text{Cs}}(\tilde{A}^1, v, \alpha), E^{\text{Cs}}(\tilde{A}^2, v, \alpha), \dots, E^{\text{Cs}}(\tilde{A}^m, v, \alpha)\} \rightarrow \min \quad (15)$$

subject to

$$v \in G^n.$$

If the minimal value of the objective function is greater than the neutral element e of the alo-group \mathcal{G} , then there is no 0-consistent priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$, see Proposition 2.(i); go to Step 3. Otherwise, if the minimal value of the objective function is less than or equal to e , then the optimal solution v^0 is a 0-consistent priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. Look for an α -consistent vector with the maximal $\alpha \in [0; 1]$, i.e. proceed with Step 2.

STEP 2. Find an optimal solution α^*, v^{α^*} to PROBLEM 2:

$$\alpha \rightarrow \max \quad (16)$$

subject to

$$E^{Cs}(\tilde{A}^k, v, \alpha) \leq e \quad \text{for } k = 1, 2, \dots, m, \quad v \in G^n, \quad \alpha \in [0; 1].$$

The optimal solution v^{α^*} is an α^* -consistent priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ such that $\alpha^* \in [0; 1]$ is maximal. At the same time, it is an α^* -intensity vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. Look for an α -intensity vector with the maximal $\alpha \in [0; 1]$, i.e. go to Step 4.

STEP 3. Set $\alpha := 0$. Find an optimal solution v^α to PROBLEM 3:

$$\max\{E^{\text{In}}(\tilde{A}^1, v, \alpha), E^{\text{In}}(\tilde{A}^2, v, \alpha), \dots, E^{\text{In}}(\tilde{A}^m, v, \alpha)\} \rightarrow \min \quad (17)$$

subject to

$$v \in G^n.$$

If the minimal value of the objective function is greater than or equal to the neutral element e of the alo-group \mathcal{G} , then there is no 0-intensity priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$, see Proposition 2.(ii); go to Step 5. Otherwise, if the minimal value of the objective function is less than e , then the optimal solution v^0 is a 0-intensity priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. Look for an α -intensity vector with the maximal $\alpha \in [0; 1]$, i.e. proceed with Step 4.

STEP 4. Find an optimal solution $\alpha^{**}, v^{\alpha^{**}}$ to PROBLEM 4:

$$\alpha \rightarrow \max \quad (18)$$

subject to

$$E^{\text{In}}(\tilde{A}^k, v, \alpha) < e \quad \text{for } k = 1, 2, \dots, m, \quad v \in G^n, \quad \alpha \in [0; 1].$$

The optimal solution $v^{\alpha^{**}}$ is an α^{**} -intensity priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ such that $\alpha^{**} \in [0; 1]$ is maximal. At the same time, it is an α^{**} -coherent vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. Look for an α -coherent vector with the maximal $\alpha \in [0; 1]$, i.e. go to Step 6.

STEP 5. Set $\alpha := 0$. Find an optimal solution v^α to PROBLEM 5:

$$\max\{E^{\text{Co}}(\tilde{A}^1, v, \alpha), E^{\text{Co}}(\tilde{A}^2, v, \alpha), \dots, E^{\text{Co}}(\tilde{A}^m, v, \alpha)\} \rightarrow \min \quad (19)$$

subject to

$$v \in G^n.$$

If the minimal value of the objective function is greater than or equal to the neutral element e of the alo-group \mathcal{G} , then there is no 0-coherent priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$, see Proposition 2.(iii); go to End. Otherwise, if the minimal value of the objective function is less than e , then the optimal solution v^0 is a 0-coherent priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$. Look for an α -coherent vector with the maximal $\alpha \in [0; 1]$, i.e. proceed with Step 6.

STEP 6. Find an optimal solution $\alpha^{***}, v^{\alpha^{***}}$ to PROBLEM 6:

$$\alpha \rightarrow \max \quad (20)$$

subject to

$$E^{\text{Co}}(\tilde{A}^k, v, \alpha) < e \quad \text{for } k = 1, 2, \dots, m, \quad v \in G^n, \quad \alpha \in [0; 1].$$

The optimal solution $v^{\alpha^{***}}$ is an α^{***} -intensity priority vector common to all matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ such that $\alpha^{***} \in [0; 1]$ is maximal. Go to End.

END.

If the minimal value of the objective function is greater than or equal to e in Step 5, then the Algorithm does not provide any joint priority vector with desirable properties; that is, some of the initial FPC matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ is too incoherent. The decision makers may wish to revise some of their pairwise comparisons; that is, change some elements of the FPC matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ and run the Algorithm again. Otherwise, the proposed Algorithm provides up to three joint priority vectors with the desirable properties, i.e. the α^* -consistent vector v^{α^*} , the α^{**} -intensity vector $v^{\alpha^{**}}$, and the α^{***} -intensity vector $v^{\alpha^{***}}$, such that their membership grades α^* , α^{**} , and α^{***} are maximal and non-decreasing ($0 \leq \alpha^* \leq \alpha^{**} \leq \alpha^{***} \leq 1$).

6. An improvement of the Algorithm

In this section, we propose an improvement of the Algorithm consisting in that we consider weights $u_1, u_2, \dots, u_m \in G$, such that $u_1, u_2, \dots, u_m \geq e$, of the m independent decision makers (evaluators) in order to express their importance and/or expertise to judge the objects c_1, c_2, \dots, c_n with respect to the given criterion. Then, in problems (15), (17), and (19), we minimize the respective weighted maximum

$$\max\{u_1 \odot E^{\text{Cs/In/Co}}(\tilde{A}^1, v, \alpha), u_2 \odot E^{\text{Cs/In/Co}}(\tilde{A}^2, v, \alpha), \dots, u_m \odot E^{\text{Cs/In/Co}}(\tilde{A}^m, v, \alpha)\}$$

of the global grades of α -inconsistency / α -non-intensity / α -incoherence, respectively, and we replace the constraints

$$E^{\text{Cs}}(\tilde{A}^k, v, \alpha) \leq e, \quad E^{\text{In}}(\tilde{A}^k, v, \alpha) < e, \quad \text{and} \quad E^{\text{Co}}(\tilde{A}^k, v, \alpha) < e,$$

in problems (16), (18), and (20), by

$$u_k \odot E^{\text{Cs}}(\tilde{A}^k, v, \alpha) \leq e, \quad u_k \odot E^{\text{In}}(\tilde{A}^k, v, \alpha) < e, \quad \text{and} \quad u_k \odot E^{\text{Co}}(\tilde{A}^k, v, \alpha) < e,$$

respectively. Notice that, if $e \leq u \in G$ and $E \in G$ is such that $u \odot E \leq e$ or $u \odot E < e$, where e is the neutral element of the $\text{alo-group } \mathcal{G} = (G, \odot, \leq)$, then $E \leq e$ or $E < e$, respectively, too, so that the respective properties (consistency, intensity, and coherence) of the joint priority vector v are preserved, see Proposition 2.

7. Conclusion

In this paper, we have extended our previous algorithm (Bartl and Ramík, 2022) for generating crisp priority vectors of desirable properties – consistency, intensity, and coherence – of a fuzzy pairwise comparison matrix (provided by a single decision maker or evaluator) to generate joint crisp priority vectors of the desirable properties of fuzzy pairwise comparison matrices (provided by a group of independent decision makers or evaluators), addressing the situation of multi-criteria decision making thus. Another topic is left for further research, however.

Given the fuzzy pairwise comparison matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$, the Algorithm proposed in Sections 5 and 6 finds a joint priority vector v . Another approach is to apply our previous algorithm (Bartl and Ramík, 2022) to each of the FPC matrices $\tilde{A}^1, \tilde{A}^2, \dots, \tilde{A}^m$ separately and obtain m priority vectors w^1, w^2, \dots, w^m ; that is, each of the m decision makers has their own priority vector. Now, given two priority vectors $v = (v_1, v_2, \dots, v_n) \in G^n$ and $w = (w_1, w_2, \dots, w_n) \in G^n$, we define that the two vectors are *consensual* if $v_i > v_j \Leftrightarrow w_i > w_j$ for all $i, j = 1, 2, \dots, n$. The goal is then to find a single consensual priority vector v , or rather (since such a vector may not exist) the goal is to find a vector v such that it is pairwise consensual with respect to each of the m priority vectors w^1, w^2, \dots, w^m as much as possible.

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REFERENCE GROUPS AS AN INDICATOR OF FUTURE METAVERSE USE

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Abstract

The metaverse brings unprecedented opportunities to firms and consumers in an immersive world. How it will transform areas such as business, shopping, education, medicine, work, or our lives, in general, is now the subject of scientific debate. User adoption of the metaverse is certainly contingent on many factors, as happens with any new technology. In connection with the metaverse, the question of safety and the risks arising from this new environment are often discussed. It can therefore be assumed that trust will be one of the important factors for consumer adoption of the metaverse. As reference groups are characterised by their ability to influence consumer behaviour, also in the context of perceived trust, it is advisable to start with them when exploring this issue. Therefore, this paper focuses on reference groups as a possible indicator of future metaverse usage. The aim of the paper is to assess the influence of reference groups on the attitude of Czech consumers towards the use of the metaverse. Primary data is obtained through the research agency IPSOS and their online panel of respondents. Responses were obtained from 1,031 respondents. The findings of the paper will increase the knowledge about the role of reference groups in changing consumer attitudes. At the same time, the outputs of the paper can help in setting up marketing communication of companies to customer acquisition in the metaverse environment.

Keywords: Attitude, Consumer behaviour, Metaverse, Reference groups, virtual reality
JEL codes: M 30

1. Introduction

This paper explores the attitude of Czech consumers towards the metaverse and its possible influence on reference groups. A reference group is most commonly defined as a group of two or more people who share the same interest and can influence each other (Ramya and Mohamed, 2016). Within reference groups in this paper, we will focus on the primary reference group (family), secondary reference group (friends, colleagues, acquaintances), and aspirational group (the group to which they would like to belong). Consumers may be influenced by these groups in different ways and may gravitate towards some more than others. For example, it has been found that people are more likely to belong to secondary reference groups, and there may be many reasons why this happens. One major explanation may be the lack of influence of family as a primary reference group (Ramya and Mohamed, 2016). Thus, if people feel a lack in this primary reference group, it can cause a loss of socialization, and people, thus, often look for a place where they can belong (Mertion, 1949). Another explanation as to why people gravitate towards secondary reference groups more often may be the loss of normative influence of the

guardian on their child. By not having influence over his or her child (the child does not trust the guardian), the guardian seeks to trust other persons or groups (Glass et al., 1986). It is typical for today that this search occurs in the online world. With the increasingly inflected term of today, the metaverse, we may soon witness this search for take in this specific environment. Research focusing on attitudes towards the metaverse confirms this assumption. For example, researchers have found that Gen Z is attracted to metaverse for a variety of reasons, one of which is social connectedness and a desire for stability and escape from reality¹. It can be assumed that in the future, more research like this will be conducted that focuses not just on one generation, but on generations of consumers as a whole, as the metaverse has great potential not only in personal life, but also in working life across generations of consumers. Already these days, we see that many institutions, groups, and organisations intend to use the metaverse to communicate with people in real-time². Our paper deals with this topic because the metaverse and reference groups together are not well studied. By making trust one of the important factors in the acceptance of new technologies, it can be assumed that reference groups can have a significant influence when a consumer enters the metaverse. Indeed, reference groups are characterised by their ability to influence consumer behaviour.

The aim of the paper is to assess the influence of reference groups on the attitude of Czech consumers towards the use of metaverse. The research question is formulated as follows. What is the influence of reference groups on Czech consumers' attitudes towards the use of the metaverse and their decision to enter it? The results of the paper extend the knowledge about the role of reference groups in changing consumer attitudes. At the same time, the outputs of the paper can help in setting up marketing communication of companies in order to attract customers in case of entering the metaverse environment. The paper is divided into several sections. The following section is devoted to a literature search that focuses on the concept of reference groups themselves, their possible influence on consumer behaviour, and perceptions of trust. The third section presents the research methods used, the characteristics of the respondents, and the chosen procedure for conducting statistical tests. The fourth chapter presents the results of the research conducted, which show how reference groups can influence consumers' attitudes toward the metaverse. The following section of the paper discusses the most significant results put in the context of previous studies, along with presenting the limitations of the research conducted. The paper concludes by summarizing the main conclusions of the research conducted and outlining future research directions.

2. Literature review

The very concept of reference groups was introduced by Merton in collaboration with Rossin in 1950 (Merton, 1950). Ramya and Mohamed (2016) define reference groups as a set of two or more individuals who share the same set of norms and whose relationship causes interdependent behaviour.

Reference groups according to Komarovskiy (1973) are not very good to distinguish. According to him, there are types that are important to consider only and not to focus too much on their meaning. If we look at reference groups from the point of view of Yitzhaki (1979) he in turn sees that a reference group can be regarded as a set of agents that are wider than the individual under consideration. From another perspective, reference groups are persons or groups of people who can influence the views of the environment, these persons or influencers can serve, as inspiration or role models (Deepak and Jeyakumar, 2019). Some authors mention that reference groups are created by famous people, someone who can easily influence consumers to buy a selected brand (Lee and Fortuny, 2021). Usually, they are mainly described in terms of stereotypes, where the extension of key knowledge about groups is examined (Lee and Fortuny, 2021). Reference groups can help consumers a lot with comparison and eventual decisions to shape purchasing behavior (Babin and Harris, 2018).

Groups can change independently of their distribution (Stark and Taylor, 1989), and groups themselves can be classified from different perspectives. According to Kemper (1968), reference groups can be divided into three groups, the first is the normative group, the second is comparative group and

¹ Web portal Ipsos [online] [accessed 21 February 2023]. Available from <https://www.ipsos.com/en-uk/gen-z-and-metaverse>

² Web portal Accenture [online] [accessed 21 February 2023]. Available from www.accenture.com/us-en/insights/technology/technology-trends-2022

the third is the auditive group. Deepak and Jeyakumar (2019) divide the reference groups according to the purchase process into problem recognition, information search, evaluation of alternatives, purchase and post-purchase satisfaction or dissatisfaction. The classification according to Ramya and Mohamed (2016) can be into many groupings, but these groupings may not be directly exhaustive or overlapping.

Most psychologists who deal with social problems believe that these groups are the greatest source of values and norms themselves (Witt and Bruce, 1970). The point is that the higher the status of an individual in the group itself the higher the social power it has and can cause a change of opinion within the group itself (Witt, 1969). Some studies also suggest that consumer choice is most often influenced by small or informal social groups that are susceptible to group influences (Witt, 1969; Witt and Bruce, 1970). The most common alternative to the influence of reference groups itself is the use of interpersonal influence. This influence can be represented by the scale of consumer susceptibility to interpersonal influence developed by Bearden, Netemeyer, and Teal as early as 1989 (Bearden et al., 1989).

In addition to the reference groups, there are also negative groups whose norms are considered unacceptable by the individual. The division of reference groups according to Boháček (2020) is into direct members and direct non-members. According to him, direct members are divided into contact and recanting members. He divides non-members direct into aspirational and dissociative. In the case of an aspirational group, we are talking about a group that an individual wishes to join and wants to identify with the whole group, but for some reason is not allowed to do so (Kotler et al., 2007). A dissociative group is a group whose values or behaviors are completely rejected by the individual (Kotler and Keller, 2013). A contact group according to Boháček (2020) is a value-oriented group. A member of the group should act for the benefit of the collective. A reviled group represents a condition in which reviled personality types emerge. In this case, it is a direct membership, but the members have a negative relationship with other members (Bohacek, 2020).

2.1 How referent group can influence consumer behavior

Reference groups can greatly influence the actual buying behaviour of consumers, which can be classified as an informal group where social class, culture or environment are present (Khan and Khan, 2012). Ramya and Mohamed (2016) classify reference groups into social factors, where family and roles and status are further included.

In terms of understanding the consumer and their purchasing knowledge, it is a very complex process. Consumers are largely influenced by cultural, social, personal and psychological factors. From these factors, referent groups can be formed. Consumers make major decisions that are usually very complex and that is why these groups can help them (Lin and Chen, 2009). The influence of reference groups itself can vary from one segment of consumers to another for several reasons (Park and Lessig, 1977). Consumer behaviour is not only influenced by social influence but also by age or gender differences that are present in the world (Eszter, 2008).

Studies comparing people by age since Greco (2014) have shown that older and middle-aged people are equally sensitive to the influence of their respective reference groups. However, if we focus at studies that relate to gender, it shows that younger women are more susceptible to the views of reference groups than older women and are more easily influenced to purchase behaviour (Kokoi, 2011).

2.2 How reference groups affect people's trust

In order to complete the buying behaviour the consumer can be helped by the buying trust which is defined as the belief or reliability, to believe in the other person or the group itself (Gambetta, 1988). The work on trust is very essential and can also be based on the personality traits of the shopper who has a relationship with a particular individual or the group itself (Rotter, 1971).

Trust in a group can be primarily mediated by a person who has the same intentions as the person who wants to trust. Trust can be either positive or negative. Positive and negative trust can occur in different organisations, communities, or social networks (Kantsperger and Werner, 2010).

The characteristics of the group itself can also help one to trust the group. The number of friends in a group increases the likelihood that a person will join and trust the group in some way (Ugander et al., 2012). We can see this confirmation in sales groups on Facebook, if the seller's rate is positive it

means that the seller has a positive evaluation of his sales reputation and is more likely to have the consumer purchase goods from him (Holtz et al., 2017; Bente et al., 2012). Ma, Cheng, Iyer, and Naaman (2019) confirm that a unit's disposition to trust others depends on the size of the group itself. In fact, consumers have been shown to trust smaller and more closed groups in particular, causing these groups to be more influential in influencing purchase behavior.

3. Methods

Data were collected following the online survey method. This method is one of the most efficient in gathering information from a large cohort of consumers. The main advantage of this method is to reduce or prevent geographical dependence. Quantitative methods offer an effective way of gathering reliable data which allows generalizing the results from a sample group to an entire group of consumers. The survey explored consumers' opinions of the metaverse in relation to their influence on reference groups. The questionnaire was used as a technique for gathering data. The subjects included in the study were selected based on information about the frequency of Internet use (filtering question). Respondents who did not provide this information or indicated that they did not use the Internet were not included in the study. This restriction was made as part of the data cleaning process based on the assumption that Internet use is one of the predictors of metaverse acceptance. At the beginning of the questionnaire, the metaverse and its specifics were described to the respondents so that all respondents had a clear idea of what was involved.

The data was obtained using an online Instant Research panel from the research agency Ipsos. A total of 1,050 respondents took part in the survey. The data-cleaning process excluded 19 respondents from the study (based on the filtering question). Table 1 shows the characteristics of the respondents included in the study.

Table 1: Respondents' characteristics

Segmentation variables	Type of variable	Frequency	Percentage
Gender	Male	514	49.9
	Female	517	50.1
Age	18 – 24 years	91	8.8
	25 – 34 years	188	18.0
	35 – 44 years	232	23
	45 - 54 years	206	20
	55 - 65 years	314	30
Size of a place of residence	Up to 1,000 inhabitants	171	16.6
	1,001 to 5,000 inhabitants	205	19.9
	5,001 to 20,000 inhabitants	186	18.0
	20,001 to 100,000 inhabitants	219	21.2
	More than 100,000 inhabitants	250	24.2
Education	Basic	110	10.7
	Secondary without A-level	350	33.9
	Secondary with A-level	392	38.0
	Tertiary	179	17.4
Frequency of internet use in leisure time	Once a month or less often	17	1.6
	One to three times a week	4	0.4
	Four to six times a week	23	2.2
	Daily, but less than 3 hours	334	32.4
	3 to 6 hours per day	248	24.1
	More than 6 hours a day	405	39.3

Source: author's calculations

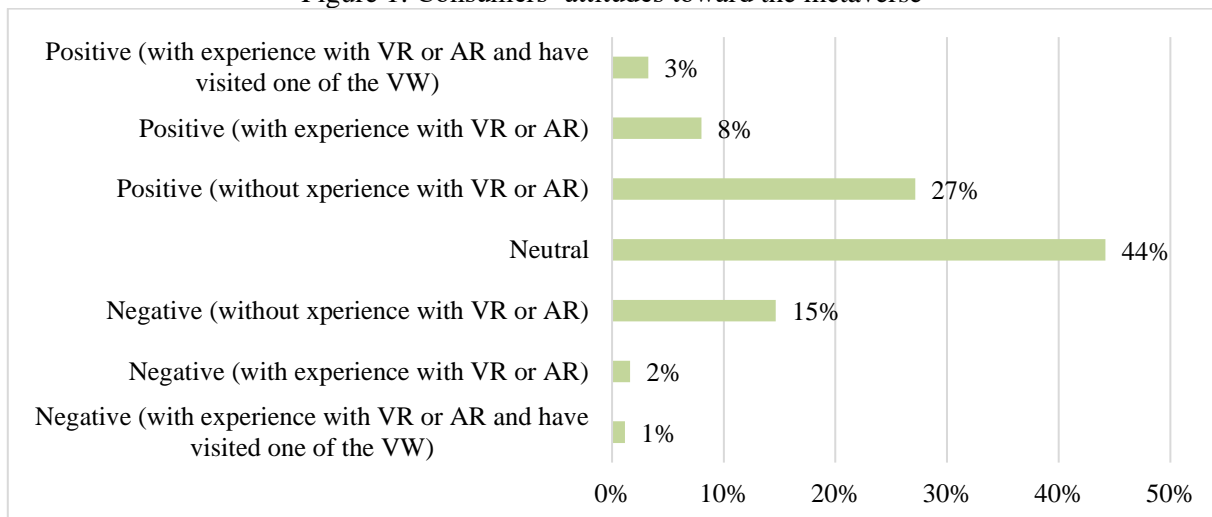
The respondent sample is very balanced in terms of men and women. The sample is less balanced in terms of age, with the largest group of respondents being consumers aged between 55 and 65. In terms of the size of a place of residence, the sample is also balanced. In terms of educational attainment, the proportion roughly corresponds to the distribution of educational attainment in the Czech Republic. It is not surprising, given the development of the Internet in the Czech Republic, that most respondents use the Internet on a daily basis.

All statistical analyses were performed using IBM SPSS software. The dependence between variables was measured using the Chi-square test of independence. All three conditions were met due to two categorical variables, two or more categories for each variable, and data independence.

4. Results

In examining how reference groups can influence consumers' attitudes toward the metaverse, the results first focus on presenting Czech consumers' attitudes toward this fictional universe. Responses differentiated whether respondents had experience with virtual reality (VR) or augmented reality (AR) or had visited at least one virtual world (VW). This makes it possible to tell whether a positive or negative attitude is based on one's own experience or whether it is fully shaped by other predictors (e.g. the influence of the media or the opinions of reference groups). The following figure reveals the aforementioned attitude of Czech consumers towards the metaverse.

Figure 1: Consumers' attitudes toward the metaverse



Source: author's research

The majority of respondents felt that their attitude toward the metaverse is neutral. Surprisingly, only one-quarter of those who have experienced both virtual reality or augmented reality and a visit to a virtual world has a negative attitude towards the metaverse. Three-quarters of these respondents have a positive attitude toward the metaverse. Similar results are also shown when respondents only have experience with virtual or augmented reality. In this case, even more than 80% of these respondents have a positive attitude toward the metaverse. Where respondents have no experience with virtual or augmented reality, the results are more balanced in terms of attitude, but positive attitudes still prevail. In this case, 65% of respondents have a positive attitude toward the metaverse, while 35% have a negative attitude.

Using a one-sample chi-square test, it was found that the selected nominal variables (attitude and reference groups) are significant, i.e., they have an effect on the questionnaire and therefore it is appropriate to conduct further tests with these variables. It was therefore proceeded to further testing, where a chi-square test for dependency was used to determine how respondents' attitudes towards the metaverse would be affected by a reference group member's entry into this environment. The results of the tests are presented in the following table.

Table 2: Results of the chi-square test on attitude and reference groups

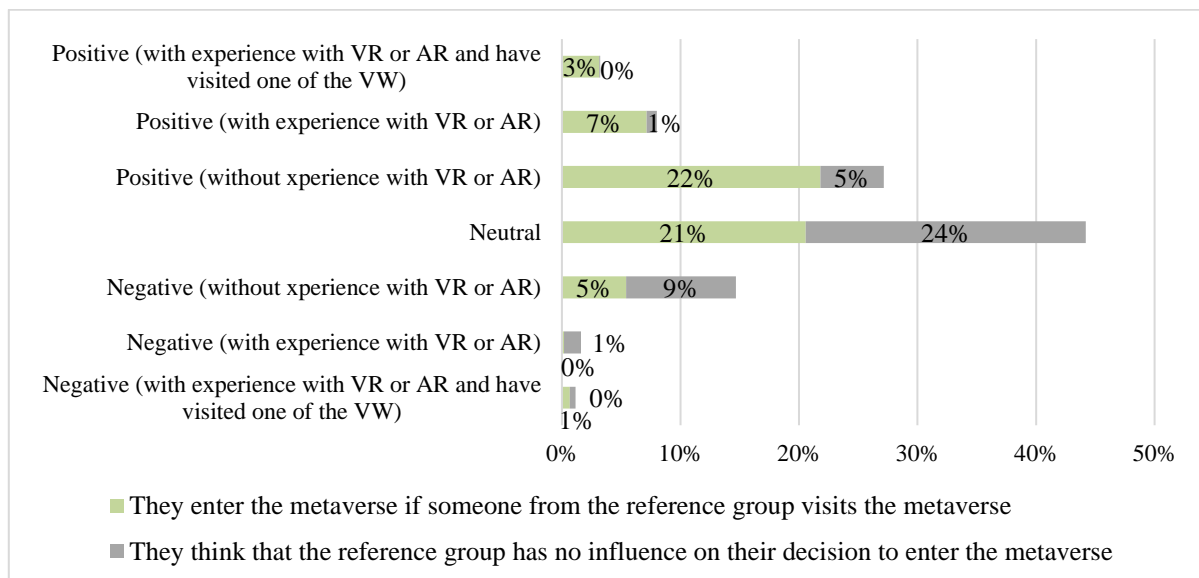
Test	Value	df	Significance
Pearson Chi-Square	182.035	6	0.000
Contingency Coefficient	0.384		0.000

Source: author's research

How strong a relationship does Cramer's V show (see the contingency coefficient in Table 2). Based on the result of the test, it can be concluded that there is a medium association between the variables under study. Certain assumptions for the successful use of the test have been met. These assumptions for the successful use of the test were met in that 7.1% of cells have an expected count of less than 5 and the minimum expected count is 4.93. The test result shows that the attitude towards the metaverse is dependent on the reference groups.

In general, the results show that 59% of respondents think that they would enter the metaverse if someone from the reference group visited the metaverse, while 41% of respondents think the opposite, i.e. that they would not be influenced by the behaviour of the reference group in this case. Figure 2 shows specific results on how reference groups affect attitudes toward the metaverse.

Figure 2: The influence of reference groups on respondents' attitudes toward entering the metaverse

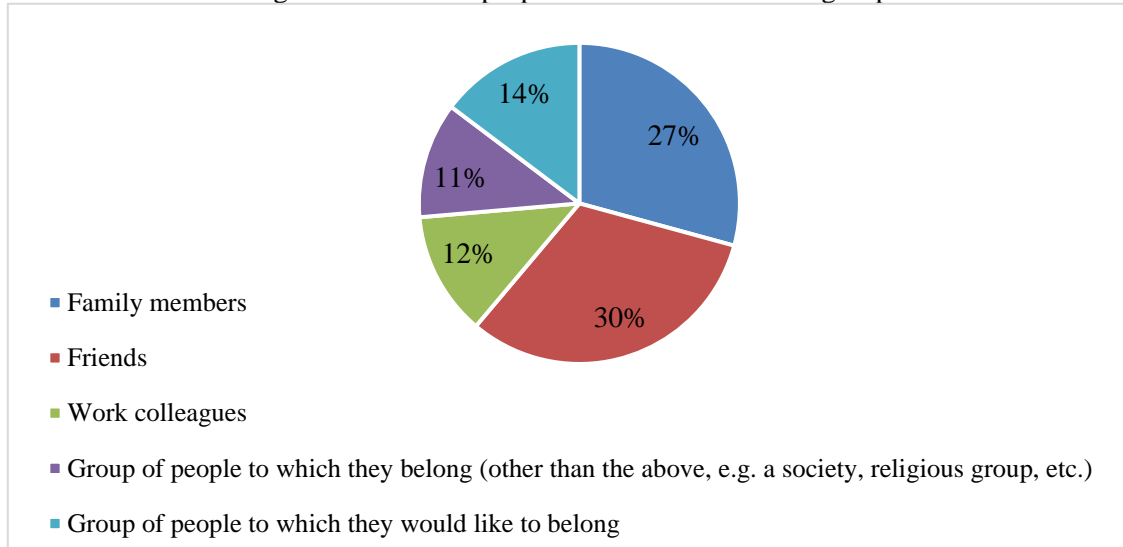


Source: author's research

It is an interesting finding that respondents who think that if someone from their reference group visited the metaverse, they would enter the metaverse too because it, already achieves a much more positive attitude towards the metaverse than those who think that reference groups would not influence them in this regard. In the case of respondents who have a neutral attitude, 53.4% of them think that the reference group would not influence their entry into the metaverse. While 46.6% think that they would enter the metaverse based on knowing that someone from the reference group visits the metaverse.

Further investigation shows how many respondents could be influenced to enter the metaverse by each reference group (Figure 3).

Figure 3: Influence proportion of each reference group



Source: author's research

According to the survey results, it is evident that most respondents (30%) would let their friends influence their decision to enter the metaverse. Up to 27% of respondents would be influenced by their family in this case. Colleagues are influential in the decision to enter the metaverse for only 12% of respondents. In the case of other groups to which the respondent belongs, the possibility of being influenced is only present in 11% of the respondents. The aspirational group can influence up to 14% of the respondent in deciding to enter the metaverse.

Further tests on how segmentation variables are associated with the influence of reference groups showed an effect in the case of education (Chi-Square test results: value = 10.493, df = 3, P = 0.015) and age (Chi-Square test results: value = 18.637, df = 47, P = 0.003). It was found that people with secondary with A-level and tertiary education are the most affected by reference groups. If the respondent has a secondary with A-level education there is a 62.6% probability of entering the metaverse based on being influenced by the reference group. In the case of respondents with a university degree, this probability is 64.9%. It is an interesting finding that the group with the largest difference in the influence of reference groups is the group of respondents aged 18-24 and 25-34. Overall, up to 75.5% of respondents aged 18-24 and up to 68.2% of respondents aged 25-34 would enter the metaverse if someone in their reference or aspirational group did so. There were no gender differences.

Overall, these results indicate that reference groups have a significant influence in the decision to enter the metaverse. In summary, these results show that the effect of reference groups varies according to the level of education and age of the influenced.

5. Discussion

An interesting finding of this research is that it can be considered that most of the respondents have a rather neutral attitude toward the metaverse, thus they are not inclined to say that their attitude towards the metaverse is either positive or negative. Another surprising finding is that if the respondents have experienced some kind of reality (VR or AR) or visited a virtual world, they have a rather positive attitude toward the metaverse itself. Only one-quarter of the respondents have a negative attitude toward this concept. If we focus only on the assessment of positive and negative attitudes, respondents who have no experience with virtual or augmented environments have a positive rather than negative attitude towards the metaverse.

In the case of reference group-oriented research results, these were found to be influential in consumers' decision-making to enter the metaverse. Consumers are most influenced by their friends (30% of them) and family (27% of them), but so are aspirational groups, work colleagues, or other groups that can influence consumers in this decision. Focusing on reference groups in relation to the decision to enter the metaverse, it is clear that the results confirm the dependence of decisions on the behaviour of reference groups. This is consistent with the findings of Ramya and Mohamed (2016), who

defined reference groups as a relationship that causes interdependence of other people's behavior. Another finding of this study is that if a person who is known to the respondent and belongs to his/her aspirational group visits the metaverse, then this situation can influence up to 14% of consumers to enter the metaverse as well. This is consistent with the very notion of an aspirational group, where an individual wants to join a group where there are other people who are close to them (Kotler et al., 2007).

The results are in line with Park and Lessig (1997), as it has been found that the influence of reference groups can vary across different segments of consumers. The results confirm that consumer behaviour is influenced by age differences (Eszter, 2008), where up to 75.5% of respondents aged 18-24 and up to 68.2% of respondents aged 25-34 would enter the metaverse if someone in their reference or aspirational group did so. In contrast to earlier findings of Eszter (2008), these results do not suggest any gender differences for the consumer behavior under investigation. In contrast to Greco (2014), our study showed that the elderly and middle-aged are not equally sensitive to the influence of reference groups. In our research, the opposite is confirmed, i.e., younger segments of consumers aged 18-24 and 24-34 are very similarly sensitive to this influence. A possible reason for this difference in results may be the examination of reference groups in the context of the metaverse. According to our research, the possible influence of the reference group when entering the metaverse is also dependent on education. Respondents with a secondary A-level education would be 62.6% likely to enter the metaverse if someone in their reference or aspirational group did so. In the case of respondents with a university degree, this probability is 64.9%.

Based on the results of our study, it can be argued that Czech consumers have a rather neutral or positive attitude towards the metaverse and their friends, family, and aspirational group have the greatest influence on their entry into the metaverse from the perspective of reference groups.

Among the limitations of the study, we can mention that by means of a questionnaire survey we rather obtained the opinions of Czech consumers on the monitored issue. It is not possible to obtain real data on consumers' behaviour in the metaverse in the context of their possible influence on reference groups through a questionnaire. For this, an experiment would have to be designed directly in the metaverse. However, since the metaverse is not sufficiently developed to be an established concept, the experiment would have to take place in virtual reality for the time being.

6. Conclusion

This study investigated Czech consumers' attitudes toward the metaverse in relation to their possible influence on the reference group. The aim of the study was to assess the influence of reference groups on Czech consumers' attitudes toward the use of the metaverse. The results of the paper extend the knowledge of the role of reference groups in changing consumer attitudes. At the same time, the outputs of the paper can help marketing communication firms in attracting customers in a metaverse environment when deciding on the setting of amplified word of mouth.

The results show that the metaverse is an interesting space about which consumers do not think exclusively negatively or positively, but rather neutrally. It was found that only 18% of Czech consumers have a negative attitude towards the metaverse, indicating a possibly high level of acceptance of this environment in the near future. The answer to the research question is that reference groups have a medium associative influence on the attitude of Czech consumers towards the metaverse, with up to 59% of them thinking that they would visit the metaverse if someone in their reference group did. The reference group of friends is the most influential in the decision to enter the metaverse, followed by the reference group with family members. The research revealed that the gender of the influenced person has no influence on the decision to enter the metaverse. Men and women are equally influenced by reference groups. However, significant differences were found in the case of the age of the influenced and their education. Therefore, the age and education of the influenced have an impact on the possibility of being influenced by reference groups.

These results suggest that there is a great potential for the use of the metaverse by consumers in the Czech market, as their attitudes are rather neutral and positive. At the same time, we see the possibility of positive influence by reference groups when considering entering the metaverse. The findings of the study show which influencers are suitable for influencing the acceptance of metaverse use and how different consumer segments are influenced by them.

These findings suggest the following direction for future research on the behaviour of people in reference groups in the metaverse. What will be the impact of reference groups on users in the metaverse? After all, when establishing relationships with avatars in the metaverse, we may have distorted perceptions of the user's identity. Will we be influenced by an entirely new group, namely avatars enabling a new user identity? What benefits might this group have on user behavior in the metaverse?

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MODELLING CORRELATION BEHAVIOUR INFLUENCING BUSINESS SYSTEM PROCESSES

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Abstract

The article highlights the issue of implementation of methods to improve the course of processes in a business system using a dedicated IT application. The problem of correlation of the method modifying unit costs, fixed costs and the time of individual processes was discussed. Correlation was performed for each of these cases in order to analyze optimization opportunities in a business system. In addition, the costs of implementing the accepted methods and their impact on the final financial result of the entire improvement procedure were taken into account. The appropriate pseudocode was introduced to illustrate the way a simulation model of the process was created. The results were presented in a descriptive, numerical and graphical way. Possibilities of application development were discussed.

Keywords: business process, mathematical model, methods, optimization, simulation model

JEL codes: C61, C63

1. Introduction

Normal optimizing business processes is one of the key issues in business management. The main starting point for process optimization is always their precise identification and parameterization using Business Process Management (BPM) techniques and methods (Dymora, 2019) and of course the subsequent detailed analysis (Cela, 2018). The goal is to optimize processes so that they create the highest possible value in the required time, based on the specified input requirements and at the lowest possible cost (Badakhshan, 2022). As stated for example in (Halaška, Šperka, 2022), for evaluating the quality, efficiency and performance of business processes, there is a number of tools, methods and procedures, among which there are simulations carried out with the use of various simulation models and algorithmic approaches. Requests for process improvement may arise from customers, as shown for example in (Markulik, 2021) or from the analysis of key performance indicators of the company linked to, for example, the cost of resources (Lopez-Pintado, 2021), introduction of new technologies while building a technological production chain (Shanin, 2020), scrap rate (Zhang, 2021), etc. Nowadays, big data and intelligent methods for their analysis are of course the key input for all business management actions, including optimization and process management (Shoilekova, 2022). Expanding the use of the above and some other activities related to the optimization and management of processes requires focusing on their cost side. It is necessary to define improvement processes that are part of business activities. The goal of the paper is to present specific starting points in the form of a mathematical model for the problem of modelling correlation behaviour which influences a business system consisting of various processes. The complementary objective is to conduct a case study showing step by step the issue of implementing methods minimising the cost of processes.

2. Mathematical assumptions

Let us assume that the business system is equipped with P processes which are subject to M modification methods. An example of such a method may be the escalation of the process, which is to lead to the streamlining or acceleration of the business process. However, not each method can be correlated with each process.

Let us introduce the matrix of general correlation of methods and business processes (1):

$$A = [a_{p,m}], p = 1, \dots, P, m = 1, \dots, M \quad (1)$$

where: $a_{p,m}$ - correlation of the p -th process with the m -th method.

It is assumed that $a_{p,m}$ takes only two values i.e. 1 or 0. If $a_{p,m} = 1$, then there exists a direct correlation of the p -th process with the m -th method, otherwise, $a_{p,m} = 0$.

Let us introduce the matrix of correlation of methods and processes in case of unit costs (2):

$$A^{c.u} = [a_{p,m}^{c.u}], p = 1, \dots, P, m = 1, \dots, M \quad (2)$$

where: $a_{p,m}^{c.u}$ - correlation of the p -th process with the m -th method in case of unit costs.

If $a_{p,m}^{c.u} = 1$, then there exists a direct correlation of the p -th process with the m -th method in case of unit costs, otherwise, $a_{p,m}^{c.u} = 0$.

Let us introduce the matrix of correlation of methods and processes in case of their duration (3):

$$A^{\tau} = [a_{p,m}^{\tau}], p = 1, \dots, P, m = 1, \dots, M \quad (3)$$

where: $a_{p,m}^{\tau}$ - correlation of the p -th process with the m -th method in case of times of processes.

If $a_{p,m}^{\tau} = 1$, then there exists a direct correlation of the p -th process with the m -th method in case of times, otherwise, $a_{p,m}^{\tau} = 0$.

Let us introduce the matrix of correlation of methods and processes in case of fixed costs of processes (4):

$$A^{f-c} = [a_{p,m}^{f-c}], p = 1, \dots, P, m = 1, \dots, M \quad (4)$$

where: $a_{p,m}^{f-c}$ = correlation of the p -th process with the m -th method in case of fixed costs of processes.

If $a_{p,m}^{f-c} = 1$, then there exists a direct correlation of the p -th process with the m -th method in case of fixed costs of processes, otherwise, $a_{p,m}^{f-c} = 0$.

Let us introduce the matrix of minimising coefficients of implementing modifying methods in case of processes (5):

$$B = [b_{p,m}], p = 1, \dots, P, m = 1, \dots, M \quad (5)$$

where: $b_{p,m}$ - the minimising coefficient for the p -th process and the m -th method in case of processes, $0 < b_{p,m} < 1$. If $b_{p,m} = 1$, there is no possibility for modification.

Let us introduce the matrix of minimising coefficients of implementing modifying methods for unit costs of processes (6):

$$B^{c.u} = [b_{p,m}^{c.u}], p = 1, \dots, P, m = 1, \dots, M \quad (6)$$

where: $b_{p,m}^{c.u}$ - the minimising coefficient for the p -th process and the m -th method in case of unit costs, $0 < b_{p,m}^{c.u} < 1$. If $b_{p,m}^{c.u} = 1$, there is no possibility for modification. Let us introduce the matrix of minimising coefficients of implementing modifying times of processes (7):

$$B^{\tau} = [b_{p,m}^{\tau}], p = 1, \dots, P, m = 1, \dots, M \quad (7)$$

where: $b_{p,m}^{\tau}$ - the minimising coefficient for the p -th process and the m -th method in case of time of the process, $0 < b_{p,m}^{\tau} < 1$. If $b_{p,m}^{\tau} = 1$, there is no possibility for modification.

Let us introduce the matrix of minimising coefficients of implementing modifying methods for fixed costs of processes (8):

$$B^{f-c} = [b_{p,m}^{f-c}], p = 1, \dots, P, m = 1, \dots, M \quad (8)$$

where: $b_{p,m}^{f-c}$ - the minimising coefficient for the p -th process and the m -th method in case of unit costs, $0 < b_{p,m}^{f-c} < 1$. If $b_{p,m}^{f-c} = 1$, there is no possibility for modification.

Let $B(\min)/B(\max)$, $B^{c-u}(\min)/B^{c-u}(\max)$, $B^\tau(\min)/B^\tau(\max)$, $B^{f-c}(\min)/B^{f-c}(\max)$ be the drawing ranges adequately for minimising coefficients of the whole business system, unit costs, times of processes and fixed costs.

Let us introduce the matrix of unit costs of processes without implementing modifying methods (9):

$$C_{P,M}^u = [c_{p,m}^u], p = 1, \dots, P, m = 1, \dots, M \quad (9)$$

where: $c_{p,m}^u$ - the unit cost of the p -th process without implementing the m -th method.

Let us introduce the matrix of unit costs of processes without implementing modifying methods (10):

$$C_{P,M}^{mod-u} = [c_{p,m}^{mod-u}], p = 1, \dots, P, m = 1, \dots, M \quad (10)$$

where: $c_{p,m}^{mod-u}$ - the unit cost of the p -th process with implementing the m -th method, $c_{p,m}^{mod-u} = b_{p,m}^{c-u} \cdot c_{p,m}^u$. Let us introduce the matrix of times of processes without implementing modifying methods (11):

$$T_{P,M} = [\tau_{p,m}], p = 1, \dots, P, m = 1, \dots, M \quad (11)$$

where: $\tau_{p,m}$ - the time of the p -th process without implementing the m -th method.

Let us introduce the matrix of times of processes with implementing modifying methods (12):

$$T_{P,M}^{mod} = [\tau_{p,m}^{mod}], p = 1, \dots, P, m = 1, \dots, M \quad (12)$$

where: $\tau_{p,m}^{mod}$ - the time of the p -th process with implementing the m -th method, $\tau_{p,m}^{mod} = b_{p,m}^\tau \cdot \tau_{p,m}$

Let us introduce the matrix of fixed costs of processes without implementing modifying methods (13):

$$C_{P,M}^{f-c} = [c_{p,m}^{f-c}], p = 1, \dots, P, m = 1, \dots, M \quad (13)$$

where: $c_{p,m}^{f-c}$ - the fixed cost of the p -th process without implementing the m -th method.

Let us introduce the matrix of fixed costs of processes with implementing modifying methods (14):

$$C_{P,M}^{mod-f-c} = [c_{p,m}^{mod-f-c}], p = 1, \dots, P, m = 1, \dots, M \quad (14)$$

where: $c_{p,m}^{mod-f-c}$ - the fixed cost of the p -th process with implementing the m -th method, $c_{p,m}^{mod-f-c} = b_{p,m}^{f-c} \cdot c_{p,m}^{f-c}$

Let us introduce the matrix of unit costs of implementing modifying methods (15):

$$C_{P,M}^{impl-u} = [c_{p,m}^{impl-u}], p = 1, \dots, P, m = 1, \dots, M \quad (15)$$

where: $c_{p,m}^{impl-u}$ - the unit cost of implementing the p -th process for the m -th method.

Let us introduce the matrix of costs of implementing modifying methods (16):

$$C_{P,M}^{impl} = [c_{p,m}^{impl}], p = 1, \dots, P, m = 1, \dots, M \quad (16)$$

where: $c_{p,m}^{tot-impl}$ - the cost of implementing the p -th process for the m -th method, $c_{p,m}^{impl} = \tau_{p,m} \cdot c_{p,m}^{impl-u}$

The matrix of total costs without modification takes the following form (17):

$$C^{nomod} = [c_{p,m}^{nomod}], p = 1, \dots, P, m = 1, \dots, M \quad (17)$$

where: $c_{p,m}^{nomod} = \tau_{p,m} \cdot c_{p,m}^u + c_{p,m}^{f-c}$

The matrix of total modified costs in a general case takes the following form (18):

$$C_B^{mod} = [c_{p,m}^{B-mod}], p = 1, \dots, P, m = 1, \dots, M \quad (18)$$

where: $c_{p,m}^{B-mod} = a_{p,m} \cdot b_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^u + a_{p,m} \cdot b_{p,m} \cdot c_{p,m}^{f-c} + a_{p,m} \cdot b_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^{impl-u}$

The matrix of total modified costs in all areas takes the following form (19):

$$C^{mod} = [c_{p,m}^{mod}], p = 1, \dots, P, m = 1, \dots, M \quad (19)$$

where: $c_{p,m}^{mod} = a_{p,m} \cdot a_{p,m}^{c-u} \cdot a_{p,m}^{\tau} \cdot \tau_{p,m}^{mod} \cdot c_{p,m}^{mod-u} + a_{p,m} \cdot a_{p,m}^{f-c} \cdot c_{p,m}^{mod-f-c} + a_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^{impl-u}$

Let us assume that each iteration $i, i = 1, \dots, I$ requires recalculation in accordance with the presented assumptions.

3. The pseudocode

In order to design an IT simulation system, it was decided to present its design using a simplified code representing key calculation operations. The task of the system is to search for the satisfactory solution for a given number of simulation iterations I .

- i) Introduce: $A, A^{c-u}, A^{\tau}, A^{f-c}, C_{p,M}^u, T_{p,M}, C_{p,M}^{f-c}, C_{p,M}^{impl-u}, I$
- ii) $i = 1$. Go to (iv).
- iii) $i =: i + 1$
- iv) Set: $B(\min)/B(\max), B^{c-u}(\min)/B^{c-u}(\max), B^{\tau}(\min)/B^{\tau}(\max), B^{f-c}(\min)/B^{f-c}(\max)$
- v) Draw: $B, B^{c-u}, B^{\tau}, B^{f-c}$
- vi) $c_{p,m}^{mod} = a_{p,m} \cdot a_{p,m}^{c-u} \cdot a_{p,m}^{\tau} \cdot \tau_{p,m}^{mod} \cdot c_{p,m}^{mod-u} + a_{p,m} \cdot a_{p,m}^{f-c} \cdot c_{p,m}^{mod-f-c} + a_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^{impl-u}$
- vii) If $i = 1$, then $C^{mod} = \min C^{mod}$. Otherwise, go to (viii).
- viii) $C^{mod} < \min C^{mod}$? If Yes, store: $C^{mod} = \min C^{mod}$ and go to (ix). Otherwise, continue to (ix).
- ix) $c_{p,m}^{B.mod} = a_{p,m} \cdot b_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^u + a_{p,m} \cdot b_{p,m} \cdot c_{p,m}^{f-c} + a_{p,m} \cdot b_{p,m} \cdot \tau_{p,m} \cdot c_{p,m}^{impl-u}$
- x) If $i = 1$, then $C_B^{mod} = \min C_B^{mod}$. Otherwise, go to (xiii).
- xi) $C_B^{mod} < \min C_B^{mod}$? If Yes, store: $C_B^{mod} = \min C_B^{mod}$ and go to (xi). Otherwise, continue to (xi) at once.
- xii) $i = I$? If Yes, go to (xiii). Otherwise, go to (iii).
- xiii) Report: $C^{nomod}, \min C_B^{mod}, \min C^{mod}$

4. Case study

The main task of this case study is to present the practical implementation of the method of minimising the costs of business processes with the possible use of exemplary methods that can be proposed if they become profitable for individual processes. The input data for the case study were randomly generated from predetermined ranges. First of all, simulation studies began with generating possible correlations as part of the combination of business processes separately with unit costs, process duration and fixed costs (Table 1). However, only those cells that guarantee the implementation of improvement methods in accordance with A^{c-u}, A^{τ} and A^{f-c} are filled with numerical values.

Table 1: Values for $B^{c-u}, B^{\tau}, B^{f-c}$ in accordance with A^{c-u}, A^{τ} and A^{f-c}

		$m = 1$	$m = 2$	$m = 3$	$m = 4$	$m = 5$	$m = 6$	$m = 7$	$m = 8$	$m = 9$	$m = 10$	$m = 11$	$m = 12$	$m = 13$	$m = 14$	$m = 15$
$B^{c-u} = [b_{p,m}^{c-u}]$	$p = 1$	0.65	0.68	0.66		0.70					0.78			0.90		
	$p = 2$								0.72						0.84	
	$p = 3$					0.60	0.74		0.77	0.86						
	$p = 4$						0.56	0.66			0.56		0.90			
	$p = 5$				0.57								0.72			
$B^{\tau} = [b_{p,m}^{\tau}]$	$p = 1$	0.65	0.68	0.66		0.70					0.78			0.90		
	$p = 2$														0.84	
	$p = 3$					0.60	0.74			0.86						
	$p = 4$						0.56	0.66			0.56					
	$p = 5$				0.57								0.72			

$Bf^c = [b_{p,m}^{f,c}]$	$p = 1$		0.68	0.66		0.70	0.80	0.66	0.76						0.50
	$p = 2$				0.81									0.84	0.90
	$p = 3$					0.74		0.77	0.86			0.83			
	$p = 4$				0.56	0.56				0.56		0.90			0.58
	$p = 5$		0.62			0.67				0.50			0.72		

Source: author's calculations

Having established cells representing the acceptable possibility of implementing improvement methods, the generated data relating to unit costs, process time and fixed costs for acceptable cells as well as costs of implementing methods throughout the course of processes should be used (Table 2).

Table 2: Initial data for $C_{P,M}^u$, $T_{P,M}$, $C_{P,M}^{f-c}$, $C_{P,M}^{impl,u}$

		$m = 1$	$m = 2$	$m = 3$	$m = 4$	$m = 5$	$m = 6$	$m = 7$	$m = 8$	$m = 9$	$m = 10$	$m = 11$	$m = 12$	$m = 13$	$m = 14$	$m = 15$
$C_{P,M}^u = [c_{p,m}^u]$	$p = 1$	9.46	8.83	7.06	9.38	6.09	8.85	6.52	9.05	5.69	6.67	9.15	8.88	7.89	5.84	7.36
	$p = 2$	5.28	8.64	8.89	9.71	7.96	9.74	7.55	8.98	5.26	9.57	8.40	8.04	9.38	6.00	7.37
	$p = 3$	5.30	5.03	7.79	9.84	7.68	8.09	5.40	8.35	7.45	6.34	8.96	7.87	7.24	9.66	9.12
	$p = 4$	6.73	6.50	8.85	5.52	6.12	5.21	7.42	5.08	6.08	8.07	7.94	7.46	7.63	6.07	7.82
	$p = 5$	8.52	7.43	5.82	8.80	8.06	7.92	9.54	8.93	6.24	6.41	8.88	5.34	5.15	8.06	5.72
$T_{P,M} = [t_{p,m}]$	$p = 1$	8.87	11.94	9.44	10.40	9.64	11.79	7.16	8.66	9.82	11.46	7.72	11.76	12.12	9.36	7.27
	$p = 2$	8.75	8.38	10.30	8.55	8.36	10.63	11.61	10.51	12.77	7.66	11.46	11.39	12.30	8.42	12.56
	$p = 3$	12.87	9.24	7.30	11.50	12.53	10.18	10.86	12.21	8.05	11.18	9.18	10.82	9.03	12.81	8.38
	$p = 4$	10.32	11.96	10.84	10.02	12.75	9.49	10.34	11.58	12.32	7.02	9.75	9.06	12.14	7.23	12.74
	$p = 5$	7.32	10.22	12.56	11.61	10.41	12.66	11.56	11.57	12.39	10.32	8.14	7.90	12.28	7.37	8.66
$C_{P,M}^{f-c} = [c_{p,m}^{f,c}]$	$p = 1$	6.8	7.06	5.41	8.18	7.86	6.69	7.14	6.41	7.96	5.05	8.36	6.06	8.52	3.47	6.07
	$p = 2$	6.43	7.01	4.25	6.97	5.22	7.41	6.35	5.4	6.28	3.63	4.94	4.79	7.7	6.74	8.72
	$p = 3$	6.94	6.98	3.06	5.39	8.43	7.33	8.61	6.36	7.41	8.38	8.43	7.35	7.76	4.25	3.45
	$p = 4$	4.44	6.09	6.2	3.75	8.36	3.1	3.64	6.41	4.93	3.13	3.44	4.83	6.12	3.41	8.84
	$p = 5$	4.17	7.2	3.51	6.04	8.24	4.98	8.12	3.71	5.61	4.14	4.26	6.87	8.56	5.54	4.348
$C_{P,M}^{impl,u} = [c_{p,m}^{impl,u}]$	$p = 1$	1.83	1.77	1.47	1.15	1.55	2.57	2.13	2.80	2.62	2.40	2.15	2.06	1.77	1.15	2.31
	$p = 2$	1.84	2.58	2.47	2.39	1.72	1.71	1.37	1.33	1.28	1.93	2.25	2.11	1.34	2.34	1.85
	$p = 3$	1.96	2.12	2.84	1.40	1.54	2.84	1.77	1.98	2.89	1.84	1.74	1.08	2.97	1.08	1.78
	$p = 4$	1.49	1.95	1.60	2.75	1.22	2.20	1.15	2.46	1.29	1.80	2.03	2.88	1.01	1.17	1.13
	$p = 5$	1.82	1.34	1.48	2.85	2.09	2.36	1.56	1.44	2.38	1.25	2.88	2.92	1.43	1.78	1.87

Source: author's calculations

Taking into account the possibilities of implementing certain methods from the set of available ones, total modified costs emerge as shown in Table 3. However, only highlighted colour-coded cells represent the correlation of processes and improvement methods that can be implemented.

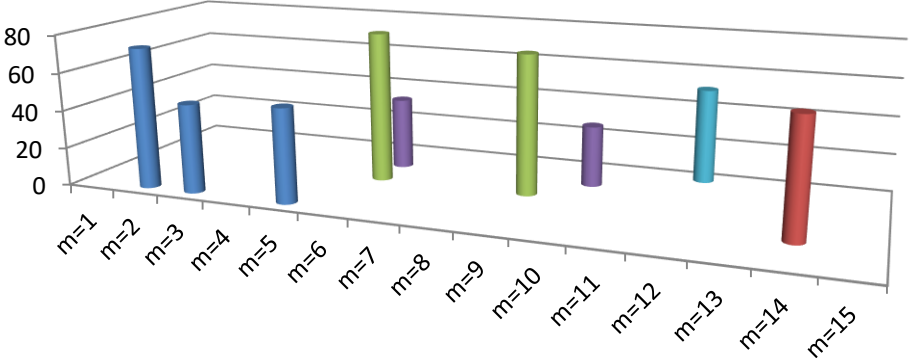
Table 3: Total modified costs C^{mod}

		$m = 1$	$m = 2$	$m = 3$	$m = 4$	$m = 5$	$m = 6$	$m = 7$	$m = 8$	$m = 9$	$m = 10$	$m = 11$	$m = 12$	$m = 13$	$m = 14$	$m = 15$
$C^{mod} = [c_{p,m}^{mod}]$	$p = 1$	58.46	74.01	46.75	117.64	49.55	139.98	66.60	107.45	89.59	78.62	95.57	134.62	107.29	68.88	73.38
	$p = 2$	68.69	100.99	121.23	109.18	86.22	129.08	109.95	86.97	89.86	91.71	127.00	120.54	139.59	60.73	123.62
	$p = 3$	100.33	73.05	80.59	134.66	62.51	79.21	86.46	107.45	73.72	99.90	106.63	102.93	100.04	141.82	94.80
	$p = 4$	89.16	107.18	119.58	86.56	98.17	37.96	48.77	93.79	95.69	32.22	100.65	90.94	111.08	55.82	119.22
	$p = 5$	79.82	94.06	95.16	72.49	111.15	135.25	136.36	123.59	109.68	83.12	99.99	50.10	89.44	78.12	70.11

Source: author's calculations

Distribution of results minimising the total costs of business processes in accordance with cells depicted in Table 3 is illustrated in Figure 1.

Figure 1: Distribution of results minimising the total costs of business processes in accordance with Table 3



Finally, the possible methods to be implemented in order to minimize the overall costs of the business processes are shown in detail in Table 4.

Table 4: Cost minimising methods for business processes

Process	Main method	Cost	Alternative method	Cost	Backup method	Cost
$p = 1$	$m = 3$	46.75	$m = 5$	49.55	$m = 2$	74.01
$p = 2$	$m = 14$	60.73				
$p = 3$	$m = 9$	73.72	$m = 6$	79.21		
$p = 4$	$m = 10$	32.22	$m = 6$	37.96		
$p = 5$	$m = 12$	50.10				

Source: author’s calculations

As it can be seen in Table 4 in accordance with Figure 1, it is necessary to assume that each of the considered processes can be set up with a method that minimizes the cost of the process. However, for $p=1$, $p=3$ and $p=4$ one alternative method can be distinguished. Additionally, for $p=1$ a backup method can be specified. On the basis of the obtained results, it is possible to conclude that the most protected process in terms of methods of minimising costs of a process is $p=1$, of course in case of implantation failure of any method previously used.

5. Conclusions

The article presents the topic of correlation of methods implemented to sample business processes. First, it was determined which sample methods can be implemented for individual processes. The subject of further considerations was the method that could be used for a given process, under the adopted assumptions, only if it was effective in the case of affecting the duration of the process, unit cost and fixed costs. The total costs of the process were supplemented by the costs of implementing the improvement method.

The case study was intended to illustrate the selection of the main method to minimize the cost of each analysed process and, if it turned out to be possible, the alternative method and possibly the backup method. Calculations were performed for the set of stochastic input data. Changing the set of input data results in the need for a recalculation procedure which, in turn, changes the result data indicating the need to implement different methods to minimize the cost of individual processes, of course, if such a possibility of implementation may be taken into account.

The topic requires continuation due to the need to take into account the impact of individual modification possibilities for single components of total costs as well as to consider the general

correlation and a possible combination of correlations. In addition, modification methods that can be implemented for specific business processes should be proposed.

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STRATEGIES FOR IMPROVING THE QUALITY OF SERVICES TO ACHIEVE ECONOMIC-FINANCIAL PERFORMANCE IN TOURISM ENTERPRISES

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Abstract

A firm's performance is a fundamental requirement in an increasingly competitive market, as the tourism market. This is conditioned by the competence of the owners, managers and executive staff and it is found in the economic and financial results of the tourism enterprise. Thus, performance represents an integrated strategic process that ensures lasting success in the activity of an enterprise. Therefore, there is an increased interest in studies, both in specialized literature and in practice, that investigate the strategies implemented by managers that influence business performance. For this purpose, based on the data collected through the survey, the main strategies regarding the improvement of quality in the view of 82 managers of tourist accommodation units from to the North-East region of Romania were identified. The results show that there is a significant relationship between strategies for improving the quality of accommodation services and firm performance, measured by sales growth (SG) and profit growth (PG). Based on this result, the most important strategic directions of action that can lead to increased performance can be outlined.

Keywords: performance, strategy, tourism enterprise

JEL codes: L19, L25, M19

1. Introduction

The strategy represents the concrete result of the implementation of top management regarding the organization's place and role in the business environment, the performances it must achieve and the means of fighting in the competitive game (Căprărescu, 2005).

In the specialized literature, strategies have been classified according to several factors internal or external to the company. Thus, Nicolescu and Verboncu, (1999) delimits three types of strategies: company strategies, economic strategies and functional strategies. The functional strategies are analyzed according to the development vector and are divided into: penetration strategies, market development strategies, product development strategies and diversification strategies. Ciobanu (1998) delineate: *the insurance strategy, the dedicated strategy, the gradual growth strategy and the opportunistic strategy*. Also, the author considered that strategies could also be classified into static strategies and dynamic strategies. Porter's approach (1985) is based on competitive advantage. Thus, from his point of view there are: strategies based on cost reduction, differentiation strategies and focused strategies. Butnaru (2009) delimited the strategies as follows: a) according to the scope, there are: global strategies and partial strategies; b) depending on the degree of participation of the company in the development of the strategy, there are: integrated strategies and independent strategies; c) depending on the dynamics of the main incorporated objectives, there are recovery strategies, consolidation strategies and development strategies; d) according to the type of objectives and the nature of the approaches, there are: privatization strategies, restructuring strategies, managerial strategies, joint-venture strategies - joint ventures, innovative strategies, offensive strategies, specialization strategies, diversification strategies, organizational strategies, informational strategies; e) depending on the nature of the vision of the

objectives and the incorporated means there are: economic strategies and administrative-economic strategies.

According to Kotler and Dubois (1991) and Maxim (2007), the achievement of quality objectives requires the development of quality improvement strategies, classified as follows: a) according to scope in: global strategies and partial strategies; b) according to the path of achievement in: extensive improvement strategies and intensive improvement strategies; c) according to the direction in which the efforts are concentrated there are: offensive strategies and consolidation strategies.

The diversification of strategies and their interference with other forms of company strategies creates some difficulties in the analysis and substantiation processes. For this reason, we cannot speak of pure quality strategies, but of strategies in which the quality issue is dominant as an objective. According to Stanciu (2003) the innovation strategy used to improve quality is based on sudden change, which achieves, in a short time, the same effect as in the case of continuous quality improvement. Olaru, (1995) is of the opinion that when quality is considered a distinct strategic element, three types of strategies can be defined, as follows: strategies for adapting the quality of tourist products and services to the requirements of each market segment; qualitative differentiation strategies compared to the offer of other competitors; quality improvement strategies when tourism firms have a strong market position. According to Psarommatis et al. (2021, p.87) enterprises should move from the classic strategies of continuous quality improvement to the strategy of zero defects due to the superior benefits obtained in practice and the durability of the products/services offered. This shows us that there must be a direct responsibility of each employee for quality. The application of the zero defects strategy is a realistic objective that can be achieved through consistent measures to prevent non-conformities and establish their causes as well as their elimination, which is equivalent to a continuous orientation towards quality in all activities. Continuous improvement through the activities of all employees implies the application of a total quality management whose main objective is, among other things, to awaken in each employee the desire for the continuous improvement of their own activity by making them aware of learning from previous errors and defects. According to research carried out by European Commission, (2016, p.2), zero defects strategy should lead to a significant impact on achieving zero defects in an enterprise, 15% cost reduction, increased production flexibility, 15% higher production rates, 10% waste reduction, adoption of new strategies in existing production systems. Considering the strategy of innovation, it requires appreciable investments to obtain the desired result (Lewandowska and Cherniaiev, 2022, p.3) with a paradigm shift in recent years for enterprises: the need for investments is reduced and the need for collaboration between partners as part of wider innovation systems is increasing (OECD, 2018, p.5). Thus, it can be appreciated that the strategies regarding the improvement of the quality management system are considered competitive strategies (Todos, 2015, p.1) with an impact on the company's performance (Hossain et al., 2019, p.100), because the quality of the mission in a company can have a positive impact on its performance (Jonyo et al., 2018, p.31). According to the authors, the strategies adopted and the financial resources allocated to the implementation of these strategies should be correlated with the stated mission.

Therefore, the purpose of this paper is to analyze the quality improvement strategies in order to obtain economic-financial performance in tourism enterprises. Whether it is about the adoption of global strategies, such as the implementation of total quality management or the continuous improvement of service quality, or about the adoption of partial strategies, namely the assimilation of new products, technologies or the improvement of existing ones, the strategies are based on the factors that influence quality: employees, materials, machines, environment, measurement, work method; strategies for reducing losses due to non-quality and non-conformities. All these strategies can contribute to achieving and increasing organizational performance.

This article is organized in the following sections: introduction, analysis of specialized literature and development of research hypotheses, research methodology, results, discussions and conclusions.

2. Literature Review

Quality, quality improvement or quality management are concepts that increasingly represent the focus of oriented organizations for performance and success (Bourke and Roper, 2017). Regardless of the product made or the service provided, the field of activity or the size of the organizations, quality is one of the most important factors on which their success depends, the key to continuous development

in conditions of strong competition, which is based on quality improvement. According to the authors Terziovski, Power and Sohal (2003), quality improvement is not only addressed to large companies, but also to small and medium ones, respectively to all companies that want to achieve performance. In this sense, the provision of quality services is one of the major challenges that managers in general, and those in tourism in particular, will face in the coming years, as it is an essential condition for success in emerging, highly competitive global markets (Kapiki, 2012). Managers to meet these challenges will need to pay more attention to quality improvement as well as strategic links between service quality and overall service performance (Drosos et al, 2017). In this framework, businesses would develop and implement more effective strategies leading to improved performance. Among them, total quality management is a comprehensive management approach. aimed at satisfying and even delighting customers. Daghfous and Barkhi (2009) states that total quality management is an organization-wide philosophy that focuses on the systematic and continuous improvement of product, process and service quality. As Lopez-Toro et al., (2010) also mentions, quality improvement is one of the strategies that many destinations as well as small and medium or large enterprises use to increase their performance and competitiveness in international markets (Ruzzier and Konecnik Ruzzier, 2006). In the field of tourism, for example, according to Ekinici et al. (2003), a strategic tool for increasing the competitiveness of island destinations is considered to improve the quality of accommodation. At the same time, the proactive incorporation of new products, technologies or IT applications into the services, operations or strategy of hoteliers is a key element that can lead to excellence in service delivery and economic-financial performance (Daghfous and Barkhi, 2009). Also in Bouranta et al., (2017) view, a special attention to employee quality management, a customer focus, but also an employee knowledge and education, can have a significant impact on both financial and customer-oriented performance.

What does "special" mean? First of all, it means being clearly superior to what was obtained in a previous period; secondly, it means being superior to the results obtained by other competitors and, thirdly, it means being different from the obviously assumed objectives, in a favorable sense (Butnaru, 2013). According to Oxford English Dictionary (2023), performance is given by the quality of execution of an action, operation, or process. It also represents the competence of a person to perform during his/her actions and last but not least the capacity, productivity, or success of a machine, product, or person when measured or compared to a standard. From a psychological point of view, according to the same dictionary, performance is given by the observable or measurable behavior of a person in a certain situation, usually an experiment. In business, performance is given by the extent to which an investment is profitable in terms of sales growth and profitability (van de Ven et al., 2022, p.7; Parmenter, 2020, p.35; Ishaq Bhatti et al., 2013, p.6). Therefore, this study proposes to test the following research hypotheses:

Hypothesis **H1**: Sales growth (SG) is positively correlated with quality improvement strategies (QIS). This hypothesis can be divided into several sub-hypotheses, among which:

- Hypothesis **H1_a**: Revenue growth (SG) is positively correlated with total quality management implementation strategy (SG1);
- Hypothesis **H1_b**: Sales growth (SG) is positively correlated with continuous quality improvement strategy (SG2);
- Hypothesis **H1_c**: Sales growth (SG) is positively correlated with the strategy of assimilating new technologies to improve quality (SP1);
- Hypothesis **H1_d**: Sales growth (SG) is positively correlated with with strategies to reduce non-compliant services (SP2);
- Hypothesis **H1_e**: Sales growth (SG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of the maximum performance offered (SO1);
- Hypothesis **H1_f**: Sales growth (SG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2);
- Hypothesis **H1_g**: Sales growth (SG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1);

- Hypothesis **H1_b**: Sales growth (SG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of the services offered (SC1).

Hypothesis **H2**: Profit growth (PG) is positively correlated with quality improvement strategies (QIS). This hypothesis can be divided into several sub-hypotheses, among which:

- Hypothesis **H2_a**: Profit growth (PG) este corelat pozitiv cu strategia implementării managementului calității totale (SG1);
- Hypothesis **H2_b**: Profit growth (PG) is positively correlated with continuous quality improvement strategy (SG2);
- Hypothesis **H2_c**: Profit growth (PG) is positively correlated with the strategy of assimilating new technologies to improve quality (SP1);
- Hypothesis **H2_d**: Profit growth (PG) is positively correlated with strategies for reducing non-compliant services (SP2);
- Hypothesis **H2_e**: Profit growth (PG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of the maximum performance offered (SO1);
- Hypothesis **H2_f**: Profit growth (PG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2);
- Hypothesis **H2_g**: Profit growth (PG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1);
- Hypothesis **H2_h**: Profit growth (PG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of the services offered (SC1).

3. Research Methodology

3.1. Description of the Research Method

This study had as a data collection tool a survey based on a questionnaire, in which participated a number of 83 managers of tourist accommodation units from the North-Eastern region of Romania. According to the criterion of the number of employees regarding the size of the accommodation units, the study registered 37 accommodation units as small enterprises and 46 accommodation units as medium-sized enterprises. The empirical research aimed to test the relationship between the variables included in the study, the investigation being carried out on the basis of 2 main research hypotheses, both with multiple secondary hypotheses. Thus, a questionnaire was proposed for active managers and business founders in tourism units from the North-Eastern region of Romania. The questionnaire was applied at the companies' headquarters and by e-mail, obtaining 83 valid questionnaires. The Stata software, a statistical program for data science was used for analysis and interpretation. In this sense, the statistical analysis was based on the following statistical operations:

1. Logistic regression analysis where the dependent variable is sales growth (SG) and the independent variables were quality improvement strategies (QIS).
2. Logistic regression analysis where the dependent variable is profit growth (PG) and the independent variables were quality improvement strategies (QIS).

3.2. Selection and Description of Variables

Table 1 shows the description of the analyzed variables, both the dependent variable and the independent variables, by type of intervals specific to the Likert measurement scale.

Dependent variables: The performance of tourist accommodation units in the North-Eastern region of Romania was measured using two business indicators: sales growth (SG) and profit growth (PG). In this study, revenue growth and profit growth - are used as dependent variables, representing the

percentage value of growth as perceived by managers. The dependent variables were measured by assigning percentage values.

Table 1: The description of the variables

No.	Var.	Description	Type	Scale
1.	SG	A variable representing the percentage increase in receipts.	Interval	-100-100
2.	PG	A variable that represents the percentage increase in profit.	Interval	-100-100
3.	SG1	A Likert-type variable measured by the answers to the question: How important is the strategy of implementing total quality management in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
4.	SG2	A Likert-type variable measured by responses to the question: How important is the strategy of continuous quality improvement in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
5.	SP1	A Likert-type variable measured by the answers to the question: How important is the strategy of assimilation of new technologies to improve quality in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
6.	SP2	A Likert-type variable measured by the answers to the question: How important is the strategy for reducing non-compliant services in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
7.	SO1	A Likert-type variable measured by responses to the question: How important is the strategy of maximum performance offered in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
8.	SO2	A Likert-type variable measured by the answers to the question: How important is the strategy of diversifying the services offered in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
9.	SC1	A Likert-type variable measured by the answers to the question: How important is the strategy of differentiating the services offered in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5
10.	SC2	A Likert-type variable measured by the answers to the question: How important is the strategy of increasing the quality of services offered in increasing the performance of tourist accommodation units? (1 – extremely important, 5 – not at all important)	Likert	1-5

Source: author's elaboration of data coding

Independent (predictor) variables are:

- a) Global service quality improvement strategies - total quality management implementation strategy (SG1) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- b) Global strategies for improving the quality of services - the strategy of continuous quality improvement (SG2) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- c) Partial strategies regarding the improvement of service quality - the strategy of assimilation of new technologies for quality improvement (SP1) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not important);
- d) Partial strategies for improving the quality of services - strategies for reducing non-compliant services (SP2) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- e) Offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of maximum performance offered (SO1) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not important);

- f) Offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- g) Strengthening strategies regarding the focus of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- h) Consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of services offered (SC1) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not important).

4. Results and Discussion

Table 2 shows the Spearman correlation coefficients with the significance value (Sig.) for each correlation coefficient and the number of cases considered in the study (N). For this study, the correlations are presented for each of the 8 strategies to improve the quality of services in order to achieve the economic-financial performance in tourism enterprises.

Table 2: Correlation coefficients

	SG	PG	SG1	SG2	SP1	SP2	SO1	SO2	SC1	SC2
Spearman Rank Coefficient	SG	1.000								
	PG	0.866*	1.00							
	SG1	0.093	0.015	1.000						
	SG2	0.193	0.137	0.729*	1.000					
	SP1	0.230*	0.186	0.631*	0.683*	1.000				
	SP2	0.159	0.172	0.258*	0.483*	0.382*	1.000			
	SO1	0.168	0.106	-0.331*	-0.280*	-0.259*	-0.287*	1.000		
	SO2	0.002	0.004	-0.406*	-0.139	-0.299*	-0.087	0.517*	1.000	
	SC1	-0.039	-0.077	-0.445*	-0.163	-0.315*	-0.127	0.534*	0.858*	1.000
	SC2	-0.121	-0.093	-0.547*	-0.411*	-0.401*	-0.231*	0.479*	0.585	0.634*

Note: * indicates that $p < 0.05$; $N = 83$.

Source: our own analysis using the statistical software Stata

The variable sales growth (SG) is positively and significantly correlated with profit growth (PG). Also, it is positively correlated with the strategy of assimilating new technologies to improve quality (SP1). However, the correlation between the dependent variable (SG) and the independent variable SP1 is a modest one (0.230).

The variable profit growth (PG) is positively and significantly correlated with sales growth (SG). Regarding the variables representing the quality improvement strategies (QIS), there are correlations between them, but in general they are not very strong correlations (< 0.800). Therefore, it can be stated that there is no multicollinearity, but linearity (Field, 2009, p.276). Multicollinearity is the occurrence of large intercorrelations between two or more independent variables in a multiple regression model. Multicollinearity can lead to distorted results. Values are generally varied, positive and negative, placed in the range $[-1, 1]$. A positive value shows that there is a positive correlation between variables (Labăr, 2008, p.84), so that an increase in the importance given to the strategies considered in the study, tends to determine an increase in sales, respectively an increase in profit. A linear correlation coefficient that has a value of 0 proves that there is no correlation between the two variables. We observe a significant positive correlation between the dependent variables SG and PG (0.8661), i.e. the increase in sales has a positive influence on the increase in profit. None of all the strategies identified is significantly positively correlated with the dependent variables. A positive, but low influence on SG and PG is attributed to the implementation of new technologies regarding quality improvement (SP1 – 0.230 / SP1 – 0.186). Also, among all the strategies applied, the combinations between SC1 – SO2 (0.8589), SG2 – SG1 (0.7298), SP1 - SG2 (0.6833), SC2 – SC1 (0.6346) and SP1 - SG1 (0.6313) obtained the highest positive values demonstrating the existence of a positive correlation between the two variables. The existing correlation between the implemented strategies ranked by the companies according to the importance granted (1 - extremely important, 5 - not at all important) and the considered indicators is verified. The values close to 0 or even negative of the obtained Spearman correlation coefficients support

the weak correlation between the examined strategies and the economic and financial results. Table 3 shows the regression coefficients for the dependent variable sales growth (SG).

Table 3: Regression coefficients for the dependent variable sales growth

	β	Std. Error	Sig. (p value)
SG1	0.260*	0.054	0.029
SG2	0.310*	0.303	0.031
SP1	0.205*	0.240	0.040
SP2	0.147*	0.170	0.041
SO1	0.689*	0.241	0.006
SO2	0.331*	0.262	0.009
SC1	0.151*	0.279	0.006
SC2	0.202*	0.187	0.028
Cons.	0.430*	0.026	0.007
Fit statistics			
R-squared			0.2616
Adj R-squared			0.1710

Note: indicates that $p < 0.05$; $n = 83$. **Dependent variable: sales growth**

Source: our own analysis using the statistical software Stata

Table 4 shows the regression coefficients for the dependent variable profit growth (PG).

Table 4: Regression coefficients for the dependent variable profit growth

	β	Std. Error	Sig.
SG1	0.231*	0.128	0.008
SG2	0.157*	0.153	0.030
SP1	0.124*	0.123	0.031
SP2	0.096*	0.090	0.028
SO1	0.301*	0.123	0.001
SO2	0.616*	0.135	0.065
SC1	0.188*	0.137	0.017
SC2	0.704*	0.094	0.046
Cons.	0.542*	0.063	0.039
Fit statistics			
R-squared (R ²)			0.2648
Adj R-squared			0.1745

Note: indicates that $p < 0.05$; $n = 83$. **Dependent variable: profit growth**

Source: our own analysis using the statistical software Stata

Tables 3 and 4 show the goodness-of-fit statistics such as: omnibus test, R² and pseudo R². The omnibus tests of the model coefficients are significant ($p < 0.05$), confirming the causal relationship of the proposed logit models and accepting the hypothesis that the β coefficients are different from zero. The model used in this study has an R² of 0.2616 for the regression analysis where sales growth is the dependent variable, which means that the model presented in this study accounts for 26.16% of the dependent variable variance that is explained by the model. For the profit growth variable, R² is 0.2648, which means that the model presented in this study accounts for 26.48% of the total variance.

5. Discussions and findings

As shown above, a hypothesis **H1**: Revenue growth (SG) is positively correlated with quality improvement strategies (QIS) was tested for 8 secondary hypotheses, as follows: for **H1a**: Sales growth (SG) is positively correlated with total quality management implementation strategy (SG1), logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables ($\beta = 0.260$, $p = 0.029$). Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1b**: Sales growth (SG) is positively correlated with continuous quality improvement strategy (SG2), logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables

($\beta = 0.310$, $p = 0.031$). Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1c**: Sales growth (SG) is positively correlated with the strategy of assimilation of new technologies for quality improvement (SP1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables ($\beta = 0.205$, $p = 0.040$). Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1a**: Sales growth (SG) is positively correlated with strategies to reduce non-compliant services (SP2), logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1e**: Sales growth (SG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of maximum performance offered (SO1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1f**: Sales growth (SG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1g**: Sales growth (SG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies. For **H1h**: Sales growth (SG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of the services offered (SC1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between revenue growth and the implementation of quality improvement strategies.

As shown above, a hypothesis **H2**: Profit growth (PG) is positively correlated with quality improvement strategies (QIS) was tested for 8 secondary hypotheses, as follows: for **H2a**: Profit growth (PG) is positively correlated with total quality management implementation strategy (SG1), logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2b**: Profit growth (PG) is positively correlated with continuous quality improvement strategy (SG2), logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2c**: Profit growth (PG) is positively correlated with the strategy of assimilating new technologies for quality improvement (SP1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2a**: Profit growth (PG) is positively correlated with strategies to reduce non-compliant services (SP2), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2e**: Profit growth (PG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of the maximum performance offered (SO1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2f**: Profit growth (PG) is positively correlated with offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2), the logistic regression analysis showed that there is a statistically significant and positive relationship

between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2_g**: Profit growth (PG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies. For **H2_h**: Profit growth (PG) is positively correlated with consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of the services offered (SC1), the logistic regression analysis showed that there is a statistically significant and positive relationship between the two variables. Therefore, there is a statistically significant relationship between increased profits and the implementation of quality improvement strategies.

5. Conclusions, Limitations, and Future Research Directions

A firm's performance is necessary for its long-term existence in an increasingly competitive market. Thus, performance represents an integrated strategic process that ensures lasting success in the activity of an enterprise. Therefore, there is an increased interest in studies that analyze the strategies implemented by managers that influence business performance. For this purpose, based on the data collected through the survey, the main strategies regarding the improvement of quality in the view of the managers of tourist accommodation units in Romania were identified. The strategies identified based on this study are:

- a) Global service quality improvement strategies - total quality management implementation strategy (SG1);
- b) Global service quality improvement strategies - continuous quality improvement strategy (SG2);
- c) The partial strategies regarding the improvement of the quality of services - the strategy of assimilating some new technologies to improve the quality (SP1);
- d) Partial strategies for improving the quality of services - strategies for reducing non-compliant services (SP2);
- e) Offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of the maximum performance offered (SO1);
- f) Offensive strategies regarding the concentration of efforts to improve the quality of services - the strategy of diversifying the services offered (SO2) was measured by assigning values from 1 to 5 (1 – extremely important, 5 – not at all important);
- g) Consolidation strategies regarding the concentration of efforts to improve the quality of services - the strategy of differentiating the services offered (SC1);
- h) Consolidation strategies regarding the concentration of efforts to improve the quality of services – the strategy of increasing the quality of the services offered (SC1).

The empirical research aimed to test the relationship between the variables included in the study, the investigation being carried out on the basis of 2 main research hypotheses, both with 8 secondary hypotheses. The results show that there is a significant link between the strategies regarding the improvement of the quality of accommodation services and the company's performance, all the proposed hypotheses being thus confirmed. Based on this result, important strategic directions can be outlined that can lead to increased performance. However, it is important to note that it is very challenging for a manager to use all the strategies mentioned in this article. Thus, a single strategy or a mix of strategies can be used, and the results obtained will depend a lot on the particularities of each individual accommodation unit.

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POSSIBILITY OF USING LOGS FROM ERP SYSTEMS FOR PROCESS MINING ANALYSIS

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Abstract

Process Mining techniques have the greatest application in processes where there are a large number of repetitions. There are many commercial or non-commercial available tools that can be used to visualize processes on the basis of event logs that are very often stored in ERP systems. Process Mining is not limited to a specific industry or part of a company because it can be used in most company areas from logistics, manufacturing, finance or administrative issues. The only limiting factor is the existence of appropriate data such as information about purchasing, receiving orders, manufacturing or logistic processes. The basic formats of event logs for Process Mining analysis include eXtensible Event Stream (XES), Object-Centric Event Logs (OCEL) and Comma-Separated Values (CSV). The main goal of the paper is to describe advantages and current trends of using ERP systems logs for Process Mining analysis.

Keywords: ERP, logs, Process Mining

JEL codes: D80, O31, L86

1. Introduction

Most business information systems routinely generate a so-called “process log.” Process Mining technology allows this data to be used to visualize business processes. There is a big potential that Process Mining opens up a new way to increase the efficiency of daily activities, saving time and costs because Process Mining is not limited to a specific industry or part of a company. It can be used in most areas from logistics to manufacturing to finance. The basic formats of event logs for Process Mining analysis include eXtensible Event Stream (XES), Object-Centric Event Logs (OCEL) and Comma-Separated Values (CSV).

The main purpose of this paper is to describe advantages and current trends of using logs from ERP systems for Process Mining analysis.

2. Process Mining overview and its benefits

The main idea of process mining is to discover, monitor and improve real processes by extracting knowledge from event logs (van der Aalst, 2005). Use and applications of process mining software have been rising for last years in the commercial sphere. We can find very expensive commercial solutions on the one hand and on the other hand there are also many opensource alternatives that are free of charge for everybody. Process mining software is working with event logs because it is possible extract knowledge from available event logs from the different types of information systems, databases, transaction logs, audit trails, etc.

The definition of process mining is generally the following: “a relatively young research discipline which can be described as a process analysis method that aims to discover, monitor and improve real processes. Process mining sits between computational intelligence and data mining on the one hand, and process modeling and analysis on the other hand” (van der Aalst, 2016). Process Mining Manifesto (van der Aalst et al, 2012) deals with very important aspects such as process discovery,

conformance checking, social network or organizational mining, construction of simulation models with the possibility of model extension and repair.

Process mining is very useful for its ability to find out how procedures in real situations work and for comparing the actual process with some predefined process (van der Aalst et al, 2004). Processes created from data allow (Šolc, 2017): to capture a complex unbiased picture of reality, to view processes from multiple perspectives, to detect deviations from the desired process or to identify causes of inefficiencies and delays in the process.

3. ERP systems and its logs using for Process Mining analysis

ERP systems incorporate a number of functions or modules. These are most often the following: accounting, finance, manufacturing, purchasing, sales, project management, warehouse management, inventory review and reporting. Each module can have different variations and extension functions depending on the supplier and the needs of the company. “ERP systems contain valuable data based on which process mining techniques provide insights regarding the underlying real-life business processes.” (Berti et al., 2022) The use of data from ERP system logging files presents a challenge, for example Chen (2022) highlighting that event log data is typically not readily available in ERP systems. “Instead, event logs need to be extracted from different database tables of one or several ERP systems, often using customized extraction scripts whose implementation requires both technical and domain expertise.”

The area of ERP systems can be divided into complex international distributors of these systems and into domestic distributors of ERP systems. From a global perspective, SAP in particular has a large market share (for example 22.5% in 2017 according to Gartner). SAP will find application mainly in multinational companies or large enterprises. “Extracting event logs from popular ERP systems such as SAP poses major challenges, given the size and the structure of the data.” (Berti et al., 2022) Oracle EBS or ERP Cloud application are also famous international complex ERP systems that holds valuable information about your business processes. Process Minery B.V. is a company that provides services such as connecting Oracle ERP instance with Process Mining software called Celonis. Process Mining is using your actual transactional data in Oracle ERP to discover your end-to-end process. (Process Minery)

There are many different ERP systems in different price ranges on the Czech market for small and medium-sized companies. From the point of view of the analysis of event logs from the Czech ERP system, it can be stated that there is still a great potential for research activities and practical application in this area.

There are also ERP opensource systems such as for example Odoo. Odoo (Odoo, 2022) is a suite of opensource business apps that cover all main company needs: CRM, eCommerce, accounting, inventory, point of sale, project management, manufacturing, etc. (Odoo) Siccardi and Sebastiani (2014) deals with event log extraction from the Odoo database and preprocessing with Xesame and loading in PROM Process Mining tool. Their analysis method was managed in the following steps:

- I. load in PROM the event log extracted by the Odoo database and preprocessed with Xesame,
- II. create the main statistics of the complete log,
- III. filter the cases in order to obtain cases that can be considered complete by a business point of view,
- IV. create model in Petri net format of the process as the company intends it,
- V. compare the filtered log to the model and draw considerations about its conformance and the general performance of the system,
- VI. analyze the filtered log to find users' behavioural patterns,
- VII. again filter the log keeping only the cases started in the first month of operation, then those started in the last two months considered and repeat steps 5 and 6 on both sets.

It is necessary to meet requirements for Process Mining data structures. We need to identify at least the following three elements: Case ID, Activity, and Timestamp (see Figure 1). These three elements allow us to take a process perspective on the data. CaseID is column A, Activity is column D and finally Timestamp is column B.

Figure 1: The three minimum requirements for process mining

	A	B	C	D	E	F	G
1	CaseID	Timestamp	Medium	Status	Service Line	Urgency	
2	case9700	20.8.09 11:46	Phone	Registered	1st line		0
3	case9700	20.8.09 11:50	Phone	Completed	1st line		0
4	case9701	23.9.09 12:23	Phone	Registered	1st line		0
5	case9701	23.9.09 12:27	Phone	Completed	1st line		0
6	case9705	20.10.09 14:21	Phone	Registered	Specialist		2
7	case9705	20.10.09 16:48	Phone	At specialist	Specialist		2
8	case9705	19.11.09 10:31	Phone	In progress	Specialist		2
9	case9705	19.11.09 10:32	Phone	Completed	Specialist		2
10	case3939	15.10.09 11:48	Mail	Registered	Specialist		2
11	case3939	15.10.09 11:48	Mail	Offered	Specialist		2
12	case3939	20.10.09 17:18	Mail	In progress	Specialist		2
13	case3939	20.10.09 17:19	Mail	At specialist	Specialist		2
14	case3939	21.10.09 14:49	Mail	In progress	Specialist		2
15	case3939	21.10.09 14:49	Mail	In progress	Specialist		2
16	case3939	28.10.09 10:17	Mail	In progress	Specialist		2
17	case3939	28.10.09 10:18	Mail	Completed	Specialist		2
18	case9704	20.10.09 14:19	Mail	Registered	1st line		0
19	case9704	20.10.09 14:24	Mail	Completed	1st line		0
20	case9703	20.10.09 14:40	Phone	Registered	1st line		0
21	case9703	20.10.09 14:58	Phone	Completed	1st line		0
22	case9702	24.8.09 12:24	Mail	Registered	2nd line		2
23	case9702	24.8.09 12:30	Mail	Offered	2nd line		2
24	case9702	24.8.09 12:31	Mail	Scheduled	2nd line		2
25	case9702	26.8.09 9:05	Mail	In progress	2nd line		2
26	case9702	26.8.09 9:19	Mail	Completed	2nd line		2
27	case9709	20.10.09 14:26	Mail	Registered	Specialist		2
28	case9709	20.10.09 14:26	Mail	Offered	Specialist		2

Source: Fluxicon (2022a)

Event Log Extraction is according to ANG Infotech (2022) technical process of extracting the process data from the enterprise systems and transform the data into an event log. Event log extraction takes up 80% of the time in the entire process mining project. Sources for event logs are often relational databases of enterprise systems or CSVs, whereas data lakes and event-based systems seem to be emerging as alternatives. These responses highlight that enterprise systems should ideally have highly integrated event log generation and extraction capabilities.

4. Formats of event logs for Process Mining analysis

The basic formats of event logs for Process Mining analysis include eXtensible Event Stream (XES), Object-Centric Event Logs (OCEL) and Comma-Separated Values (CSV).

eXtensible Event Stream (XES) is the standard format for Process Mining supported by the majority of process mining tools. XES was adopted in 2010 by the IEEE Task Force on Process Mining as the standard format for logging events. It has become an official IEEE standard in 2016. (Processmining.org). We can see a list of Process Mining tools that are supporting XES format in the following Table 1.

Table 1: Process Mining tools supporting XES

Tool	XES certified
Apromore	Import, Export: A1, B1, C1, D1
Celonis Process Mining	Import: A1, B1, C1, D1
Disco	Import, Export: A-D, X
Icris Process Mining Factory	---
MEHRWERK Process Mining	Import, Export: A-D, X
Minit	---
myInvenio	---
PM4KNIME	Import, Export: A-D, X
Pm4py	Import, Export: A-D, X
PMLab-Lite	Import, Export: A-D, X
Process Diamond Intelligence	Import, Export: A1, B1, C1, D1, X1
ProcessGold Enterprise Platform	Import: A-D, X
ProM	Import, Export: A-D, X
ProM Lite	---
QPR ProcessAnalyzer	Import: A1, B1, C1, D1
RapidProM	Import, Export: A-D
Rialto Process	---
SNP Business Process Analysis	---

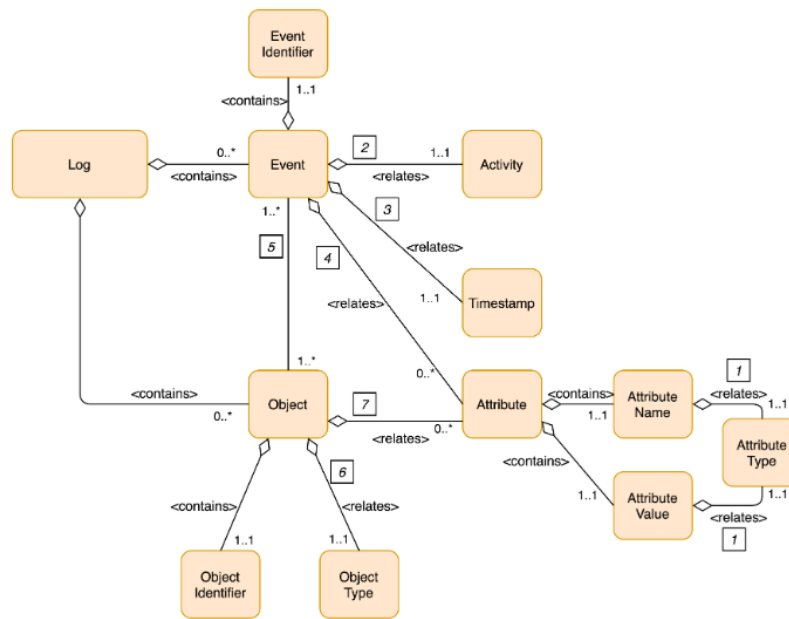
Source: <https://www.xes-standard.org/tools>.

“The XES standard defines a grammar for a tag-based language whose aim is to provide designers of information systems with a unified and extensible methodology for capturing systems behaviors by means of event logs and event streams is defined in the XES standard. An XML Schema describing the structure of an XES event log/stream and a XML Schema describing the structure of an extension of such a log/stream are included in this standard.” (XES-STANDARD.ORG, 2021a)

Another file format for Process Mining is called Object-Centric Event Logs (OCEL). “The purpose of the OCEL standard is to provide a general standard to interchange object-centric event data with multiple case notions. The OCEL standard has been proposed and is maintained by the Process and Data Science group of the RWTH Aachen University”. (OCEL standard)

We can see the UML class diagram for conceptualizing the OCEL in the following Figure 2.

Figure 2: The UML class diagram for conceptualizing the OCEL



Source: OCEL standard (<https://www.ocel-standard.org/1.0/specification.pdf>)

The third file format for Process Mining is called Comma-Separated Values (CSV). “Often Comma-Separated Values (CSV) files are used as an intermediate format. The rows in a CSV file correspond to events and the columns to attributes of events. There should be columns for the case identifier, the activity name and the timestamp of an event, but there may be many more attributes. CSV files are a popular format especially for manual pre-processing of data from log files to tools for Process Mining. For example opensource ProM and commercial tool Disco by Fluxicon can convert a CSV file into an event log by assigning columns to process mining concepts.” (Processmining.org) There is a plug-in in the ProM which can convert CSV into the required XES structure.

Fluxicon (2022b) provide Data Quality Checklist as a guide to assess the quality of data. This guide can us help with the data validation process. There are these following questions:

- I. No errors during import?
- II. No gaps in the timeline?
- III. Expected amount of data?
- IV. Expected distribution of attribute values? No unexpected empty values?
- V. No cases with unexpected number of steps?
- VI. Expected timeframe? No unexpected long throughput times?
- VII. No unexpected ordering of sample cases? No unexpected flows in the process map?
- VIII. Data validation session with domain expert done?
- IX. Documented all quality issues and data questions?
- X. If you had to exclude data due to data quality problems, is the remaining data set still representative?

5. Process Mining software

There are many Process Mining software tools that help us to visualize business processes. There will be some examples of Process Mining software tools such as Appian, Bizagi, Disco and ProM.

“Appian is a software company that automates business processes. The Appian Platform includes everything you need to design, automate, and optimize even the most complex processes, from start to finish. The world's most innovative organizations trust Appian to improve their workflows, unify data, and optimize operations—resulting in better growth and superior customer experiences”. (Appian, 2023) There are several ways to add an event log to Process Mining in Appian (Appian, 2022a) documentation:

- I. upload a log file manually,
- II. schedule a transformation and upload from Mining Prep,
- III. upload a log using Mining API and a transformation script,
- IV. schedule an upload from Mining Prep with a transformation script.

In addition to uploading CSV files, Mining Prep can import data sets from a database or ERP application. Standard connectors come out of the box for the following systems (Appian, 2022b): PostgreSQL, MariaDB, MSSQL or Oracle.

Users of Bizagi Modeler Enterprise can now access process mining capabilities to leverage their process data and optimize business operations. This allows organizations to automate as-is process discovery, provide accurate business impact analysis and help teams focus on the change that will provide the most value. (Bizagi, 2021) There is a Bizagi Modeler desktop application with Enterprise plan that allows users Process Mining feature. The following formats are in Bizagi supported: Extensible Event Stream (XES) format as input and Comma Separated Value (CSV) used in custom logs. (Bizagi, 2022)

Disco is Process Mining tool that has been developed by former leading academics from Eindhoven University with many years of Process Mining experience. Disco allows us to use the most efficient algorithms for Process Mining, and for filtering protocols using the framework. Disco is very user-friendly and intuitive tool. It is possible to create process maps that are based on raw data. There are also used interactive charts to provide an overview of data that contains in-depth information about attribute values, resources, and all activities. Disco is commercial tool but is also offer an education license for research purposes.

“ProM is an extensible framework that supports a wide variety of process mining techniques in the form of plug-ins. It is platform independent as it is implemented in Java, and can be downloaded free of charge. ProM 6 is distributed in parts, which offers maximal flexibility. First, the ProM 6 core is distributed as a downloadable package using the GNU Public License (GPL) open source license.” (PROM, 2022)

6. Conclusion

The aim of this article was to summarize the possibilities of using event logs from ERP systems for Process Mining on a theoretical level. The basic formats of event logs include eXtensible Event Stream (XES), Object-Centric Event Logs (OCEL) and Comma-Separated Values (CSV). Very famous format is especially Comma-Separated Values (CSV), which can often be exported from most database systems and then imported into the Process Mining tools after necessary data preprocessing. Xtensible Event Stream (XES) is referred as the standard format for Process Mining supported by most Process Mining tools. This format is usually not possible to export directly from the ERP system database. In conclusion, if there is suitable data, it is possible to analyze using Process Mining methods and techniques various business processes from purchasing to financial, production or logistics. The main advantage is that the process that we extract from the data using Process Mining corresponds exactly to reality and we are able to analyze the current state of processes.

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CROSS-PLATFORM AND NATIVE MOBILE APP DEVELOPMENT

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Abstract

Mobile computing devices and their software are playing an increasingly important role. Due to the nature of the hardware and the specifics of its use, mobile application development sometimes follows different processes and approaches than desktop applications. This paper focuses on the other options for mobile application development. It compares two basic methods, namely native application development and cross-platform development. It shows the advantages and disadvantages of selected multiplatform tools such as React Native, Flutter, and Xamarin by examples and comparison of solutions to practical tasks and patterns. The work compares cross-platform development tools and the basic tools for native development, i.e., Android Studio and Xcode. It includes a study and comparison of selected concepts, frameworks, and tools for cross-platform development. Another goal of the paper is to point out the fundamental differences from desktop application development. The differences between native and cross-platform mobile application development are in the technical and programming areas and the economic costs. Although, at first glance, it may seem that multiplatform development is more economically advantageous, this may not always be the case. A comparison of the development of practical projects shows that cross-platform development has the most disadvantages compared to native mobile application development in terms of application user interface and the use of the specifics of individual operating systems and hardware components. Based on the results of several case studies with high school and university students, this paper demonstrates the benefits of teaching native mobile applications and the potential of this area for motivating students in learning programming.

Keywords: cross-platform development, education, mobile application, native application

JEL codes: Z

1. Introduction

Due to the importance of mobile devices nowadays, mobile app development plays a significant role. There are two competing operating systems currently used in the mobile phone and tablet industry, namely Android and iOS, and their variants. Software companies are forced to develop applications for two different systems, which is often costly in terms of time, money, and human resources. The two most widely used mobile operating systems have many standard features. Yet, some fundamental differences make it challenging to develop them in a common and unified way. Some fundamental differences include the more closed nature of iOS (sandboxing, limited distribution, inability to modify and tamper with the system, complete application control, limited variants of supported hardware, and more).

In contrast, Android operating system devices can use differently configured hardware. The operating system belongs to the Open-Source category. Therefore, individual companies can customize the system according to their requirements. The applications we create can be distributed in various ways without significant restrictions. The systems differ in user interface requirements, which play a much more important role in mobile systems than desktop applications.

Mobile application development can be handled in two primary ways. The first is to create native apps, i.e., apps built specifically for a particular hardware and software system, using specialized tools and languages for that platform. The second way is to develop cross-platform applications. The latter does not focus on a specific system but seeks to create an application usable on all target platforms. Popular cross-platform development frameworks and tools include Flutter, Xamarin, React Native. (Ahti, 2016) (Bardram, 2020). Other cross-platform development approaches can be, for example, PWA or Kotlin multiplatform. PWA - Progressive Web Applications uses web application development practices. These applications can also be used in offline mode. The advantage is the usability on all platforms, not just mobile operating systems. The disadvantage is the limitations and restrictions of web browsers. PWAs are becoming increasingly popular nowadays. It uses technologies and languages familiar to web application development, such as HTML, CSS, JavaScript.

Kotlin cross-platform system makes use of the new Kotlin programming language. It is newly used for developing mobile applications for Android OS and should replace Java. Kotlin can also be partially used for iOS development. Depending on the type of project, up to two-thirds of Kotlin code can be used for cross-platform development. However, the visualization parts and the parts using the specifics of both systems need to be developed natively. Therefore, Kotlin cannot be used for complete cross-platform application development. (Kuitunen, 2019) (Pulasthi, 2021).

2. Methodology

The basic approach of this thesis was a comparison of different methods in the development of mobile applications. The paper shows only some comparisons. The whole field is much more complex and extensive. We set some basic research questions:

- Which framework is more suitable for cross-platform development?
- Does the choice of framework and development tools affect cross-platform development?
- Which type of application is more suitable for native development, and which type of multiplatform development?
- What are the differences between using Java and Swift programming languages?

Three frameworks that are among the most popular tools for cross-platform mobile app development were compared. These were Flutter, Xamarin, React Native. The comparisons were made using practical examples for which prototypes of the underlying problems were designed:

- Working with the camera
- User environment
- Working with the database
- API usage

The main criteria observed were the code required to solve the prototype. Also evaluated were the available libraries, the created application's responsiveness, and the application's size. Uniformity of application behavior on both platforms and differences in user experience. The individual criteria were scored, where more points mean a better score. For example, for the amount of code, 3 points were given to the platform with the least amount of code. A system received 2 points if it had 10% more code. A system with code 20% more extensive received 1 point, and a system with 30% more code received 0 points. For support of libraries for working with hardware elements, 3 points were awarded to a system supporting all the required libraries. 2 points were awarded to a system with libraries covered by organizations and are likely to develop and update them. One point is for a system where, although there are at least some libraries, they are more likely to be developed only by the programming community,

and there is no certainty of long-term support. 0 points were awarded for a system lacking some required libraries. For a prototype verifying the user interface, points were assigned in the following way: 3 points if the prototype is automatically adapted to all UI requirements for a specific platform. A system scores 2 points if the prototype has automatically adjusted at least half of the UI elements for a particular platform. One point is given to a system where less than half of the UI elements are automatically adapted. A system scores 0 points without automatic UI modification for a specific platform (Pawlas, 2022).

Developing native mobile apps requires knowledge and the use of two different programming languages. For Android applications, Java has been the most widely used programming language so far. For iOS apps, the Swift programming language is currently used. The two languages use different syntaxes in many solutions in addition to other implementation techniques and approaches. We compared the behavior of specific solutions in both programs. We've made several speed measurements of Swift and Java programs. Measurements were performed on MacBook Pro (13-inch Retina Late 2013), Intel Core i5-4258U processor, 2.4 GHz, 8 GB 1600 MHz DDR3 memory, 256 GB SSD.

Since 2016, case studies have been conducted among high school and university students. Four case studies have been conducted with high school students during courses focused on mobile app development and programming education. Fifty-seven students participated in the courses. Another observation was conducted annually at the university among a total of 198 students during a course on Mobile Application Development. It monitored how motivated the students were, how they worked, and how successful they were in creating their mobile projects.

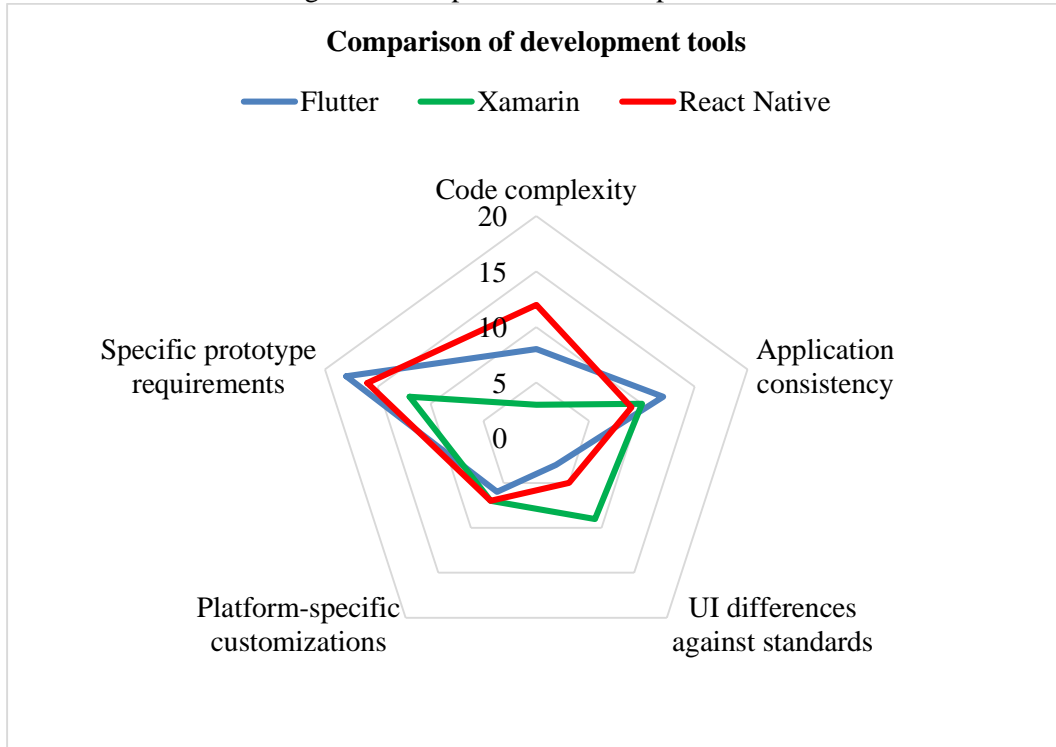
3. Results

Experience with practical projects and programming lessons shows that mobile application development differs in many ways from desktop application development. The user interface of the application plays a significant role. Both platforms use different standards. Android apps are created according to the Material Design standard, while iOS uses Human Interface Guidelines. The graphical interface and the way mobile apps are operated are very important. The controls of smartphones and tablets are in many ways different than desktop apps. There is usually less use of the keyboard and mouse. The user relies primarily on moving his fingers across the screen or voice commands. Very often, mobile applications are operated with only one hand, and the user interface needs to be adapted to this. Users are accustomed to mobile applications following the requirements and standards for the user interface of a particular system. For example, the difference between the two systems is also in the minimum touch on display. Android uses a minimum 48x48 pixels area, while iOS has a minimum control area of 44x44 pixels, which can cause problems in cross-platform mobile apps. Other differences in the user interface are, for example, in the top bar area, which on Android aligns to the left on iOS and the middle. Android prefers to use the tabs at the top of the mobile device screen to present the primary menu, while iOS uses the bottom navigation menu (Delia, 2015) (Rieger, 2019) (Zohud, 2021).

3.1 Comparison of multiplatform development systems

The following results compare selected frameworks Flutter, Xamarin, React Native for cross-platform development. The chart in Figure 1 shows the overall comparison of the frameworks. Individual prototypes - solved examples were scored. The graph shows the sum of points for each solved example (Pawlas, 2022). The maximum was 20 points for all prototypes. More points mean a better score in particular category. The React Native framework has the most balanced results.

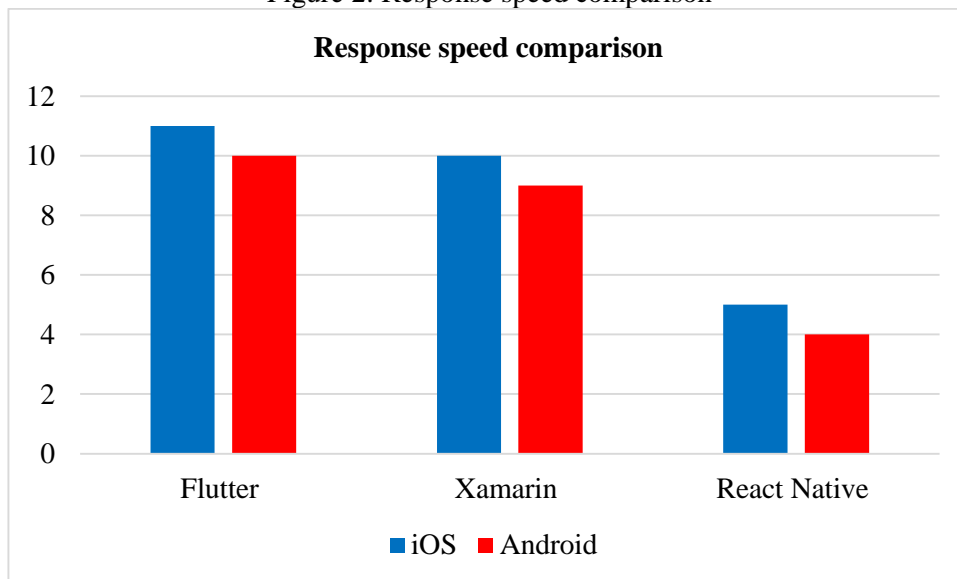
Figure 1: Comparison of development tools



Source: Pawlas (2022)

Figure 2 shows the results in the response speed of the prototypes created. The scoring of applications was done separately for each platform and each prototype. At the same time, applications built using the evaluated frameworks may behave differently depending on the tested platform and thus may achieve different evaluation results. The graph shows the resulting score for each framework and target operating system. The Flutter framework scores the most points - the best one for both target platforms.

Figure 2: Response speed comparison



Source: Pawlas (2022)

Unifying the GUI on both platforms in cross-platform development may cause problems for users who are used to a particular way of using the operating system. Changes and the non-standard

appearance of a mobile application may discourage users from using such an application. Cross-platform application development allows the creation of software for multiple operating systems. Developers create only one code for all platforms. Typically, up to 80% of the code for both mobile operating systems can be used this way. The other 20% often needs to be developed for each platform separately (Biørn, 2018) (Shah, 2019).

The essential advantages of cross-platform mobile app development include the need for only one development team, while the disadvantages include the following:

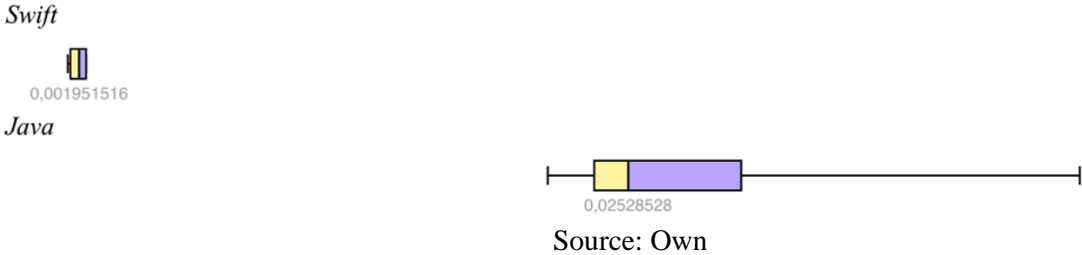
- The problem of dealing with different user interfaces and controls.
- More deficient use of unique capabilities of individual operating and hardware systems.
- Poorer use of specialized libraries and frameworks.
- Multiplatform tools introduce some libraries and system capabilities with a delay.
- Some tools and frameworks for cross-platform development require knowledge of other programming languages.
- Natively developed applications can work more efficiently and quickly.

3.2 Native mobile app development

Native development requires two separate development, two implementations, and testing, two programming teams. The two platforms also have different application architectures. iOS uses the Model-View-Controller architecture for mobile app development. In contrast, Android uses the Model-View-Presenter architecture for its applications. Some cross-platform tools use different architectures. For example, Xamarin uses the Model-View-ViewModel architecture. This requires programmers to be familiar with multiple design and implementation methods (Nawrocki, 2021) (Schmitt, 2022).

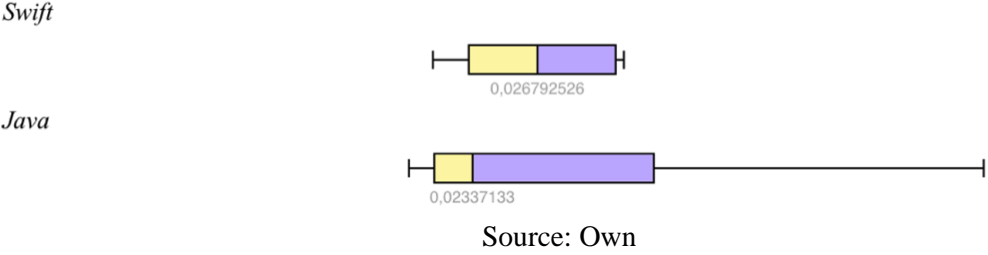
Native development requires using two different programming languages, which have been compared in this thesis using practical examples. We carried measurements in collections programs. Swift offers three collections: Array, Dictionary, and Set. In this article, we will show the results of array rate measurement. We used the Array collection in Swift, and in Java we used the ArrayList collection. We launched each program ten times. First, we measured the time to add 18050 elements to the collection. The elements were random numbers (Double). Figure 3 shows that Swift had better results (shorter time) than Java. The following results show differences between the two languages not only in the writing and amount of code but also in the resulting programs' behavior, their complexity, speed of execution, etc.

Figure 3: Measuring the time of adding elements



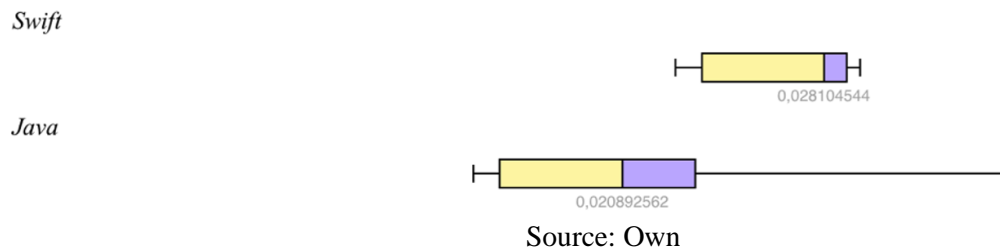
We also measured the speed of sorting elements in the collection using the sort() method. Swift had similar results to Java. The results are shown in Figure 4.

Figure 4: Measuring the sorting of elements in the collection



The graph of figure 5 shows the measurement results of the gradual removal of 6000 elements from the beginning of the field. Swift had the worst results in this test.

Figure 5: Results of time measurement remove elements



Source: Own

The different behavioral results of programs written in Java and Swift show that more attention needs to be paid to the differences during development. Otherwise, there is a risk that the developed application will behave differently on different mobile platforms, which is undesirable.

3.3 Teaching mobile app development

It turns out that for teaching programming and mobile app development, it is more appropriate to start with native development. However, it is a prerequisite that students have a basic understanding of object-oriented programming, and that hardware and software support is available. The advantage is that students will become more familiar with the specifics and requirements of each system. Through native development, students get a detailed look at each platform's capabilities, peculiarities, libraries, hardware, and software requirements. The disadvantage is the need to master two different development approaches and two different programming languages in the course.

Different forms of teaching have been tried. During the COVID-19 pandemic, it was not possible to teach native iOS development during distance learning because most students did not have access to macOS computers. The face-to-face instruction was conducted on macOS computers. Teaching native mobile application development has two fundamental problems. There is a need to teach two different development approaches, two different development systems, and two different programming languages. The second problem is that while any desktop computer can be used for Android app development, iOS app development requires a macOS computer, i.e., an Apple computer. These computers are less common than MS Windows computers, and Apple computers are also more expensive. Therefore, many educational institutions do not own these computers. The same is true for students, among whom macOS computers are less common. Any computer can be used to teach cross-platform development, as development tools and frameworks are available for most desktop systems.

4. Conclusion

When deciding whether to use cross-platform or native development, we must be clear about what we expect from the application. Suppose the mobile application is mainly used to mediate data stored on the server, and there is no need to make intensive use of each platform's hardware and software specifics. In that case, cross-platform development is usually preferable. On the other hand, for applications that need to make extensive use of hardware and software, where computing power, graphical interface, some platform specifics, etc., play an important role, then native development seems to be more advantageous. This may be the case, for example, for games, computationally intensive applications, applications using device specifics, etc. It also depends on the specific software company. If it is equipped for native development, switching to cross-platform development may not be economically and organizationally advantageous. In the transition time, it is necessary to have three teams instead of two. Maintain legacy native versions, retrain developers on new tools, find and learn new practices and programming or scripting languages, etc.

The most significant advantage of the Flutter framework is maintaining the consistency and reliability of the applications created across both platforms. It implemented all functionalities in all

tested projects - prototypes and provided sufficient library support. The worse results were in the area of the application user interface. Therefore, more manual adjustments are required for each platform.

The Xamarin framework adapted the user interface appropriately in all examples solved. On the other hand, the framework has the most extensive code scope, which is also due to the need to create separate XML files for the UI and for the page logic, which is created in C#. The framework required the most platform-specific customizations.

The least amount of code needed to be created in React Native. Practical results show that the framework is suitable for working with databases. From the examples studied, the framework appears to have minor requirements on the amount of code created.

The Flutter framework seems to be the most suitable for novice programmers, as it has a clear code structure, a sufficient number of libraries, and good documentation (Nivaho, 2019) (Shvets, 2019) (Wu, 2018).

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COMPUTING PRIORITY VECTORS OF PAIRWISE COMPARISON MATRICES: A REVIEW OF EXISTING SOFTWARE FOR SMALL AND MEDIUM-SIZED ENTERPRISES

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Abstract

This paper reviews existing software for computing priority vectors of pairwise comparison matrices, with an emphasis on applications for small and medium-sized enterprises. It provides an overview of freely available software, including features, advantages, and disadvantages. The paper compares three popular software options according to criteria including cost efficiency, accessibility and availability, of example solutions.

Keywords: pairwise comparison, priority vectors, small and medium-sized enterprises, cost efficiency, accessibility

JEL codes: C60

1. Introduction

Pairwise comparison is a widely used method for decision-making and prioritization in various domains, including business, engineering, and social sciences; e.g., see Ramík (2020) for an overview. It involves comparing two alternatives based on a set of criteria to determine their relative importance or preference. The result of a pairwise comparison is a matrix of values that represent the pairwise comparison judgments. However, the interpretation and utilization of such matrices often require a process of converting them into priority vectors, which indicate the relative weights of the criteria or alternatives.

Computing the priority vectors of pairwise comparison matrices is a relatively complex task that requires mathematical techniques, which have been studied extensively in the field of multi-criteria decision-making (MCDM). While many methods exist for computing priority vectors, the most commonly used one is the Analytic Hierarchy Process (AHP), which was introduced by Saaty in the 1980s; see Saaty (1980).

As a result of the increasing demand for MCDM methods and the popularity of AHP, a variety of software tools have been developed to facilitate the computation of priority vectors. However, there is a lack of comprehensive and up-to-date reviews of the existing software options, particularly in the context of small and medium-sized enterprises (SMEs). This paper fills this gap by providing a comprehensive review of existing software for computing priority vectors of pairwise comparison matrices, with an emphasis on applications for SMEs.

The paper is structured as follows. In Section 2, we introduce the concept of priority vectors and the methods for computing them. In Section 3, we briefly present selected software tools for computing priority vectors, including their features, advantages, and disadvantages. In Section 4, we compare several popular software options according to criteria including cost efficiency, accessibility, and availability of examples. Section 5 concludes.

Overall, this paper aims to provide a valuable resource for SMEs and other users who are interested in using pairwise comparison and AHP methods for decision-making and prioritization. The review of existing software tools and the comparison of their features can help users to make informed decisions about which software tool is best suited for their specific needs and requirements.

2. Computing Priority Vectors

A priority vector is a normalized vector of weights that indicates the relative importance or priority of the criteria or alternatives being compared. There are various methods for computing priority vectors, including the two most popular ones: the Eigenvector method (Saaty, 1987) and the Logarithmic least squares method (Crawford and Williams, 1985), which is also known as the Geometric mean method. The former is underlying the most widely used approach to derive the weights for a set of criteria according to their importance/significance, the Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty during the 1970s; Saaty (1980).

The AHP method is based on the concept of pairwise comparison and uses a hierarchical structure to represent the decision problem. The hierarchy consists of a goal, criteria, and alternatives. The goal represents the overall objective of the decision problem, while the criteria represent the sub-objectives or factors that contribute to achieving the goal. The alternatives represent the options or choices being considered for the decision problem.

To compute the priority vector for a pairwise comparison matrix, the AHP method involves the following steps:

1. Construct the pairwise comparison matrix: In this step, we compare each pair of criteria or alternatives and assign a score to each pair. The scores are typically given on a scale from 1 to 9, where 1 indicates equal importance and 9 indicates extreme importance.
2. Normalize the matrix: In this step, we divide each element in the matrix by the sum of the elements in its column. This gives us a matrix of relative weights for each criterion or alternative.
3. Compute the row averages: In this step, we calculate the geometric mean of each row of the normalized matrix.
4. Compute the priority vector: In this step, we divide each row average by the sum of all the row averages. This gives us the priority vector, which represents the relative importance of each criterion or alternative.
5. Check for consistency: In this step, we check the consistency of the matrix by computing the consistency index (CI) and the consistency ratio (CR). The CI measures the degree of inconsistency in the matrix, while the CR compares the CI to a random index to determine if the matrix is consistent. If the matrix is inconsistent, we may need to revise your pairwise comparisons.

The AHP method has been widely applied in various domains, including business, engineering, and social sciences, and has been implemented in many software tools. However, the method has some limitations, including its assumption of transitivity and the difficulty in obtaining consistent judgments in complex decision problems. Therefore, alternative methods and extensions of the AHP method have been proposed to address these limitations. In the next section, we review existing software tools for computing the priority vectors of pairwise comparison matrices, with an emphasis on applications for SMEs.

3. Overview of Existing Software

Due to the number of MCDM methods available, SMEs are confronted by the difficult task of selecting the appropriate MCDM method, as each method has its own limitations, particularities, hypotheses, premises and perspectives and can lead to different results when applied to an identical problem (Ishizaka and Nemery, 2013). This paper thus aims to provide a basic overview of three software tools. Out of many similar ones available, these are selected in order to meet frequently observed requirements of SMEs:

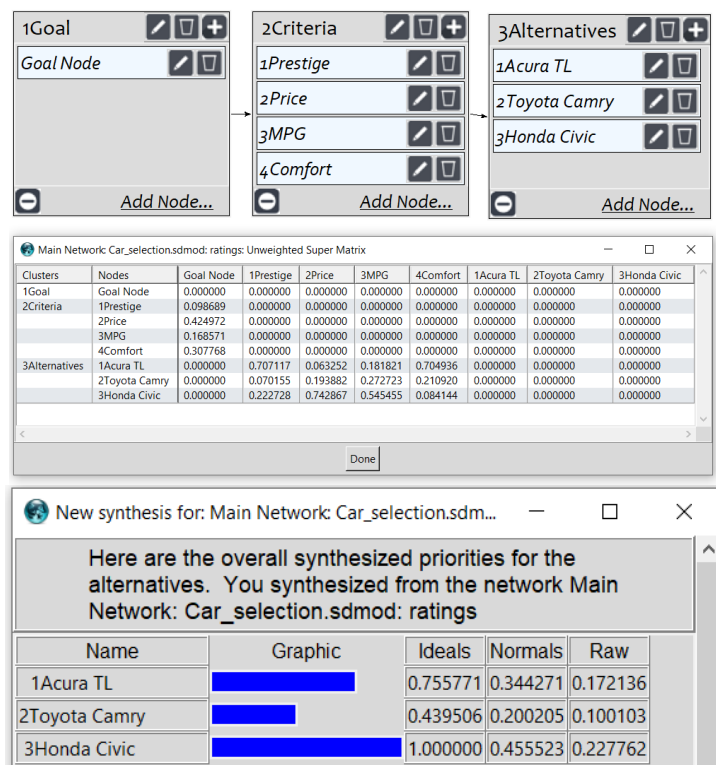
1. The software has to be cost efficient (being for free is the best from this point of view).
2. The software has to be quickly available (as SMEs typically try to dramatically reduce the time inefficiency of the employees).
3. The software has to be easy to understand (the same reason as for the previous point).

According to these criteria, we have chosen three software options available for computing priority vectors of pairwise comparison matrices: SuperDecisions¹, AHP-OS² (Goepel, 2018) and 123AHP³. In what follows, we provide a brief overview of the software options, an illustrative example of their use and emphasize several of their interesting properties.

3.1 SuperDecisions

The SuperDecisions software is the only *free* educational software that implements the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). The software was developed by the team of the creator of the method, Thomas Saaty. After registration, which is *required* to download the software, the user can install and run SuperDecisions and immediately start the decision-making process, according to the available video. This immediacy is strongly supported by examples accessible from the software's website, under the link "sample models". Most of the sample decision models include a short description, the SuperDecisions software file, a powerpoint presentation describing the major findings and a final report about the decision. Notably, these models mostly come from the MBA and PHD students in Professor Thomas L. Saaty's "Decision Making in Complex Environments" class from 2001 until today at the Katz Graduate School of Business, University of Pittsburgh, USA. The students were usually employed fulltime in companies in the city of Pittsburgh so many of the models are related to their businesses so consequently they showed in designing the model. In Figure 1, the reader can see an example application of the software – a car selection AHP task – where the best option out of three cars (alternatives) is selected based on four typical criteria.

Figure 1: Screenshots from a car selection AHP task in SuperDecisions.



Source: Own

When a SME faces a complex decision problem, this software can, after registration, download and installation, immediately serve as a decision-support tool. Finally note that the software is not limited just to AHP and ANP models, but also support rating, BOCR (benefits, opportunities, costs, and risks) and share models, which are described in detail in the tutorials section on the software's website.

¹ <https://superdecisions.com/>

² <https://bpmsg.com/ahp/>

³ <http://123ahp.com>

3.2 AHP-OS

The AHP-OS is a web based AHP supporting tool for decision making processes. In contrast to other software for decision making, which are often not fully transparent to the users as they primarily target companies and pursue a business objective, the intention of AHP-OS was to provide a complete and *free* software tool for educational and research purposes where the methods and algorithms are well documented and validated (Goepel, 2018). The software is implemented by using PHP and SQL. After registering, which is free but *required*, AHP-OS offers a lot of features, including the following ones:

- Flexible definition of decision hierarchies as text input, following a simple syntax with multi-language support using Unicode character coding,
- Weight calculation (hierarchy mode) and alternative evaluation (alternative mode) using the AHP eigenvector method,
- Pairwise comparison input, highlighting the top-3 most inconsistent judgments,
- Group consensus calculation based on the Shannon α - and β -entropy,
- Weight uncertainty estimation using Monte Carlo simulation,
- Sensitivity analysis,
- Weighted sum model (WSM) and weighted product model (WPM) for the aggregation of alternatives,
- Export of input and result data as comma separated value (CSV) files for further processing or presentation in a spreadsheet program.

To start a program, the user can choose from the following options: My AHP Projects, AHP Priority Calculator, AHP Hierarchies, AHP Group Session or Group Consensus Cluster Analysis. In Figure 2, the user can observe the visual appearance of AHP-OS during a task in AHP-OS involving computation of the priority vector.

Figure 2: Screenshots from a car selection task in AHP-OS involving computation of a priority vector (continues on the next page).

AHP Criteria Names

Please fill out

AHP priorities

Name of Criteria

1	<input type="text" value="Quality"/>
2	<input type="text" value="Safety"/>
3	<input type="text" value="Design"/>

max. 45 character ea.

	A - wrt AHP priorities - or B?	Equal	How much more?
1	<input type="radio"/> Quality <input checked="" type="radio"/> Safety	<input type="radio"/> 1	<input checked="" type="radio"/> 2 <input checked="" type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7 <input type="radio"/> 8 <input type="radio"/> 9
2	<input checked="" type="radio"/> Quality <input type="radio"/> Design	<input type="radio"/> 1	<input checked="" type="radio"/> 2 <input type="radio"/> 3 <input checked="" type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7 <input type="radio"/> 8 <input type="radio"/> 9
3	<input checked="" type="radio"/> Safety <input type="radio"/> Design	<input type="radio"/> 1	<input type="radio"/> 2 <input type="radio"/> 3 <input checked="" type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7 <input type="radio"/> 8 <input type="radio"/> 9
CR = 38.3% Adjust highlighted judgments to improve consistency			

Resulting Priorities

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat	Priority	Rank	(+)	(-)
1	Quality	2	18.4%	18.4%
2	Safety	1	30.4%	30.4%
3	Design	3	8.4%	8.4%

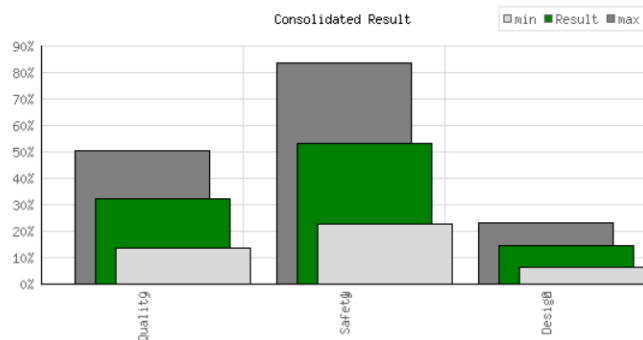
Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3
1	1	0.33	4.00
2	3.00	1	2.00
3	0.25	0.50	1

Number of comparisons = 3
Consistency Ratio CR = 38.3%

Principal eigen value = 3.368
Eigenvector solution: 7 iterations, delta = 3.8E-8



Source: Own

3.3 123AHP

123AHP is a multi-objective decision support tool based on AHP. In order to start using this tool, it is even *not necessary* to register. However, after registering, one can fully exploit all offered features. Depending on the type of the problem the SME faces, three modes for the web application can be chosen:

- Single-mode – standard AHP modeling, includes a pairwise comparison of alternatives with respect to criteria.
- Team-mode – a mode with the possibility to invite another user (friend, coworker, expert) to help the user in evaluation in one or more criteria. The moderator sends invitations to a participant by email, with instructions about decision problems and registration on 123ahp.com. The moderator considers participants' answers but independently decides about the problem.
- Group-mode – mode in which one group wants to make a decision. The moderator sends to each participant by email a link and instructions about the model and registration. Each participant evaluates alternatives with respect to all criteria of the model defined by the moderator. The decision combines pairwise comparisons from each participant.

In Figure 3, the visual appearance of 123AHP during an AHP car selection task is illustrated.

Figure 3: Screenshots from an AHP process example in 123AHP.



Source: Own

4. Comparison of Three MCDM Software Tools

The software options presented in the previous section are compared according to criteria that emphasize properties of a software when it comes to serve in a SME. We thus emphasize *cost efficiency*, represented by the price of the tool, *immediacy*, represented by the requirement of registration before the first use, *accessibility*, represented by the need of downloading the software, *visual appearance* of the software tool, and *availability of examples*. The comparison is summarized in Table 1.

Table 1: Comparison of three MCDM software tools

	SuperDecision	AHP-OS	123AHP
cost efficiency	free	free	free
registration	required a detailed one	required a less detailed one	not required for basic evaluations
accessibility	download and install	web access	web access
visual appearance	fully elaborated	mostly using basic HTML elements	a bit more elaborated than AHP-OS
examples availability	large set of examples, elaborated by students of Thomas L. Saaty	basic set of examples in a text form	relatively large set supported with nice illustrations

Source: own source (author's research)

In particular, we would like to emphasize 123AHP, with its best immediacy while still having a nice and clear interface. If the reader would like to choose the best tool according to her/his needs, it might be an interesting idea to perform an AHP task with the alternatives being the three software tool compared here. Then, we would suggest to use 123AHP, as this could be done immediately with the

lowest effort. Considering SuperDecision, we would like to emphasize the large and elaborated set of examples available. Finally, AHP-OS is the most transparent software tool with most of its functionality described in detail in Goepel (2018).

5. Conclusion

We compared existing software options for computing priority vectors of pairwise comparison matrices, with an emphasis on applications for small and medium-sized enterprises. An overview of three freely available software was provided, including cost efficiency, accessibility and availability of example solutions. After a brief presentation of the tools, features that are important from the SME's point of view were summarized in a table based on five criteria.

Note that there exists a plethora of other MCDM software tools, including, e.g., popular ones like Expert Choice or TransparentChoice Software. These tools are however either commercial software or parts of commercial software, so we did not consider them here, as we emphasize the lowest possible price, which is so vital for many SMEs. However, if the software tools considered here limit the potential users, these commercial options are then worth of consideration, while taking into account the budget of the decision task under concern.

In further research, we would like to consider other criteria like the time it takes to process the request, whether the application is cloud-based and requires data to upload (a risk from the company's perspective), or what are the limitations of the educational versions.

Acknowledgement

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HOME WORKING DURING COVID-19 PANDEMIC IN THE CZECH REPUBLIC AND ITS POSITIVES AND NEGATIVES FROM THE PERSPECTIVE OF EMPLOYEES: A CASE STUDY

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Abstract

The main aim of this article is to summarize the experience and positive and negative aspects of home working during the pandemic in 2020 and 2021 from the employees' point of view in the Czech Republic and then to discuss recommendations for home working in the Czech Republic and other similar economies in the future. A partial goal is to find out what is the opinion about home working of representatives of Generation Z, this means the future employees, who will have experience with home working not as a benefit, but almost as a standard work mode in the future. The secondary data were obtained by selection and content analysis of 475 quantitative and qualitative print and virtual information published on the given topic. The survey then provided insight into this issue.

Keywords: Covid-19, future, home working, negatives, positives

JEL codes: M152, M54, I12

1. Introduction

The pandemic of the virus disease Covid-19 caused by the coronavirus SARS-CoV-2, which occurred for the first time in December 2019 in Chinese Wuhan, which then spread all over the world, turned into a global economic and social disturbance. It has dramatically affected lives of people in the Czech Republic in private and work-related areas (ManpowerGroup, 2021). The year 2020 was full of challenges for many companies, and so has been year 2021. The pandemic has taught everybody to adapt, it has changed the settings of work and in many cases, it has totally changed the company culture as well (HR Forum, 2021a). According to a research by the company ManpowerGroup Czech Republic under the name of “ManpowerGroup Index of the job market”, the pandemic of covid-19 has negatively influenced business of 57 % of Czech companies, from which 10 % had to be shut down completely. Thirty-five per cent of companies have not noticed any changes in business activities and 3 % have increased their business. In the international comparison effects of the pandemic on companies in the Czech Republic are similar to, for example, Germany or Slovakia (EIPA, 2020; Deloitte, 2021b; TfN, 2021). Czech data is not different from global average, where 63 % of the companies have stated negative effects of the pandemic on business (ManpowerGroup, 2021).

The pandemic has had an impact on many areas and industries. Even the most conservative employers had to reevaluate their ways of functioning. Those, who had reclined new technologies, home working, on-line work, or virtual meetings, had to change their perspective quickly (ManpowerGroup, 2021).

Work from home has been the number one topic in this period. Either if people want it and do not have it, or do not want it and experience it (Anguelov and Angelova, 2021). This has also been shown by the number of media posts about home working. Between the years 2019 and 2020 the number increased eight times (Hájková, 2021). The transition to home working was a huge and sudden change. The shift, which happened last year, would normally take four or five years. The companies and employees did not have any time for preparation (Očenášková, 2021b). Before the coronavirus period the possibility to work from home was a welcomed employee benefit. The pandemic shuffled the cards and home working became a necessity (Buřinská, 2021). We can expect that the number of e-workers, who will work from home, will be increasing every year even after the pandemic; so-called hybrid work,

a combination of home working and work from office, is expected to rise (Novinky.cz, 2021b; Nolan et al., 2021). According to Castrillon (2020) by 2025, an estimated 70 % of the workforce will be working remotely at least five days a month. Gartner survey of 800-plus HR leaders states that 48 % of employees will likely work remotely at least part of the time after Covid-19 versus 30 % before the pandemic (Baker, 2021). Eunhwa et al. (2021) add that the strict traditional view of “showing” up in the office from Monday through Friday is likely on the decline.

Even though there are many surveys which cover different kinds of impacts of the coronavirus pandemic on both Czech employers and employees, there are not, according to the authors and available facts, any data anywhere cumulatively presented, neither there are any conclusions made from them. This could help to better organize work from home in the future. Therefore, the aim of this article is to fill this research gap and to thoroughly analyze the experience and positive and negative aspects of home working in the period of the covid-19 pandemic in the years 2020 and 2021 from the employees’ point of view in the Czech Republic and based on this to discuss recommendations for working in such mode in the Czech Republic and other similar economies in the future. Even in the future and not only in our conditions, but also in other similar economies, people will work from home. It is necessary for employees and employers as well to realize this experience, the positives, and the negatives, and to approach home working in the future in a way that will guarantee the needed productivity of employees and whole organizations and to limit the negative effects that home working may have on employees. A partial goal is to find out what is the opinion about home working of representatives of Generation Z, this means the future employees, who will have experience with home working not as a benefit, but almost as a standard work mode in the future.

The paper is structured into five parts, where after the introduction, literature review and description of the methodology of the paper, the main part of the paper follows, i.e. the findings regarding the experience of home working, its positives and negatives from the perspective of current and future employees. The next part of the article presents recommendations for successful management of home working not only from the employee’s perspective, but also from the perspective of an employer. The conclusion then summarizes the state of the covered issues in the period of writing of this article and outlines further steps in addressing issues related to home working.

2. Theoretical Background

Before the pandemic, only 5.4 % of employed in the EU-27 usually worked from home – a share that remained rather constant since 2009 (EU, 2021). In the conditions of the Czech Republic it was around 4 % of employees (Kyzlinková et al., 2020). The concept of home working begins to emerge at the coming of the Covid-19 pandemic and becomes an alternative strategy for many organizations all over the world (Mustajab et al., 2020), including the Czech Republic. Working from home has replaced an earlier attractive benefit and has become a standard way of work, which protects lives and health of employees (Mikešová, 2021). Working from home now represents a crucial dimension of the future of work (Bai et al., 2020).

Working outside of the workplace is put into the category of so-called flexible forms of work. It is a form of employees’ benefits, where the employee can work partially from home (Dandová, 2021). Working from home does not require physical presence in the work environment, but employees naturally live within commuting distance of the office and do their work in their home environment. (Choudhury et al., 2020; Garrett and Danziger, 2007).

Home working brings positive effects to most employees and employers, these include the increase of employee work effort, self-leadership, engagement and well-being of employees by providing them with more autonomy (Bathini and Kandathil, 2019; Galanti et al., 2021; Nakrošienė et al., 2019; Wood et al., 2018; Rupietta and Beckmann, 2018). Furthermore, based on many surveys it is possible to state that if employees work from home there are other benefits, such as: flexibility, improved employee retention, attracting new talent, convenience, increased productivity, increased employee motivation, freedom of work schedule, more time for and with family and more leisure time, improved efficiency, improved employee health and well-being, cost and time savings on commuting to work, better work-life balance (Businessinfo, 2021; Hylland and Prottas, 2017; Okuyan and Begen, 2021).

On the other hand, home working has a negative impact on employees and employers as well. Negative aspects of home working can be seen especially in social isolation, stress, work-family conflict

(Galanti et al., 2021; Eng et al., 2010). Furthermore there are also other disadvantages of working from home, such as: home working does not suit everyone, difficulty in monitoring performance, home distractions, potential burnout, greater work-related fatigue, cost of working from home, problems with staff development, lack of working transparency, difficulty in accessing relevant technology and important documents from home securely, difficulty in controlling the balance between work and life, information security risk, physical and emotional exhaustion, decreased staff morale, not all jobs suit home working etc. (Businessinfo, 2021; Galanti et al., 2021; Palumbo, 2021; Okuyan and Begen, 2021; Vione and Kotera, 2021).

Minimizing the negative effects of home working is important for maintaining the productivity and well-being of individuals, especially during the covid-19 pandemic (Okuyan and Begen, 2021).

3. Material and Methods

The main aim of this systematic reviews article is to summarize the experience and positive and negative aspects of home working during the pandemic in 2020 and 2021 in the Czech Republic from the employees' point of view and then to discuss recommendations for home working in the Czech Republic and other similar economies in the future.

A systematic review provides a critical and constructive analysis of existing published literature in a field of home working. The results found through content analysis were then presented for evaluation by students (Generation Z) in a quantitative research to find out the potential no/mismatches in the evaluation by employees and prospective employees (students). This comparison was a partial goal of the article.

In the first phase of the work in July 2021, 87 suitable printed articles (often available in electronic form) were selected and 365 virtual retrospective quantitative and qualitative articles on the impact of the pandemic on the world of work and employees in the Czech Republic were filtered.

Because these findings covered the situation in the Czech Republic, authors of around 75 % of printed articles in the Czech language were local experts in given field – personalists, economists, directors, owners and managers of companies and recruitment consulting agencies, e.g. Hájková, A., Očenášková, A., Černošková, L., Housková, S., Kazdová, A., Kvapil, K., Hovorková, L., Jarošová, B., Reiner, T., Stegura, T. and others. These authors publish in Czech important specialized magazines which cover given problematics (for example Profi HR, HR Forum, Personál, Ekonom, Praktická personalistka and so on). Furthermore, to show the whole surveyed area and for the possibility of comparison of the situation in the Czech Republic with foreign countries, around 25 % of printed articles in English were found (using keywords related to the topic such as remote, work, home, Covid-19, impacts, positives, negatives and so on) in the databases of Web of Science and Scopus. These were articles published in renowned magazines such as Journal of Applied Psychology (Dutch authors Stollberger, J. et al.), International Journal of Manpower (Israeli author Nadiv, R.), Journal of Corporate Real Estate (American authors Eunhwa, Y. et al.), Frontiers of Psychology (Swiss authors Zurcher, A. et al.), Stress and Health (Dutch authors Darouei, M. and Pluut, H.), Journal of Labour Market Research (Norwegian authors Holgersen, H. et al.), Technology in Society (Macedonian authors Prodanova, J. and Kocarev, L.), Gender, Work and Organization (British authors Antonacopoulou E. P. and Georgiadou A.) and others.

Digital articles covering the problematics of remote work were filtered (using the same keywords) through Google in the following structure: 20 % of articles written in Czech and 80 % articles written in English. These were articles written by Czech authors (for example Drahošová, B., Vacková, H., Verner, I., Klímová, Z. and others), as well as foreign specialists in given field (for example British author Cook, J., French author Laljee, J., American author Zeidner, R., Australian author Dalzell, S., British author Partridge, J. and others) publishing on specialized websites and platforms and news servers.

Furthermore 23 printed and virtual researches provided for example by the Czech Ministry of Labour and Social Affairs, Czech and foreign analytical and consulting and recruitment agencies, or other subjects (McKinsey & Company, OECD, Grafton Recruitment, Deloitte, ManpowerGroup, Gallup, AON, Pew Research Center, Global Workplace Analytics and others) were found published in the same period covering the topic of working from home. Thus, a total of 475 print and virtual sources

were used. Printed and virtual articles were published in the second part of 2020 and the first half of 2021.

Search, comparison and synthesis in August 2021 provided an insight into this issue and information about positive and negative aspects of home working in the Czech Republic from employees' point of view. Based on the main objective stated above, the first research question was formulated.

Q1: What do the employees in the Czech Republic consider as the main positive and negative aspects of home working?

Then, based on accomplishing the main goal with the use of induction, deduction and personal experience of the authors, recommendations for the future use of home working not only for the Czech economy, but also for similar economies, were discussed.

In order to meet the partial goal, in June 2021, respondents were asked to find out the views of Generation Z on working from home. The question was: What negative and positive aspects do you perceive as the result of home working from the employee's points of view? Further two questions were asked based on the above-mentioned set partial goal:

Q2: Does Generation Z perceive positive and negative aspects of home working from the employees' point of view in the same way as employees, who worked from home for a year during the pandemic, and is the perception same if we also consider gender?

Q3: If there are any differences in perception of home working from the employee's point of view of Generation Z and those employees who worked from home for a year during the pandemic, what differences are there and do these differ if we also consider gender?

Basic and at the same time sample number (100 % return was reached) of respondents consisted of 172 students (110 women and 62 men) studying 2nd year of bachelor's degree programs focused on economics and management and marketing and trade at the faculty of economics at one of state universities in the Czech Republic. The respondents were answering in a written free form of text, they could provide more positive and negative aspects of home working from the employee's point of view. The evaluation of answers was done using the method of content analysis and descriptive statistics with second-level classification based on gender. No other statistical methods or analyses were used because of the above-mentioned partial goal.

4. Results and Discussion

Home working became an absolute necessity for many companies and state institutions and with the ongoing pandemic situation, it has become a common routine (Profi HR, 2020b; Kvapil, 2021).

4.1 Key Results Identified by Content Analysis

According to research by the Ipsos agency and HR company Welcome to the jungle, which was done at the beginning of 2021, it was found out that 28 % of Czechs, this means almost 3 million, had new experience with home working (Hájková, 2021; Očenášková, 2021b). Sixty-three per cent of economically active population came to their place of work, 37 % worked from home. Twenty-two per cent were switching between home working and the office, where one fifth was working from home for three to four days a week in average, and roughly same number stayed at home for one to two days a week, and 15 % of employees were working from home all the time, which was also confirmed by a research by the SC&C agency on the sample of 1400 employees who were working from home from March 2020 (Buřinská, 2021). Until the outbreak of the pandemic in 2020, 4 % of employees worked from home in the Czech Republic, this meant around 260 000 workers. During the first, spring wave of the infection spread in 2020, 1/3 of workers worked at least partially from home, in autumn 2020 this meant 18 % of people (Očenášková, 2021b). Four times more people who work from home work mentally, in comparison to manual labour, home working is more connected with graduates and especially with managing employees (61 %) (Hájková, 2021). When it comes to the distribution of age, 50 % of people who work from home are between 18 to 29 years, 25 % are people over 50 years old (Očenášková, 2021b).

Regarding the whole European Union, since the outbreak of the Covid-19 pandemic, working from home has become the norm for millions of employees in the EU. Eurofound (2020) estimates that

almost 40 % of EU employees worked full-time from home as a result of the pandemic. A recent study by the Joint Research Centre (JRC) provides a rough estimate that approximately 25 % of employees in EU industries worked from home as a result of the pandemic. Before the outbreak, only 15 % of EU employees worked from home (European Union, 2021).

According to the above-mentioned researches, those who had experience with home working, consider as positive aspects the possibility to manage their time according to themselves (68 %), time saving (e.g. commuting, make up etc., 64 %), money saving (e.g. lunches, commuting, 30 %), positive influence on the feeling of independence (59 %), possibility to take care of household during work (63 %), or the possibility to have more time for family (33 %) (Hájková, 2021; Očenášková, 2021a). It is also possible to see the fact that many employees have used the pandemic as a time for personal growth, as was published in last year's research of the ABSL association, which associates centres of company services. Sixty per cent of centres registered growth in online education, 66 % of employees improved in soft skills, 41 % aimed at obtaining new competencies and 33 % took part in online language courses (Profi HR, 2020c).

When it comes to productivity, according to the research done by Institute of Technology and Business in České Budějovice, 51 % of employees are more productive when working from home, 36 % can do the same amount of work, only 13 % of them are less productive at home. Higher productivity is increased by the fact that employees do not have to commute to work, are not distracted by their colleagues and are able to plan their work more efficiently (Novinky.cz, 2021b). For example, a research by the company LMC shows that 60 % of managers reported that during the spring and autumn wave of coronavirus home working had surprisingly high results (Černohlávková and Housková, 2021).

Employees working from home have stated in researches that negative aspects are missing colleagues (37 %), bad communication with colleagues (31 %), lack of necessary tools for work (28 %), troubles with time management (23 %) or disturbing and distraction by children (14 %) (Hájková, 2021; Langvik et al., 2021). People also suffer from the feeling of loneliness, they experience lack of trust from the side of micromanagers, they perceive worse flow of information and that they do not have such insight into the activities within the company. The willingness to cooperate is decreasing and a possibility of socialisation is missing (Novinky.cz, 2021a, Očenášková, 2021b; Kvapil, 2021). During total or long-term homeworking compared to partial home working, the employees have been negatively evaluating the effects on relationships with colleagues and relationships with their superiors (Očenášková, 2021b).

According to the analysis by ApuTime and DAP Service, during long-term home working, the inner motivation for work has dropped in comparison to the year 2019 by 6.5 % (IDnes.cz, 2021a). Research by the SC&C agency for company System4u presents that home working does not suit every other person, it means that more than a half of employees find homeworking difficult. They are bothered mainly by the complicated contact with colleagues (42 %), it means difficult communication with them via phone or email, they feel the absence of full-fledged access to company applications (each eighth), instability of connection and limited user rights are also a huge problem, they are bothered by complicated and non-functioning connection to company internal network (each sixth), one tenth of employees is unsatisfied with insufficient equipment which they have to work with (Buřinská, 2021). This is also confirmed by the research by the communication agency AMI Communications, according to which the present situation has influenced relationships among colleagues at 48 % of respondents, each eighth employee views the situation in the group rather as worsening and this is also for example due to cooling of relationships and envy of working conditions among colleagues, 34 % of respondents have changed their relationship towards their employer, either positively or negatively (Profi HR, 2020a).

According to the research by Survio which was conducted in the spring of 2021, long term work from home is damaging to junior employees, those who need to be close to their experienced mentors (Kvapil, 2021). The pandemic negatively influenced physical and mental health of people working from home (Okuyan and Begen, 2021). According to research of the company MultiSport, only one fifth of people did sport with the same intensity during the pandemic as before it, each third person had not done any physical activity even once a week (HR Forum, 2021b).

A long-term remote work does not suit a third of people, as shown by a survey conducted by Profesia in the spring of 2021. Nevertheless, it has proved its worth in many companies, and large and busy offices will soon become a thing of the past. A survey among HR professionals in Czech companies

have showed that in the future more than two-fifths of them assume a combination of work from home and at a workplace, the so-called hybrid model of work (Novinky.cz, 2021a). For example, one fifth of the employees of the company Google will work from home within the whole work week, the rest will, for at least three days a week, return to their offices (IDnes.cz, 2021b). Other companies choose a different regime - for example, the possibility that only people on certain positions will permanently go to the workplace or that employees will meet only for meetings and necessary events at work (Jarošová, 2021). Although remote work will be used to a greater extent, over 60 % of people in the Czech Republic work in branches where it is not possible to work from home due to the nature of their work (Očenáčková, 2021a).

Before the pandemic, about 20 % of employees occasionally had the opportunity to work from home - companies allowed this benefit only a few times a month according to the research done by the company LMC (Černohlávková and Housková, 2021). The main reason was mistrust. However, the technical unpreparedness of employers also played an important role. The test of preparedness was very tough in the spring of 2021, nevertheless thanks to it, the attitude of employers to this issue has changed fundamentally (Profi HR, 2020c). After the experience with the pandemic, half of the employers say that more frequent remote work will become the new norm (Černohlávková and Housková, 2021).

4.2 Research Questions

Based on research, comparison and synthesis of the above-mentioned survey results, it is possible to answer (A1) the first question Q1 like this:

Q1: What do the employees in the Czech Republic consider as the main positive and negative aspects of home working?

A1: The employees see as the main *positive* aspects of home working the possibility to manage their time according to themselves, saving time, saving money, a positive effect on their feeling of independence, possibility to take care of household during work, possibility to have more time for family, personal growth, productivity growth, no distraction by their colleagues, better work planning. The employees see as the main *negative* aspects missing colleagues, bad communication with colleagues, lack of necessary tools for work, troubles with time management, disturbing and distraction by children, feeling of a thin line between work and private life, feel of social distancing, feeling of loneliness, lack trust from the side of micromanagers, worse flow of information, not such insight into the activities within the company, lower willingness to cooperate, poorer relationships with colleagues and supervisors, decrease in motivation, no full-fledged access to company applications, instability of connection and limited user rights and negative influence on their physical health and mental problems as well.

In comparison with positive and negative aspects of home working identified by various global surveys in similar economies as for example Slovakia, Germany or Poland, we can see that the positive and negative aspects of home working in these states are very similar to the ones in the Czech Republic (EIPA 2020; Deloitte, 2021b; TfN, 2021; Businessinfo, 2021).

Because none, with one exception, of cited surveys dealt with the processing of results based on identification signs (age and gender) of the respondents, and because the authors of this article are in daily contact with young people, future employees, representatives of Generation Z, the authors set *a partial goal of the article* to find out what was the opinion of representatives of Generation Z about home working. Generation Z is a generation which will enter the work market in near future and the employers should know the opinion of these young people and to use the strengths of this generation.

The respondents (172 students, 110 women and 62 men), representatives of Generation Z, answered the above-mentioned question in the form of free writing, they could state more positive and negative aspect from the employee's point of view. The results are presented in Table 1.

Based upon the evaluation of respondents' answers, it is also possible to affirmatively answer (A2) the question Q2.

Q2: Does Generation Z perceive positive and negative aspects of home working from the employees' point of view in the same way as employees, who worked from home for a year during the pandemic, and is the perception same if we also consider gender?

A2: Meaning that Generation Z perceives positive and negative aspects of home working from the employee's point of view in the same way as the employees who worked for the whole year from

home during the pandemic (results of all above-mentioned surveys). There are some differences in perception of positive and negative aspects of home working according to gender.

Table 1: Positive and negative aspects of home working from the employee's point of view

Positive aspects	Total	Men	Women
Savings in time	79 (45.9 %)	31 (50 %)	48 (43,6 %)
Savings in costs	56 (32.6 %)	24 (38.7 %)	32 (29,1 %)
Growth of self-reliance, responsibility, and efficiency	41 (23.8 %)	28 (45.2 %)	13 (11,8 %)
Flexibility	41 (23.8 %)	5 (8.1 %)	36 (32.7 %)
No need to take care about appearance	23 (13.4 %)	8 (12.9 %)	15 (13.6 %)
Less stress	21 (12.2 %)	11 (17.7 %)	10 (9.1 %)
Higher productivity	15 (8.7 %)	9 (14.5 %)	6 (5.5 %)
Skills development	10 (5.8 %)	2 (3.2 %)	8 (7.3 %)
Prevention of workplace related conflicts	8 (4,7 %)	6 (9.7 %)	2 (1.8 %)
Negative aspects	Total	Men	Women
Missing personal contact	97 (56.4 %)	38 (61.3 %)	59 (53.6 %)
Worse work ethic, motivation, lower efficiency	75 (43.6 %)	29 (46.8 %)	46 (41.8 %)
Disturbance by other members of household	35 (20.3 %)	12 (19.4 %)	23 (20.9 %)
More time spent working	27 (15.7 %)	6 (9.7 %)	21 (19.1 %)
Health issues	12 (7 %)	4 (6.5 %)	8 (7.3 %)
Connectivity issues	9 (5.2 %)	5 (8.1 %)	4 (3.6 %)
Impossibility to use employee's benefits	9 (5.2 %)	3 (4.8 %)	6 (5.5 %)
Increased household costs	8 (4.7 %)	4 (6.5 %)	4 (3.6 %)
Feeling to be constantly online	8 (4.7 %)	2 (3.2 %)	6 (5.5 %)

Source: own calculation

Based upon the evaluation of respondents' answers it is also possible to answer (A3) the third question Q3.

Q3: If there are any differences in perception of home working from the employee's point of view of Generation Z and those employees who worked from home for a year during the pandemic, what differences are there and do these differ if we also consider gender?

A3: There are some differences, these perceptions also differ according to gender. In comparison with the results of all the above-mentioned surveys, respondents mentioned the prevention of workplace related conflicts as another positive from the employee's point of view; in the case of negatives, they also mentioned the impossibility to use employee benefits and increased household costs. All these positive and negative aspects were not mentioned by a larger number of respondents, these were minor further opinions referring to the above-mentioned surveys.

4.3 Working from Home Approaches in the Future

Because the situation may arise again that it will be necessary to work from home, organizations and employees should be prepared for such a situation definitely better than in spring 2020, when the coronavirus pandemic manifested fully in the Czech Republic and similar economies. What then can an employer do for a successful management of home working, this means high-quality level of working from home? How to approach home working to make it sustainable? And how should home working be approached by an employee?

According to research by the company Deloitte called "From surviving the crisis to lasting prosperity. Trends in human capital in 2021 in the Czech Republic and the world", 58 % of Czech respondents stated that measures which were applied during the first wave of the pandemic helped to increase the balance between work and personal life, 61 % respondents considered the effects of home working as positive. The second wave presented a question on how to make virtual workplace sustainable. The key elements from the point of view of Czech and foreign business and HR leaders were correctly chosen collaboration tools, possibilities in choosing the task and the way of fulfilling it, new norms of organizing and planning of meetings, or providing appropriate working environment at homes for employees (Deloitte, 2021a).

The research showed that technologies were considered as key elements for managing home working. Correctly chosen and set tools could lead to elimination of distractions and anxieties from overworking, efficient connection with colleagues, as well as building an environment of trust, and providing conditions for faster learning (Deloitte, 2021a). Some employers do not always allow their employees to use given tool in the whole extent. This however makes employees miss many features, which could make their work easier and allow efficient information sharing. Newly developed solution APAT, developed by Deloitte, can help in evaluating whether the technological tools are used properly. This tool allows to anonymously evaluate not only if the technological tools are used well, but also how the working habits have changed during home working, if employees have time for necessary breaks, if they do not spend excessive time with work (HR News, 2021).

Next key element is the change of approach towards meetings and appointments, their organization and planning of work schedule. Solution to this could for example be the so-called smart meetings (they start five minutes past the hour and finish five minutes to the hour, so workers do not reconnect from meeting to meeting), walking meetings (where each worker, who is able to, is encouraged to use the meeting as a walk as well). It may seem like a detail, but each step and moment, when we do not look into monitors, is beneficial.

It certainly should be allowed for workers to divide their work in teams according to their strengths and possibilities and they should also have the autonomy in the way how and when the task will be delivered.

Next important approach, which will help companies to deal with home working and will help them to gain from it as much as possible, is individualization. It is not possible to apply the same approach to all, because a millennial who is single has other possibilities of functioning than a single mother (Wang and Cotton, 2017). What should be decisive is only if the job is done and in what quality, and not if it is delivered between 8:00 a.m. and 5:00 p.m. (HR News, 2021). When it comes to workers, home working means a different work mode, different way of work, sometimes the whole family together. Home working can be stressful even for workers, who do not mind this way of work. If people work from home, moreover over longer periods of time, as it was in 2020 and 2021, they should follow these rules: to prepare home workplace to have enough light, to have enough fresh air, to have the workplace blocked from surrounding noises and activities; to prepare the workplace correctly regarding ergonomics; it is ideal to separate workplace from the space which is designated for sleeping and eating or where people spend their free time with their families; to check if the home wi-fi password is strong enough, to install safety updates of the OS and anti-virus; to ask other members of the household to respect that one works; to dress similarly as one would dress to work; not to skip breakfast and not to be dehydrated; to start with the most challenging task or the biggest problem; to work from-to, i.e. to balance work and personal life (work-life balance), to realize that they do not have to be available all the time, this means not to be connected to work e-mail, chat, phone all the time; to allow themselves a short break for rest, stretching, a walk, relaxation etc. several times a day; to maintain social contact with members of the household; to be in touch with colleagues and friends through phone, computer and internet; to take care of their physical and mental health and so on.

Employers/leaders should follow these rules in periods when their subordinates work from home: to provide technical equipment of high quality and safe remote connection; to move from often used traditional management style to a management based on a given process and focused on results; to make webinars for workers on how to manage home working; to set a clear role to each member of the team; to trust their subordinates; to sometimes expect below standard performance not even standard performance when working from home; to set a regime, regularity, routine, to keep rhythm, for example similar schedule of meetings or timing of deadlines as in “normal mode”; to set rules that workers are not in constant alert, so they can relax from work and not be in stress due to constant phone ringing or work e-mail notifications; to communicate with subordinates often, in positive tone, empathetically, not only about work related topics, but also about their day to day worries and personal problems; to communicate and share all important information with subordinates via one tool; to provide regular feedback to subordinates, after a partial task as well as after completing the whole goal; to offer to workers benefits focused on physical and mental health; to provide to workers the access to online medical counselling; to offer them free online anonymous psychological counselling in cases of mental problems and so on.

5. Conclusion

The paper dealt with how the pandemic of virus disease covid-19 caused by the coronavirus SARS-CoV-2 has affected employees in the Czech Republic.

The methodology of this article was based both on the main aim and on the partial aim of the article. The main aim of this article was to thoroughly analyze the experience and positive and negative aspects of home working in the period of the covid-19 pandemic in the years 2020 and 2021 from the employees' point of view in the Czech Republic and based on this to discuss recommendations for working in such a mode not only in our conditions, but also in other similar countries. The partial goal was to find out what was the opinion about home working of representatives of Generation Z.

Methodology of this paper is based on positive-objective approach, where the systematic reviewing of 475 quantitative and qualitative printed and virtual articles published on the topic of effects of the pandemic on the world of work and employees in the Czech Republic is used as the main method. Moreover, methods of research, comparison, synthesis, induction and deduction are also used. Evaluation of answers was done by using the method of content analysis and descriptive statistics with second-level classification based on gender.

Home working was processed in detail as a phenomenon of the pandemic situation. The identification of the positive and negative aspects of this situation from the point of view of employees in the Czech Republic was based on many surveys. The authors also found out the opinion about positive and negative aspects of home working of representatives of Generation Z.

Theoretical contribution: By providing a clear set of positive and negative impacts of working from home during Covid-19 for employees in the Czech Republic the study contributes to the field of human resource management in terms of creating and maintaining the aspects of caring for employees while maintaining performance.

Practical contribution: Recommendations for successful management of home working from employees' point of view as well as employers' point of view are presented for discussion.

Limitation of the overview study may be the fact that even with the maximum effort of the authors to catch all available information to this given topic, with regards to the number of published articles this did not have to be fully successful. Partially limiting is also the fact that the article is focused only on the Czech Republic so it's difficult to generalize. However, based on studied and processed publications, it is possible to claim that, besides partial differences, e. g. in the approach to productivity control, the Czech Republic and other comparable states do not differ much. Other partial limitation can be the fact that the analysis of the secondary data was used. This means that the authors did not have control over conceptualization of the research and data collecting. On the other hand, use of secondary data brought simplification of the realization of the study and saving of time and financial resources.

The future direction of this researched area is viewed by the authors in the possibility to focus on the survey of positive and negative aspects of home working from the employers' point of view, which may bring further beneficial opinions about the future form of home working.

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DIFFICULTIES IN BUSINESS PROCESSES TO SUPPORT CUSTOMER LOYALTY BASED ON CRM SYSTEMS

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Abstract

The implemented business processes play an important role for CRM (Customer Relationship Management). CRM systems are responsible for managing customer relationships. It involves the collection of data from realized processes and the emphasis is placed on identifying challengers and difficulties. This article explores ways to simplify them using artificial intelligence (AI), log files, low-code applications, or templates. The adopted solution of the method uses literature research with the search for suitable modeling applications to create a 360 degree view of business processes based on inspiration from CRM. For the purposes of analyzing variability in business processes, examples from AI support integrated in CRM systems or individual applications are discussed. There is also interest in low-code applications as a promising innovative way for business as well as research.

Keywords: business processes; CRM; ERP; information technology; knowledge

JEL codes: C80, D70, D80

1. Introduction

Business processes create an essential part of business and there is great variability (Beest et al., 2019). The support of this variability in business process is a challenge based on flexibility. In many cases, it is about customization, integration, pricing, or scalability, security, and user-friendliness. The specification of selected requirements and needs is difficult, and it is useful to use optimal tracking and analysis. Many business processes are automated; therefore, it is possible to use various structures such as log files, templates, models, and artificial intelligence (AI) with low-code applications also play an important role here. A current view on this topic shows that this difference is present in processes from the point of view of control-flow, data, performance, and resources (Estrada-Torres et al., 2021). Managing them requires the necessary time, optimal coordination, and these tasks tend to make or cause mistakes. One from the proven solutions is in detailed classification and a formalization.

Classification and a formalization help with variability and there is also interest in design and plan for variability (Food, 2022). A key difficulty is caused by profitability, which is at risk based on uncertainty and variability. This reality increases costs and the solution is again visible in flexibility and adaptive planning processes. Processes require an agile and responsive approach and optimal timing, scale, and speed. An interesting idea is about the dimensions of flexibility, which is understood as a business variable. This is not about analyzes from MS Excel, but about customization and digitization such as one from actual trends (Food, 2023).

From this perspective, business processes are closely linked to knowledge about customers (Castagna et al., 2020; Bonney et al., 2020) and CRM (Customers Relationship Management). Customers use different shopping methods; perhaps the default need is to have an e-shop and an optimal website with an integrated chatbot to guide customers in the way of shopping through digital channels. From the customer view, it is about personalized shopping and an experience with emotions, but in variability according to personal preferences. This trend again creates contradictions in business processes with the requirement to have and offer fresh, new, attractive, exciting alternatives.

For more detailed information on the current situation, this article focuses on the variability of CRM systems for small and medium-sized businesses such as a part of ERP (Enterprise Resource Planning)

systems. Another interest is in the variability of ways of solving the variability of business process using links to CRM such as log files, models, and the use of artificial intelligence with low-code applications.

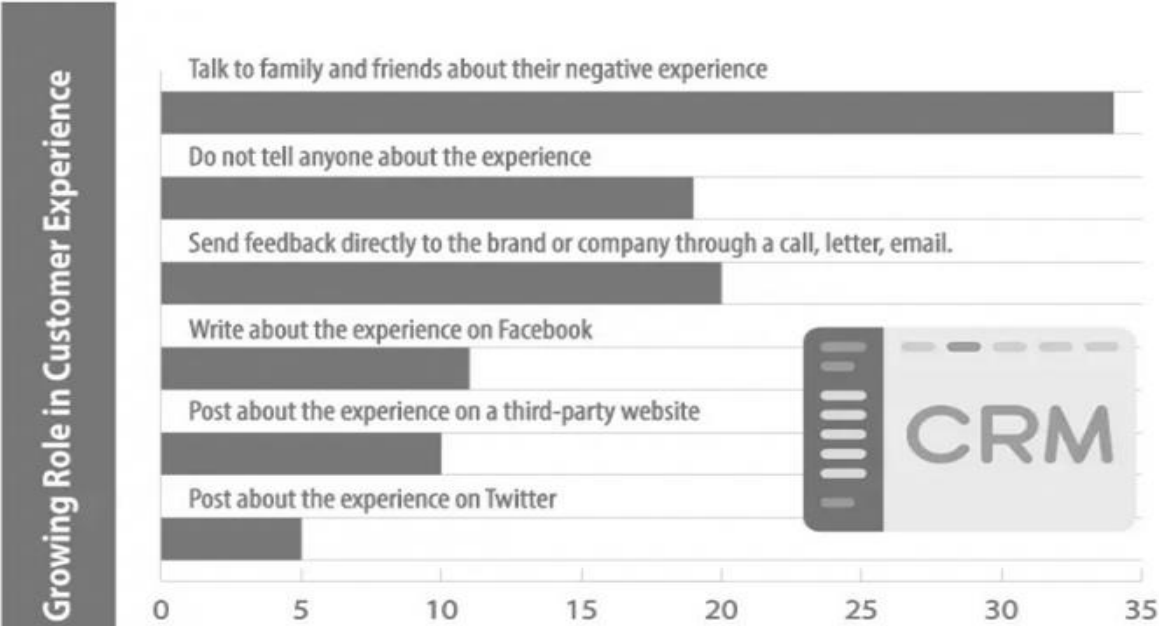
2. CRM for business processes such as a part of ERP systems

Customers and relationships with them are one of the sensitive issues in business. This is natural because CRM has an impact on customer retention and satisfaction (Zhang and Dai, 2020; Rodriguez et al., 2018). From the current statistics (The Ultimate List Of CRM Statistics For 2023, 2023), there are interesting numbers:

- 65% of businesses implement CRM technology within the first 5 years of existence.
- 70% of salespeople say a CRM system is important to closing deals.
- 74% of respondents say that CRM solutions provide better access to customer data.
- 82% of businesses use CRM systems for sales reporting and process automation.

It is not only a 360 degree view of customer (Sheng, 2020; Higgins et al., 2020), but about CRM systems to support a 360 degree view of business processes. The benefits are visible in improving customer support, increasing customer satisfaction, sharing data in business processes, finding new business opportunities or supporting automation, monitoring and forecasting customer activities. According to Salesforce representatives (The 6 Greatest Benefits of CRM Platforms to Know, 2023), all large businesses will rely on CRM systems based on CRM benefits. The growing impact of CRM on customer experience is shown in Figure 1.

Figure 1: The growing role of CRM in the customer experience



Source: The Ultimate List Of CRM Statistics For 2023 (2023)

It is not only positive experiences and expectations from CRM systems, such as an integral business process. There are also difficulties and challenges in CRM processes, see Table 1.

Table 1: Difficulties and challenges in CRM processes

Identified challengers	Percent of companies
Manual data entry	17%
Lack of integration with other tools	17%
My sales team doesn't use it	16%

Identified challengers	Percent of companies
Don't know/not applicable	14%
Difficult to track my sales funnel	12%
Invalid of incorrect data	8%
It's too complicated to use	7%
Managers don't use it	5%

Source: own work based on 23 key CRM statistics (McCain, 2023)

On the IT (information technology) market, there is a great variability of CRM systems, from simple tools to comprehensive solution. For example, Capterra (Capterra, 2023) analyzes more than one thousand five hundred products in the CRM software category, and estimates that about 30-40% are an integral part of ERP systems. For this case, CRM forms one of the five ERP pillars (Is CRM part of ERP or a separate business software category?, 2020), which are financial accounting, distribution, manufacturing, and human resources. Interest is in activity dashboard, calendar system, contact management, document storage, email marketing, interaction tracking, internal chat integration, lead generation, lead management, marketing automation, mobile access, segmentation, social media integration, task management, or territory management. CRM systems are for the cloud, computers with Mac, Windows, or Linux and there is also mobile access (Android, iPhone, or iPad).

Linking ERP with CRM brings greater synergy of business processes. CRM takes care of contact with customers, opportunities and sales, marketing, and customer service. The default ERP has responsibility for business processes; handles order placement, tracking, billing, shipping, accounting and supply chain. The main advantages of ERP and CRM integration (The Beneficial Relationship Between ERP CRM Systems, 2022; Writer, 2018) are:

- Centralization of contacts.
- Easier ordering.
- Internal cooperation.
- Reduction of data duplication.
- Stronger visibility and forecasting.

Business processes are diverse and need support based on modern information technology trends such as artificial intelligence and low-code applications. Artificial intelligence has its irreplaceable place in ERP and CRM systems. In numbers, businesses plan to increase their use of AI by 47% and CRMs by 40% (The Ultimate List Of CRM Statistics For 2023, 2023).

3. Artificial intelligence and low-code applications for business processes and CRM

From a CRM perspective, AI has influence on machine learning, predictive analytics, automation and emotion analysis (Chouffani and Robinson, 2022; Libai et al., 2020). Machine learning is responsible for teaching from an automated system to make it more productive and efficient in changing conditions for business. Predictive analytics uses advanced dashboards and processes that focus on trends of development of monitored values at all levels to increase customer engagement. Automation is one of the attractive benefits of information technology. It performs selected processes in a short time and more accurately. In many cases, there is a place for AI. Sentiment analysis empowers customer service to know about customer emotions from interacting with them through channels such as phone, live chat, email and social media.

Not all CRM systems have integrate AI into solution, but well know solution are Salesforce Einstein (Quickly build AI-powered apps for employees and customers on a complete artificial intelligence platform, 2023), IBM Watson (IBM Watson is AI for business, 2023), cloud AI service from Microsoft Azure (Azure AI, 2023), Oracle artificial intelligence (Artificial Intelligence (AI), 2023), or SAP AI (AI solutions on SAP Business Technology Platform, 2023). For example, Salesforce Einstein provides the following benefits:

- Ad hoc analysis of data.
- AI training resources.

- Care about sales and customer service.
- Customer service chatbots.
- Customization and forecasting.
- Deep learning features to learn how customers feel about offered services and goods.
- Discovery patterns in customer behavior with relation on campaign and trends.
- Natural language processing to identify customer intent.

It was about AI integrated into CRM systems but the IT market also offers individual solutions such as open-source software (Hernandez, 2023; Best Artificial Intelligence Software, 2023). Capterra analyzes more than a hundred such applications (Best Free Artificial Intelligence Software, 2023). This software is dedicated for e-commerce, healthcare, sales teams, chatbots, multi-language matters, predictive analytics, process automation, and virtual assistants. Among the sectors, there is interest in data security, finance, manufacturing, or also automotive. This software is used to develop and train own models (Machine learning models) using the available library. A positive benefit is the ability to derive performance from data of business, and advanced predictive modeling is used. Data processing support, intuitive guider for model building, process automation and relation to predictive analytics are important for practical work.

The use of artificial intelligence is one from the necessary conditions for optimizing work with data to find new models and relationships. Another challenge is to integrate into work low-code applications for more efficient application development. It sounds like a promising innovative way for business as well research. The development of such an application uses pre-defined templates and it is necessary to include them in modules. Such an approach is used in data analytics, marketing tasks for CRM support, or pre-built artificial intelligence solution (Brewster, 2023). Active solutions are offered by Salesforce Lightning and Zoho Creator with links to CRM, or Creatio and Microsoft Power Apps are interested in business processes for automating business ideas. From an perspective of small and medium-sized businesses, there are solutions for this business in the cloud, on the web, or default Windows, Android, and iOS (10 Best Low-Code Development Platforms In 2023, 2023).

4. Method and Data

The method solution uses a basic literature search and other available sources from the Internet. The question was about business processes extended by CRM. Whether it is appropriate to think about such a relationship and whether there is a suitable potential for finding hidden links and public models for solving existing difficulties and challengers. The scope of the selected literature is oriented towards scientific journals indexed in Scopus and Web of Science, and other journals. There are also online resources that show recommendations from vendors and businessmen. Zoom supports small and medium-sized businesses.

5. Results and Discussion

The conducted literature research shows the variability of solutions and views on the given topic of business processes to support customer loyalty based on CRM systems. There are difficulties based on uncertainty that affect development prices and profitability. Existing challengers are associated with data processing, process complexity, or non-use of available information technology tools. From a business process perspective, CRM is one from of the five ERP pillars, and CRM processes have the ability to influence business processes.

Existing variability is also key to addressing business processes. This variability requires automation based on information technology trends such as artificial intelligence and low-code applications may help too. For the future work, it is the ability to transfer a 360 degree view of customer from CRM systems for a 360 degree view of business processes with a requirement for modeling, especially predictive modeling. The starting points for work on this topic also need information from existing research and the achieved results. Inspiration brings, for example:

- A teaching module illustrating ERP item value automation (Singh et al., 2023).
- Design secure business processes for blockchains with SecBPMN2BC (Kopke et al., 2023).
- Effect of blockchain technology initiatives on firms' market value (Ali et al., 2023).
- Service strategies and channel coordination in the age E-commerce (Amrouche et al., 2023).
- Use of contextual and model-based information in adjusting promotional forecasts (Sroginis et al, 2023).

Many articles are focused on business processes indexed in the Scopus database, and they are interested in design, modeling, strategy to support automation and forecasting.

6. Conclusion

This article explores ways to evaluate business processes in their variability with references to CRM. Difficulties create variability and some degree of uncertainty about expected profitability. To understand business processes, it is not just about control flow, data, performance, and resources. It is good to use ERP pillars that also include CRM. The positive thing is that linking ERP with CRM brings synergy to business processes. It is a challenge to create a 360 degree view of business processes with a requirement for modeling, especially predictive modeling. The real difficulties and benefits of integrating ERP with CRM are identified. To specify the variability of formalizations and classifications, it is necessary to understand the dimensions of flexibility of the business processes. For these analytics purposes, it is useful to use modern trends of information technology such as artificial intelligence and low-code applications. A promising tool is the use of an integrated AI solution in CRM systems or individual applications for finding new models and relationships and automating business ideas. Unfortunately, the log files are more linked on implemented systems than demo versions. Access to the log files depends on the specific ERP or CRM system and the information in the documentation is only general.

Acknowledgement

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SOCIAL MEDIA AND ONLINE BEHAVIOUR AMONG HIGH SCHOOL AND UNIVERSITY STUDENTS

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Abstract

The purpose of this paper is to describe the behavior of young people in the social media environment. The method chosen for data collection was a questionnaire survey on a representative sample of 1,706 valid respondents from Czech Republic. We used chi-square, analysis of variance, and factor analysis to explain relationships in data. Besides social media popularity ranking, our results showed that the more time respondents spend on the internet, the more social media brands they use. We also inspected the applicability of duplication of a purchase law in the social media context. Data showed that popular modes of communication among students include photos and texts followed by a video. Additionally, we found a similar use of social media among students and their parents. Last, with the use of exploratory factor analysis, we concluded that social media varies according to the content users go to it for, which carries implications for marketing communication strategy.

Keywords: duplication of purchase law, social media, social network, marketing communication, media consumption

JEL codes: M31, L82

1. Introduction

Considerable competition exists for students in the marketplace of higher education. Universities around the world are gradually finding popularity in using modern ways of marketing communication towards potential applicants and students. Social media as a rapidly spreading medium is one of these tools. Despite its widespread popularity, there is still a lack of research focusing on the behavior of a group of young people who are potential future students.

The topic of social media is increasingly relevant in all areas of communication management. It is no longer a novelty that social media has caused an alteration in marketing communication, giving organizations a new interactive platform for communication with customers and stakeholders. Kumar et al. (2016), Swaminathan (2016) and Stojanovic et al. (2018) confirmed a positive relationship between the intensity of social media use by companies and brand awareness. Similarly, Schivinski and Dabrowski (2014) found a relationship between social media communications and brand attitude. Tokarčíková (2011) states that professionally oriented social network sites (SNS) offer benefits both for individuals and for companies, industrial enterprises, and organizations of various kinds.

While speaking about social media and social networks, it is worth defining a few basic concepts for the purposes of this study. Kaplan and Haenlein (2010) provide a typology using a set of theories to generate six types of social media, including blogs, social networks (Facebook), virtual social worlds (Second Life), collaborative projects (Wikipedia), content communities (YouTube), and virtual game worlds (World of Warcraft).

There is fruitful research on social media. Many studies have investigated the viability of social media as a marketing medium, while others have explored various aspects of the medium itself, including the risks associated with its use, the value it creates, and the negative stigma attached to it within workplaces (Kapoor et al., 2018). Research on social media as a marketing tool consists of, for example, the role of consumer-brand relationships in the context of effective personalized advertising (Hayes et al. 2021), or the reasons for avoiding the native advertisement on social networks (Chung and Kim, 2021). Some studies focus on specific target market segments and their behaviour. For example, Newman et al. (2021) targeted older adults. Perčić and Perić (2021) were looking for effective promotional media in three age cohorts. They found that for each segment, it is more efficient to invest in a different combination of communication mix tools. Braciniková and Matusšínská (2020) found dissimilarities in brand meaning across generations.

In a university context, where research includes students as a research subject, topics emerged around organizational and individual level. Example of the first is the communication via social media between students and university as a brand (Bonilla et al. 2021; Raza et al. 2020; Bamberger et al. 2020; Assimakopoulos et al. 2017; Constantinides and Stagno, 2012; Rutter et al., 2016); the latter evolved around the use of social networks in teaching and communication between teachers and students in general (Cunha Jr et al. 2016; Sánchez et al. 2014; Kozel et al. 2012; Roblyer et al. 2010). Furthermore, we can include individual social media and the use of social networks of university students described in other literature streams focused on motivation, social media behavior and its results (Hussain, 2012; Zavodna and Pospíšil, 2018; Cheung et al. 2011; Pampek et al. 2009).

This study joins efforts to describe students' online behavior on social media. Therefore, we surveyed students in the Czech Republic and examined their behavior on social media, particularly on social networks and content communities. A total of 1,706 respondents to the research declared which social media are most used and what information they expect on the platforms most often. The survey also looked at what content university and high school students create and how many hours a day they spend on social networks.

2. Data and methods

The survey was aimed at students in the Czech Republic aged 17-26 who are interested in studying at a university or already studying one. The aim was to find out how the target group uses the Internet and social media. The questionnaire was distributed among bachelor's students of four Czech universities and among third- and fourth-year high school students. In most cases, the questionnaire survey in secondary schools was carried out in cooperation with secondary school teachers by prior arrangement and with their consent.

It was a self-selection between undergraduate students and third- and fourth-year high school students. 1 852 questionnaires were obtained. 1,706 questionnaires were processed. 112 respondents stated that they did not want to study at university and 28 stated that they did not use social media, therefore they did not meet the requirements of the target group and were excluded from processing. Six responses were eliminated from the sample due to incomplete responses.

Overall, 1,706 respondents were surveyed meeting minimum sample size determined by the following equation (Kothari, 2004) $n = (z^2 \cdot p \cdot q) / e^2$. Where n is the sample size, z is the standard variate at a given confidence level, p is a sample proportion ($q = 1 - p$), and e is an acceptable error. Then the calculation for 95% confidence level goes as follows: $n = ((1,962) \cdot (0,5) \cdot (1-0,5)) / 0,052$; $n = 0,904 / 0,0025$, $n = 384$. Hence, the minimum sample size for this study is set to 384 respondents. Traditionally representative surveys usually work with a sample of around thousand respondents (with a corresponding composition according to the quota features of the sample (gender, age, and education). The research sample shows signs of representativeness by having characteristics close to the population,

such as gender and school type (Tables 1 and 2). We decided not to limit the data by strata via quota sampling for the sake of ultimate representativeness.

Table 1: Sample distribution by gender

Gender	Absolute	Relative	Population
Male	687	40,4 %	49,1 %
Female	1019	59,6 %	50,9 %
Total	1706	100 %	100 %

Source: own research data and (Czech Statistical Office, 2020a)

The questionnaire included 24 questions. Of these, 2 were used to filter respondents and 6 were used for personal identification. The entire questionnaire included various types of questions, both closed (yes/no), semi-open, scales, and 3 open-ended questions. The questionnaire was distributed electronically using the Google forms tool.

Table 2: Sample distribution by school type

School type	Absolute	Relative	Population
High school	612	35,8 %	46,1 %
Higher vocational school	30	1,9 %	2,6 %
University	1064	62,3 %	51,3 %
Total	1706	100 %	100 %

Source: own research data and (Czech Statistical Office, 2020b)

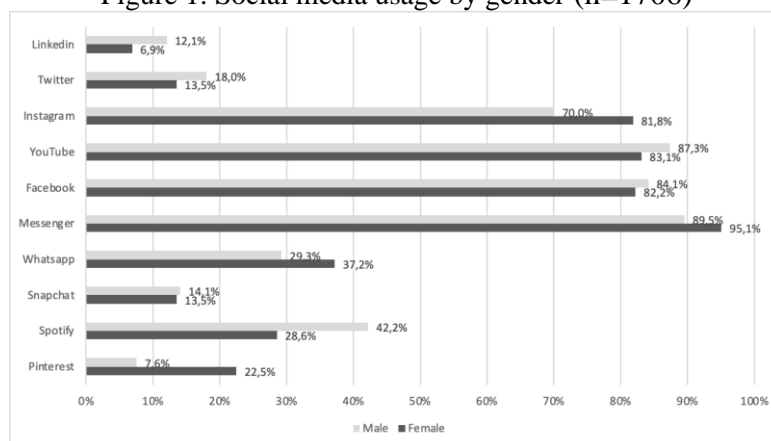
The questionnaire was divided into two main research parts. One examined how respondents use social networks and the other focused on the use of not only social networks but also other communication platforms that young people use on the Internet (blogs, advertising).

3. Results

We start the results section with descriptive statistics. Basics popularity of particular social media in our sample is described in Figure 1. Messenger, YouTube, Facebook, and Instagram are the main social media platforms that attract student attention. If we consider Messenger to be a spinoff app from Facebook, this finding is consistent with previous literature where Facebook and Youtube have been identified as most popular (Singh and Gill, 2015). Likewise, Zavodna and Pospíšil (2018) observed that Facebook, Instagram and Youtube are the most popular among university students.

Messenger as an instant messaging app is dominating WhatsApp. Similarly, YouTube is the dominant content community far from Spotify second and Pinterest third in this category. Moreover, there are differences between genders in the use of social media. The figure also shows a significant deviation in Pinterest and Instagram popularity among women. On the other hand, Spotify seems to be more popular among males, and this also applies, albeit only weakly, to LinkedIn and Twitter.

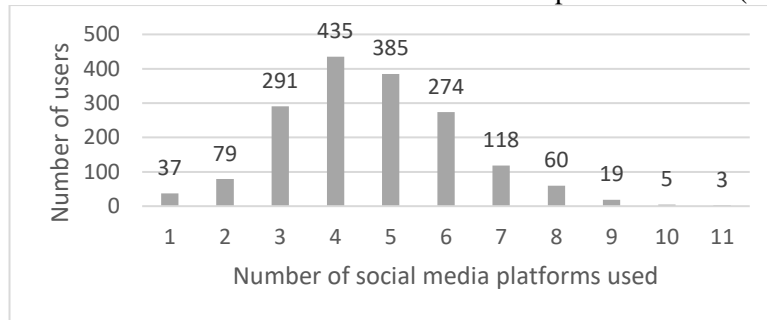
Figure 1: Social media usage by gender (n=1706)



Source: own research data

The most frequent number of social media platforms that students regularly used was four (Figure 2).

Figure 2: Distribution of the number of social media platforms used (n=1706)



Source: own research data

It is obvious from the ranking that students regularly use more than a single social media, violating loyalty to just one platform. Therefore, the question of which platforms are used together will be answered here. Table 3 shows that all social media have the highest cross-use with Messenger. For example, 94% of Youtube users use Messenger or 78% of Youtube users use Instagram. On the other hand, only 6% of Snapchat users have a Twitter account, and so on. This pattern of polygamous media consumption has been observed previously in magazines (Agostini, 1962; Cannon, 1983), television (Goodhart and Ehrenberg, 1969; Headen et al., 1979; Webster, 1985; Jardine et al., 2016), radio (Lees and Wright, 2013), gaming (Lam and Ozorio, 2013) or websites visits (Webster and Lin, 2002) and is called duplication law (the name is always supplemented by the specific area where the duplication occurs, e.g. purchasing, viewing, or listening).

The underlying premise of duplication is that consumers rarely exhibit loyalty to any brand, but select from a repertoire of acceptable choices, favoring these brands in line with each brand's market share (Wilson and Winchester, 2019). The law is also confirmed in the consumption of social media by students here since the top social media brands by penetration would also capture cross-use from other social media in the same ranking order (Table 3). The only exception is that Pinterest has higher penetration than Twitter but lower average cross-use. Overall, the correlation between penetration and average cross-use demonstrates high values ($r = 0.99$), and the law holds.

Table 3: Cross-usage within social media platforms (n=1706)

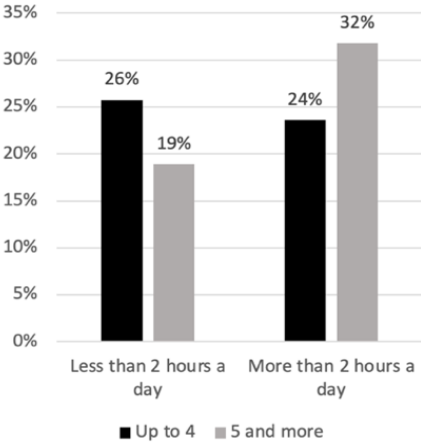
Users of...	% penetration	% who are also users of...										
		ME	YT	FB	IN	SP	WH	PI	TW	SN	LI	TI
Messenger	93		86	85	79	35	35	17	15	15	9	4
Youtube	85	94		86	78	37	35	18	16	15	10	4
Facebook	83	95	88		77	35	36	16	16	15	10	5
Instagram	77	95	86	83		38	36	19	17	17	9	4
Spotify	34	96	92	85	85		38	23	25	20	15	7
Whatsapp	34	95	86	88	83	38		20	18	19	14	7
Pinterest	16	97	92	82	89	48	41		23	21	13	5
Twitter	15	92	89	85	84	55	40	25		25	14	11
Snapchat	14	98	91	89	93	49	47	25	28		6	12
LinkedIn	9	94	90	90	78	56	54	24	24	10		10
Tinder	4	93	86	91	80	58	58	20	39	38	20	
Avarage		95	90	87	84	50	47	28	29	27	20	16

Source: own research data

In addition, we were interested in whether there is any influence of the number of social media platforms used and the time spent with these media. Approximately half of the sample used up to four social media, and the other five and more. We have split the sample and compared the groups with the

average time spent on social media a day. As Figure 3 shows, the cross-tabulation clearly indicated that the more social media platforms students use, the more time they admit spending on social media. The statistical test for the relationship goes as follows $\chi^2(1, n=1706) = 37.8, p = 0.0$, but with the small effect size of $\phi = V = 0.15$.

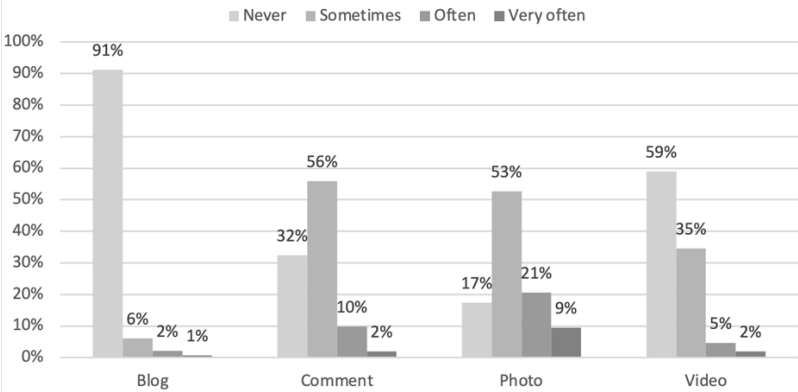
Figure 3: Time spent on social media and number of platforms used (n=1706)



Source: own research data

Next, we were interested in typical forms of communication by its content. Most of the selected items were photos, comments, and videos. Clearly, blogs are out of the interest of majority as a figure 4 shows. Surprisingly, only 2 % of respondents comment on social media very often. In contrast, 9.4 % use a photo as a form of communication extensively. This implies that photos are the most popular form of communication on social media.

Figure 4: Types of content by its frequency of use in communication by users (n=1706)

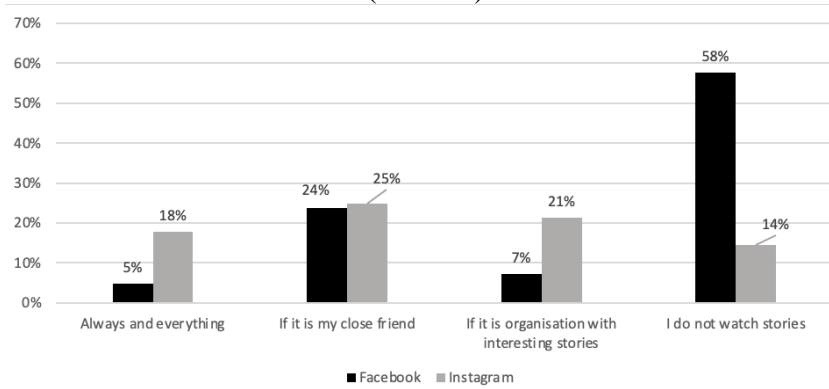


Source: own research data

Our results are consistent with previous studies. Poecze et al. (2018) report significantly higher effectiveness for posts containing photographs. Contrary to these results, Marešová et al. (2020) point out that on Facebook, even top universities, unlike most consumer brands, do not use photos or videos to the same extent as top brands, although photos achieve the highest engagement.

We then explored further the way students consume video content in the form of short videos fading after several hours called stories. We measured the behavior on two popular platforms, Instagram and Facebook, and let students pick as many options as they want to describe their common behavior. As our data show (Figure 5) more than half of users do not watch stories on Facebook at all, contrary to only 14.5 % ignoring this type of communication on Instagram. Interestingly, the willingness to watch stories on Facebook is related to authorship. If the content is created by a close friend, users behave the same on both platforms and around 24 % of them would view the stories.

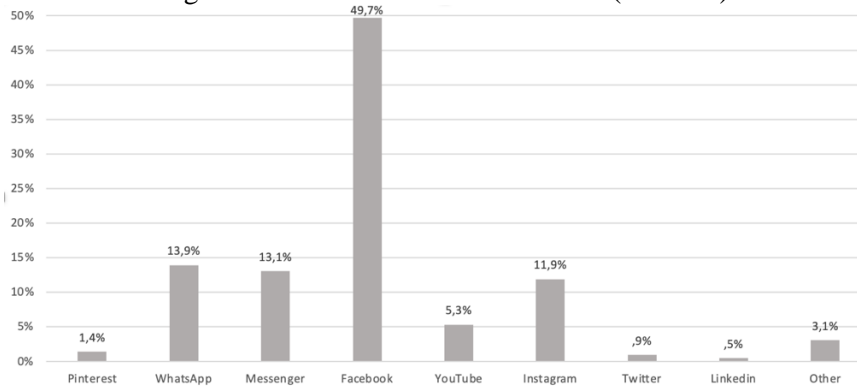
Figure 5: Differences in Stories (short fading videos) consumption on Instagram and Facebook (n=1706)



Source: own research data

Since parents can influence one’s decision about university selection, we also asked our respondents about the behavior of their parents on social networks online. Despite the fact that this information is mediated and thus can be distorted, we find dominance of Facebook within the social media used. Follow WhatsApp, Messenger, and Instagram. A complete overview is presented in Figure 6.

Figure 6: Parental use of social media (n=1706)



Source: own research data

In addition, we tested the assumption that students and their parents consume media in an interconnected way. To be precise, the preference for an online social media of a student is influenced by the preference of his or her parents for the media and vice versa. To test this assumption, we performed several statistical tests of the data at hand.

Firstly, we were interested in whether the Facebook use of a parent somehow influences the Facebook use of a student. There were theories presented by social media experts that the young generation leaves Facebook for the reason of parents joining the network and making online behavior of their children exposed. Thus, we used the independence test for two variables, both categorical in nature, Facebook use of students and Facebook use of their parents. A Chi-square test for independence (with Yates’s continuity correction) indicated a significant positive association between the use of Facebook by students and the use of Facebook by their parents $\chi^2(1, n=1706) = 4.77, p = 0.03$, but with a small effect size of $\phi = V = 0.05$. No cells had expected count less than 5 thus the statistics is not distorted. Results show the relation between Facebook usage of students and their parents exists.

Secondly, in the same manner, we tested Instagram, WhatsApp, and Messenger. The results are as follows. The use of Instagram by students and their parents $\chi^2(1, n=1706) = 47.4, p = 0.0$, with a small effect size of $\phi = V = 0.17$. Messenger use by students and their parents $\chi^2(1, n=1706) = 8.3, p = 0.02$, with a small effect size of $\phi = V = 0.07$. WhatsApp use by students and their parents $\chi^2(1, n=1706) = 88.7, p = 0.0$, with a medium effect size of $\phi = V = 0.22$. In all pairs there has been a statistically significant relationship. The effect size ranges from small for Facebook, Instagram, and Messenger to

medium for WhatsApp. There has been this common belief that young people avoid platforms where their parents are. However, our data suggest otherwise. Students and their parents use social media in parallel.

In our analysis, we moved from describing media usage habits to what specific content young users expect to see on social media. To do that, we had to reduce the complexity of the data by employing exploratory factor analysis (EFA) and inspected the underlying correlations between variables related to themes of social media content. These were measured on scales ranging from never to very often. The variables analyzed were information acquired on social media on fashion, sport, culture, education, health, jobs, and dating. The value of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.638. Malhotra and Birks (2006) recommend a minimum KMO value of over 0.5 for this test. This indicates that factor analysis is appropriate as a method for data analysis. Furthermore, Bartlett's sphericity test shows 0.0 significance, and therefore there is a correlation between the values. The number of factors was determined based on Kaiser criterion (Hardy and Brymann, 2004). Components with eigenvalue greater than 1 were included. In conclusion, three underlying factors were identified. The oblique rotation method (Promax) was used to rotate the factors. Matsunaga (2010) suggests that any exploratory factor analysis should employ an oblique rotation for several reasons. Most importantly, almost all phenomena that are studied in social sciences are interrelated to one another, and complete orthogonal (unrelated) relationships are rare. Thus, we use the oblique rotation.

Table 4: Pattern matrix

Pattern Matrix ^a			
	Component		
	1	2	3
News	0.775		
Education	0.724		
Culture	0.690		
Fashion		0.870	
Health		0.706	
Dating			0.746
Sport			0.708
Jobs			0.367
Extraction Method: Principal Component Analysis. Rotation Method: Promax with Kaiser Normalization.			
a. Rotation converged in 5 iterations.			

Source: own research data

One of the weaknesses of exploratory factor analysis is the subjectivity associated with naming factors. To avoid this common problem, we will use only order factor numbers for future analysis and leave the reader with the option to see all the measured variables behind the latent factor (Table 4). Thus, factor one (F1) consists of information about news, education, and culture, factor two (F2) fashion and healthy lifestyle, and last factor (F3) dating, sport, and jobs. Once we have data on social media usage and typical content expected here on the user level, we move on to analysis of social media brands. We were then able to explore the relation between the use of a particular social media and the interest in specific content. We used analysis of variance (ANOVA) to measure the effect of social media use (nominal variable yes or no) and factor loading on the individual level (continuous variable). In Table 5 we can see the results of the statistical test. ANOVA showed significant differences in the means of students using or not using Facebook in all three factors. Moreover, for YouTube, there was no significant difference, and two out of three factors are dependent on Instagram use.

Table 5: ANOVA results (n=1706)

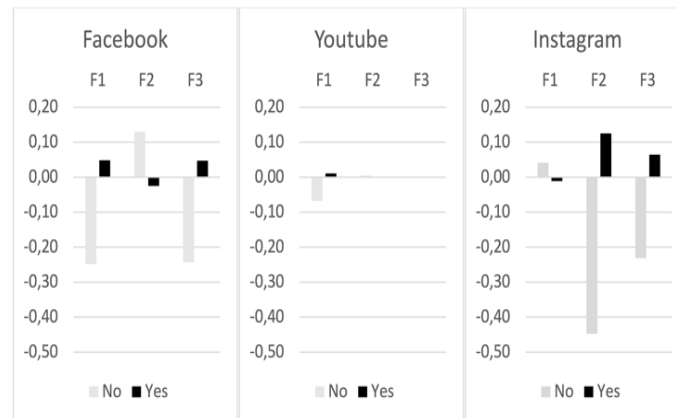
Factors	Facebook		YouTube		Instagram	
	F	p-value	F	p-value	F	p-value
F1: news, education, and culture	18.021	*0.000	1.114	0.291	0.702	0.402
F2: fashion and healthy lifestyle	4.895	*0.027	0.005	0.944	88.785	*0.000
F3: dating, sport, and jobs	17.311	*0.000	0.000	0.998	22.691	*0.000

*statistically significant at 0.05

Source: own research data

The following figure 7 illustrates the direction of the relationship visually. First, users who use Facebook most often search information connected with factors 1 and 3 and conversely do not search that much for information about fashion and health (F2) on social media compared to nonusers. Second, YouTube use does not clearly explain any relation to topic of interest and thus does not show significant differences in users and non-users. Third, Instagram users tend to search for more information about fashion and health (F2) and similarly to Facebook users also dating, sports, and jobs (F3).

Figure 7: Facebook, YouTube, and Instagram use and most popular areas of interest searched on social media



Source: own research data

Moreover, we looked at the gender differences in information that is typically consumed on social media. Again, ANOVA has been used to measure the effect of gender (nominal variable male or female) and factor loading on individual level (continuous variable).

Table 6: ANOVA results (n=1706)

Factors	Gender	
	F	p-value
F1	0.883	0.000
F2	348.489	*0.000
F3	57.510	*0.000

*statistically significant at 0.05

Source: own research data

The results of the test are shown in Table 6. There are significant differences in factor two and three depending on the gender. The direction of a relationship goes as follows. Females consume much more intensively fashion and healthy lifestyle content, compared to men who are more interested in dating, sports, and jobs. Both genders take the same approach to consuming content about news, education, and culture.

4. Conclusion

The research in this study focused primarily on university students and final-year high school students in the Czech Republic. From the description of online behavior, main beneficiaries can be universities, but also industries that target their product at young people or companies looking for potential employees among graduates of secondary schools and universities. The information is particularly useful for the selection of appropriate communication channels, the form, and content of promotional messages.

The results indicate that young people in the Czech Republic mainly use Messenger, YouTube, Facebook and Instagram. But there are differences in gender. Women are more in favor of Pinterest and Instagram. Men are more likely to use Spotify than women. For example, design schools with a higher prevalence of female applicants can use Pinterest very effectively, to showcase their students' work, and thus attract new applicants. The same applies to businesses working in the fashion industry.

We also dealt with the question of loyalty to a particular platform among students and observed rather polygamous consumption user behavior. This tendency is explained by the duplication law. Duplication of social media use in this case. Social media platforms share more of their users with larger competitors and fewer users with smaller competitors. This finding is in accordance with previous research in mass media (Agostini, 1962; Goodhart and Ehrenberg, 1969; Cannon, 1983; Webster, 1985; Lees and Wright, 2013; Jardine et al., 2016).

Further, we examined the association between the number of social networking sites used and the time spent on SNSs. For example, Ashley and Tuten (2015) reported that engagement scores consider the number of social media channels used. Our research confirms a similar fact. This is an important finding that supports the idea of using multiple types of social media and focusing on creating interesting and original content on each channel. Universities often do not create their own content but share it. If they create their own content and have multiple social media channels, then they share the content on their channels. Again, this does not encourage students to follow multiple channels (the content is almost identical). As a result, colleges lose followers' time and their engagement scores. This was also confirmed by Marešová et al. (2020). This fact leads to a recommendation for universities not only to focus on one social media network, but also to use other SNSs and adjust the content on each platform to its users. This will become more important as SNS users spend more and more time online. Of course, the fact that it is necessary to generate interesting, useful or entertaining content for the target audience also applies.

On the topic of content, or rather its form, the research found that young people do not use blogs in their communication, but welcome to produce mainly photos and video content. Hence, encouragement to share a photo (e.g., a competition for the funniest photo with our product) is better than encouraging verbal comments. Moreover, students follow short fading stories more often on Instagram than on Facebook.

For colleges and universities, an important piece of information may be to refute the common assumption presented by the media experts that young people are leaving Facebook for their parents. We found that this social media site is used by students and their parents simultaneously. Yang (2016) points out that Facebook is where parents meet their children who are leaving home and adapting to a new school environment, and the connection with parents through SNS is perceived positively. Therefore, our recommendation is to use this SNS for promotion that will target both students and their parents. They still have influence on the decision-making process when choosing a university.

Variances and similarities have been identified on different social networks regarding the typical information consumed by students. Instagram users tend to search more information about fashion and health, and similarly to Facebook users, also dating, sports, and jobs. Besides, Facebook users consume information about news, education, and culture and neglect the fashion and health lifestyle information. Gender also comes into play. Not surprisingly, women consume much more intensively fashion and healthy lifestyle content, compared to males being more interested in dating, sports, and jobs.

The obvious limitation is the use of one nation sample only, thus the intercultural or cross-national comparison and overall generalization of a results is limited. Furthermore, the cross-sectional and longitudinal approach of the study could provide deeper insights into tendencies and provide data for prognosis. The emerging social networks such as Clubhouse and TikTok have not been included, and thus further studies could incorporate them in the questionnaires. The last limitations lay in self-

reported data collection since this method is limited by the fact that it rarely can be independently verified.

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PREDICTING CUSTOMER CHURN IN E-COMMERCE USING LOGISTIC REGRESSION

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Abstract

The purpose of this paper is to investigate the utility of logistic regression in predicting customer churn in an e-commerce setting. We employed logistic regression as a machine learning method to analyze customer behavior patterns in an effort to identify customers who are likely to disengage from the customer base. By utilizing data from an enterprise resource planning system, we aimed to establish the applicability and effectiveness of logistic regression in predicting customer churn and to identify factors that are associated with customer retention. The results showed that the model had high accuracy and precision, indicating its ability to accurately identify customer behavior patterns. The theoretical contribution of this paper lies in advancing the understanding of a previously under-researched but highly potential research area by both bringing new insights and exploring consumer behaviour in e-commerce.

Keywords: e-commerce, customer lifetime value, customer loyalty, logistic regression, retention

JEL codes: M 30

1. Introduction

The e-commerce market, which is inherently highly dynamic, has grown rapidly in recent years. The COVID-19 pandemic was accompanied by restrictions that led, among other things, to a shift of shopping from brick-and-mortar stores to e-shops. This has led to a sharp increase in the number of customers shopping online and also in the number of companies operating e-shops. The increased demand in the e-commerce market has thus led to an increase in supply. However, the easing of restrictions and the evolution of the economic situation may cause a decline in demand and consequently intensify competition. In order to generate profits in this environment, e-shops need to continuously strengthen their competitiveness. To do this, they need a fixed marketing strategy based on relevant data that is also in line with the e-shop's capabilities and resources.

One of the pillars of the marketing strategy is customer segmentation, which also serves as a basis for resource allocation planning. Which customers should the e-shop focus on? Which channels to use? How to allocate investments? Should it focus on acquiring new customers (acquisition) or re-selling to historical customers (retention)? The answers to these questions can only be obtained by analysing the relevant data. One possibility is, for example, customer profitability analysis (CPA) and the resulting customer lifetime value (CLV). The value of a customer, customer cohort or segment and its future development can be very valuable information for e-shops and a tool for developing a marketing strategy or specific steps leading to long-term prosperity. In fact, decision-making about future activities would

be much more effective if the e-shop is able to estimate the potential profitability of individual customers or customer segments.

Thus, the aim of the paper is to bring new insights to support strategic decision making based on empirical data. The paper is structured as follows, first the issue of customer value is described in a general perspective, then the method of determining customer value using the CLV metric is presented. CLV is then placed in the context of the e-commerce environment, thereby providing the insights needed to characterise the data analysed in the research section. The last part of the theoretical area is devoted to customer churn. In the following section, the methods, data and the 4 selected e-shops to which the customer churn prediction is further applied are presented. The research results indicate that the chosen research approach is applicable to scientific and corporate practice with adequate reliability.

2. Managing customer value

Marketing is undoubtedly one of the key areas of management, which to some extent affects almost all company activities. It involves a whole range of activities and therefore costs, which can create the association for many people outside the marketing community that marketing equates to a source of high costs. We therefore consider it necessary to emphasise the role of marketing in generating revenue and increasing the value of the company. This topic has been addressed by a number of researchers who have demonstrated the positive relationship between marketing components and firm value in several possible perspectives, such as a) customer satisfaction and shareholder value (Anderson et al. 2004) b) brand differentiation and brand worthiness and firm value (Mizik and Jacobson 2008) c) advertising and shareholder value or customer equity and total firm value (Srinivasan and Hanssens 2009).

In general terms, the customer is the main source of revenue and also a source of information for, among other things, creating or optimizing the marketing mix. Thus, we can argue that it is at the centre of all marketing, which is in line with the generally accepted theory of customer orientation (Sheth et al., 2000, Wang, 2015, Zang et al., 2020). If the entire firm is to be customer-centric and invest energy, time and money in creating and maintaining the relationship, it must know the real financial value of the customer, both past, present and future. This is captured by the widely used metrics of customer equity (CE) and customer lifetime value (CLV). where customer equity (CE) is the sum of the lifetime values (CLV) of all customers, which brings us to the relationship between customer value, hence CLV, and firm value (Kumar and Shah, 2009).

2.1 Customer lifetime value

In the simplest terms, CLV is the sum of all cash flows generated by a given customer (Kotler, 1974; Borle et al., 2008). A more realistic view of customer value is then obtained by subtracting the costs associated with customer acquisition and the cost of capital (Gupta et al., 2004; Kumar et al., 2004; Bauer and Jannach, 2021, Martinez et al., 2021). By knowing the value of customers, a firm can build profitable relationships through customer relationship management (CRM) to gain competitive advantage, gain information about the health of the firm that cannot be determined using conventional financial metrics or predict future cash flow, or estimate if and when a customer will buy in the future using retention rate analysis (Estrella-Ramón et al, 2013). At the same time, conventional marketing metrics such as brand awareness or market share are not sufficient to evaluate marketing investments, especially in the long run, in which CLV is very telling, as it also contains elements of customer profitability and is essential to the customer-centric paradigm (Kumar et al., 2004).

Through CLV analysis, firms can also identify which customers or customer segments offer the highest potential and then focus on these, or exclude customers or segments with the lowest potential from the targeting of marketing activities in order to increase the profitability of marketing activities. It is the building of long-term customer relationships that is considered by many researchers as a key tool for increasing firm profitability (Verhoef, 2002; Reinartz and Kumar, 2003; Chang et al., 2012; Vanderveld, 2016).

2.2 CLV in the e-commerce market

The dynamic nature of the e-commerce market combined with the volume of available and globally standardized data creates a strong need for consistent work with data and its use in making strategic decisions and planning marketing activities. To be specific, this is a highly competitive environment with a very low barrier to entry and increased customer bargaining power. Customers thus have essentially unlimited possibilities to choose and compare offers from vendors almost worldwide. Their behaviour is thus different from shopping in an offline environment. Thus, academics and firms cannot rely on existing resources based on studies of the offline environment. Thus, they need new insights obtained through empirical research for their work. Another factor is that e-commerce provides an almost unlimited amount of data that can be used for research. On the one hand, this gives an advantage to firms that are already working with data in some way, but it also lowers the barriers to data collection and analysis, thus levelling the playing field and making firms more concerned about defending their market position. Analysis and prediction of CLV in the e-commerce environment can thus be valuable and, with some exaggeration, essential tools for the success of companies.

2.3 Customer churn prediction

The customer's future buying behaviour can be viewed both in terms of whether and in what volume he will buy in the future, or whether he will end the buying relationship, i.e. not buy again, which is referred to as customer churn. The ability to determine which customers will terminate the relationship in the future and therefore not repeat purchase helps companies to decide which customers they should focus on in the future or, on the contrary, divert attention from them and thus increase the effectiveness of marketing activities and the related spending of corporate resources. The fact that customer churn rate is higher in e-commerce than in offline retail (Fu, 2022) increases the importance of analysing and then predicting customer purchase behaviour. The importance of research in this area is increased by the confirmed fact that repeat customers are more profitable than new acquirers (Reichheld and Sasser, 1990, Subramania and Somani, 2017, Jain et al., 2020). but this is only true if the firm spends adequate resources on customer retention and thus does not try to re-sell to customers for whom repeat purchase is unlikely (Ammar and Maheswari, 2017).

To make customer churn analysis and prediction actionable, it is necessary to use methods that are both sufficiently understandable and actionable for managers. This is also related to the type of data that is needed for this work. These, in turn, must be widely standardised and easily accessible to guarantee the aforementioned usability in practice. Such data can be, for example, the number of purchases, the volume of sales, and the timing of individual purchases, which can help us determine the length of the purchasing relationship with the customer or the time since the last purchase (recency). This data is available to every e-shop as it is automatically retrieved and stored in the e-shop platform and is thus easily accessible (Cao, 2010). One important factor in churn prediction is the type of relationship (Estrella-Ramón et al., 2013). and whether it is a contractual (e.g. in the case of insurance companies or telephone operators) or non-contractual setting (e.g. selling products on an e-shop). Incorporating insights from customer churn analysis can help a firm to target positive influence on CLV, which is also the focus of this paper.

Customer churn has been investigated by a number of authors in the past and thus there are many different approaches and models. In research practice, multiple techniques tend to be used, which are then compared on the basis of prediction accuracy (Jain et al., 2020). For example, Zhu et al. (2009) used 4 different techniques, namely Bayesian network, rough set, SVM and Survival Analysis, where the Bayesian network technique had the most accurate predictive ability. However, these methods are quite complicated for ordinary managers and their application requires considerable knowledge of methodology and data processing, which is contrary to the intent of our paper. One common technique for churn prediction is logistic regression which has demonstrated high predictive capability across different areas and product categories (Olle, 2014, De Caigny et al., 2018, Jain et al., 2020). However, it should be noted that these studies have often focused on telecommunications services, which are inherently different from online retail. The applicability and predictive performance of logistic regression in a non-contractual e-commerce environment was demonstrated by some authors (Buckinx and Van den Poel, 2005; Renjith, 2015; Subramania and Somani, 2017; Yanfang and Chen, 2017;

Xiahou and Harada; 2022) who worked with behavioural data such as recency, frequency, and monetary value, among others. However, the fact is that the number of studies in this area is very low and there is thus a significant knowledge gap, which implies the need for more similarly focused empirical research. This is also the main motivation of the authors, who have as a long-term research goal to fill this gap. The research will therefore focus on the application of logistic regression in B2C e-commerce for the purpose of churn prediction using transactional data of e-shops that sell products and the relationship with customers is non-contractual.

3. Data and methods

In this study, we used logistic regression as a machine learning method to predict the likelihood of repurchase by customers in an e-commerce setting. Logistic regression is a widely available tool in statistical software such as Excel and has been used in previous literature to predict binary outcomes such as repurchase behavior. To strengthen the external validity of our research (Uncless and Kwok, 2009). we used four datasets from the e-commerce enterprise resource planning (ERP) system, which recorded all transactions made by customers. The data comes directly from the e-shop, so it is not distorted in any way and its volume is also not limited by anything, as it can be for example when exporting from Google Analytics, where the collection and storage of data is subject to, for example, restrictions related to cookies.

First e-shop A in our datasets sells clothing and accessories for motorists. The data for the 58-month period from 1 January 2018 to 31 October 2022 were used. In total, 97,636 customers were included in the research, who made a total of 160,797 transactions and purchased a total of 196,668 products with a total sales volume of EUR 19,541,003. The average customer made 1.6 transactions over the period, with an average transaction value of EUR 122 and an average revenue per customer of EUR 200. Other three e-shops (B, C, D) sell also products beyond clothing and accessories like spare parts but all four operate in same segment – motorist goods. Due to anonymity of the data provided, we only know the specific categories and not particular brands sold in e-shops B, C and D. A summary of the data is available in Table 1.

Table 1: Datasets basic description

E-shop	Customers	Transactions	Products sold	Revenues (EUR)
A	97 636	160 797	196 668	19 541 003
B	11 812	19 744	337 348	26 100 826
C	35 212	36 400	186 871	9 831 237
D	22 558	23 045	111 326	1 955 879
TOTAL	167 218	239 986	832 213	57 428 945

Source: own data

These datasets were separated into training and testing sets, with the dependent variable being the repurchase behavior (retention) of the customer in the second period (see Table 2). The independent variables were the purchase frequency, individual customer revenue, and number of items purchased. Retention was defined as at least one transaction in the testing period, while purchase frequency was the number of transactions made by the customer during the training period. Customer revenue was calculated as the total amount spent by the customer during the training period, and the number of items purchased referred to the total number of products purchased by the customer during the training period.

Table 2: Training and testing periods for each dataset

E-shop	Number of transactions	From	To	Retention rate
A	Overall	01.01.2018	31.10.2022	23%
	Training	01.01.2018	31.12.2020	
	Testing	01.01.2021	31.10.2022	
B	Overall	01.04.2020	30.04.2022	2%
	Training	01.04.2020	23.04.2021	
	Testing	24.04.2021	30.04.2022	
C	Overall	01.04.2020	30.04.2022	0,2%
	Training	01.04.2020	06.02.2021	
	Testing	06.02.2021	30.04.2022	
D	Overall	01.04.2020	30.04.2022	0,1%
	Training	01.04.2020	29.04.2021	
	Testing	29.04.2021	30.04.2022	

Source: own data

E-shop A has a distinct period for training and testing as compared to the rest of the e-shops. The first training period for E-shop A is four years, spanning from January 1st, 2018 to October 31st, 2022, and the testing period is one year and 10 months, spanning from January 1st, 2021 to October 31st, 2022. In contrast, the other e-shops were split in half chronologically by the date of customer orders. This difference in the time frame for E-shop A should be taken into consideration when interpreting the results of the logistic regression analysis for this e-shop.

To ensure that the assumptions of logistic regression were met, we analyzed the correlations between the independent variables and found one statistically significant correlation higher than 0.7, including a correlation of 0.888 between frequency and items sold for e-shop A, significant at the 0.01 level (2-tailed). As a result, we ran one separate model without combining the correlated variables for this e-shop. This allowed us to compare models in predicting the likelihood of repurchase behavior in the e-commerce setting.

4. Results

The results of the logistic regression analysis of the four e-shops show that the Nagelkerke R-squared value is not always a good indicator of the model's ability to make accurate predictions. For example, the e-shop A had a low Nagelkerke R-squared value of 0.092, but a high classification accuracy of 81.9% (see table 3). On the other hand, the e-shop B had a high Nagelkerke R-squared value of 0.891 and a high classification accuracy of 99.8%. It's worth noting that the third and fourth e-shops had extremely low percentages of returning customers, with only 31 and 11 returning customers respectively, compared to a large number of non-returning customers. This imbalanced data may have led to different results in terms of model precision. The model may have been able to predict that most customers would not return, and still achieved almost perfect prediction with a low Nagelkerke R-squared value. The high classification accuracy of 99.8% and 99.9% for the third and fourth e-shop respectively, despite the low Nagelkerke R-squared value, suggests that these models are still able to make accurate predictions, however, it's important to note that these results should be interpreted with caution due to the imbalanced data.

Table 3: Logistic regression results

E-shop	Nagelkerke R Square	Correct prediction	Frequency		Revenue		Items	
			Sig.	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)
A	0,092	81,9	<,001	1,775	<,001	1,000	0,188	0,989
A (alternative)	0,090	81,9	<,001	1,755	<,001	1,000	Excluded	Excluded
B	0,891	99,8	<,001	9,469	<,001	7,007	0,692	1,003
C	0,024	99,8	0,375	1,124	0,831	1,000	0,022	1,071
D	0,084	99,9	0,883	1,248	0,019	1,001	0,207	1,011

Source: own data

Table 3 presents the results of a logistic regression analysis that was conducted to examine the predictors of customer churn for four e-shops. The first e-shop had low frequency as a significant predictor of churn, with an Exp(B) value of 1.755 (odds ratio), indicating that a lower frequency of shopping is associated with a higher odds of customer churn. Revenue was also found to be a significant predictor, but the Exp(B) value of 1.0 suggests that it does not have a significant impact on the odds of churn. The number of items sold was not found to be a significant predictor of churn, even at a 0.1 level of significance. The results of an alternative model, which excluded the number of items sold variable, were found to be consistent with the results of the normal model. The second e-shop had both frequency and revenue as significant predictors of churn, with Exp(B) values of 9.469 and 7.007, respectively. Both variables were found to be strong predictors of churn, with lower frequency of shopping associated with higher odds of customer churn. The third e-shop had only the number of items variable as a significant predictor of churn, with an Exp(B) value of 1.071, which is relatively small. The fourth e-shop had revenue as a significant predictor of churn, but again with a small Exp(B) value of 1.001. However, we have to keep in mind the third and fourth e-shops had small retention rates, which may lead to different results in terms of model precision and should be interpreted with caution. The results of analysis on the e-shops C and D are somewhat specific due to their low retention rates. These e-shops have a very small proportion of returning customers compared to non-returning customers, which can affect the ability of the logistic regression model to make accurate predictions. Imbalanced data can lead to overfitting, where the model is too closely fit to the majority class and does not generalize well to new data.

We can now move to the model prediction success. Logistic regression classification table is given by the so-called confusion matrix of correctly and incorrectly predicted fitted values (Hilbe, 2015). In rows the values represent the actual values from our observations in databases and in the columns, there are predicted values by the model.

Table 4: E-shop A confusion matrix

	Predicted	
	Non-returning	Returning
Non-returning	26 116 (true negative)	251 (false positive)
Returning	5 612 (false negative)	500 (true positive)

Source: own data

The classification table 4 displays the performance of the model in terms of correctly identifying customers who did not make a purchase in the next period, as well as customers who returned and were also predicted to do so. Specifically, the model correctly identified 26,116 customers who did not make a purchase in the next period and 500 customers who returned and were also predicted to do so. However, there were 251 customers who were predicted to return but did not, and 5,612 customers who were predicted not to return but did so in the testing period. These results provide a comprehensive understanding of the model's performance in terms of correctly identifying customer behavior patterns.

From the confusion matrix we can calculate model sensitivity which measures the proportion of actual positives that are correctly identified as such, and precision which measures the proportion of predicted positives that are actually true. We calculate the sensitivity as a number of correct positive

predictions divided by the sum of true positives and false negatives and model precision as true positives divided by the sum of true positives and false positive. Model sensitivity for e-shop A is 8 % however its precision is 67%. Depending on the practical use of a marketing manager the model cut value could be adjusted to trade precision for sensitivity.

Table 5: E-shop B confusion matrix

	Predicted	
	Non-returning	Returning
Non-returning (6 067)	6 066 (true negative)	1 (false positive)
Returning (105)	10 (false negative)	95 (true positive)

Source: own data

The classification table 5 model was able to accurately predict 6,066 customers who did not make a purchase in the next period, as well as 95 customers who returned and were also predicted to do so. However, there were 1 customer who was predicted to return but did not, and 10 customers who were predicted not to return but did so in the testing period. Model sensitivity is 92% and model precision is 99%. These results provide a comprehensive understanding of the model's ability to accurately identify customer behavior patterns.

5. Conclusion

In conclusion, this paper presents the results of a logistic regression analysis that was conducted to examine the predictors of customer churn for four e-shops. The results of the analysis indicate that both e-shops A and B showed a dependency of the odds of repeat shopping on frequency. This suggests that habit plays a crucial role in customer behavior, as regular shopping is the strongest predictor of consecutive behavior. E-shops C and D had imbalanced samples, which limits the ability to conduct logistic regression. This highlights the importance of considering the proportion of returning customers when using this method, as it may not be appropriate for every situation. Despite the limitations, logistic regression showed very good results for e-shop A and B, and it can be used in practice to determine customer retention and churn as also previous research showed (Mand'ák and Hančlová, 2019). It is an important tool for businesses to identify patterns of customer behavior and make informed decisions to improve customer retention.

Retention analysis is a simple, effective and practical business-focused methodology with a wide range of applications is a research direction with great potential for academia and business, according to Estrella-Ramón et al. (2013). and one that they recommend focusing on. For the purpose of practicality, the use of widely available tools such as Microsoft Excel is in order. The latter, for example, was used by Fader et al. (2005) for the purpose of processing customer transaction data, providing a tool for predicting customer purchasing behaviour using a detailed methodology. The only data needed for the calculation were frequency (number of purchases). recency (time since last purchase). monetary value (total sales volume) and period length (difference between the date of first purchase and the end of the observation period).

As a further line of research, it is suggested to use the above data for more detailed CLV calculation and subsequent prediction. Essentially, this will be an optimization, testing and extension of the methodology used in this paper, but it may provide a number of valuable insights and contribute to illustrating the bigger picture of a given e-shop.

The theoretical contribution of this paper lies in advancing the understanding of a previously under-researched but highly potential research area by both bringing new insights and creating a workable methodology that researchers can use to inform their work, which can scale the development of the research area. It has also created space and clear direction for a wide range of academics. The potential of the methodology used is also supported by the fact that logistic regression and its relatively simple application on standardized and widely available data has proven to be quite reliable at a given level of prediction accuracy, which is in line with the claims of authors who have explored this area of research (Buckinx and Van den Poel, 2005, Renjith, 2015, Subramania and Somani, 2017, Yanfang and Chen, 2017, Xiahou and Harada, 2022).

For practitioners, this paper has provided a tool for simple and effective analysis of customer buying behaviour in cases where there is enough convenient data. The process of data collection, processing, evaluation and interpretation can be very easily applied by e-shops of any focus to their business to provide a basis for the strategic and operational management of the business. The outputs can be used to evaluate the current situation and predict future developments, which will support the creation of strategic decisions and, ultimately, the competitiveness of the company.

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THE IMPACT OF SELECTED MACROECONOMIC INDICATORS ON THE NUMBER OF SMES IN THE CZECH REPUBLIC

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Abstract

Small and medium enterprises (SMEs) are important for the economic growth and development each of country. SMEs, account for approximately one-third of GDP in the Czech Republic. The aim of this article is to find if there exists the impact of some macroeconomic indicators (rate of unemployment, GDP, inflation rate, real effective exchange rate) on SMEs growth. The primary aim of the contribution is to find out if there is the long-term, resp. short-term relationship between macroeconomic variables and SMEs growth in the Czech Republic. The hypotheses were confirmed or rejected through statistical methods such as VEC model, Granger causality. The EViews 12 was used for data evaluation.

Keywords: ADF test, Granger causality, macroeconomic variables, SME, VEC model,

JEL codes: C23, L26

1. Introduction

Since the transition to a market economy, small and medium enterprises (SMEs) have played an indispensable role in terms of growth of the Czech economy, job creation and innovation. In addition to the macroeconomic aspect, SMEs are not only economically but also culturally and socially important at the regional level. They help to shape the local environment, contribute to building community cohesion and strengthening interpersonal relationships, as their owners often live in the place where their business operates. At the same time, however, they are extremely sensitive to economic fluctuations, often run into existential difficulties and are prone to disappear, especially in the early years of their existence. Simultaneously, while larger companies can afford to invest more money in innovation and systematically increasing added value, SMEs tend to find it more difficult to invest and they also face challenges in terms of increasing their productivity. Therefore, it is extremely important to support them, and it is one of the strategic priorities not only in the Czech Republic but also in the European Commission, as SMEs are crucial for the dual transformation to a sustainable and digital economy.

For the period 2021-2027, the SMEs' support strategy will contribute to the development of the following key areas in the Czech Republic:

- business environment
- access to finance
- access to markets
- workforce, skills, and education
- research, development, and innovation
- digitalisation
- low-carbon economy and resource efficiency.

In innovation, the Czech Republic has long been a moderate innovator. In the field of product, process, marketing and organisational innovations and investments in research and development, innovation is, however, mainly directed towards larger enterprises, or foreign companies. In general, SMEs have experienced a stagnation or reduction in innovation performance in recent years. Czech SMEs perform better only in the criterion of product or process innovations. But they perform much

worse in terms of the share of SMEs that introduce either product/process innovations or marketing/organisational innovations. At the same time, the Czech Republic has a lower share of SMEs investing in R&D compared to neighbouring Germany and Austria but outperforms the rest of the countries in the CEE region. At the same time, it is behind Germany and Austria and ahead of the rest of the region in all types of innovative cooperation involving SMEs (within companies, between companies, and with universities).

On the other hand, the Czech Republic is an example of a significant investment in other innovative inputs, particularly in workplace training. However, it is much weaker in case of improving management skills, where there is a significant gap between large enterprises and SMEs. SMEs have a lower management quality compared to larger enterprises. However, the Czech Republic lags in advances digital skills, which shows the importance of increasing investment in this area.

Data available from the Czech Statistical Office (2023) and the Ministry of Industry and Trade (2023), show that SMEs account for approximately one-third of GDP and over 50% of the value added. In addition, SMEs represent 60% of total employment, and also account for 99.8% of all registered enterprises in the Czech Republic.

It could be interesting to explore the influence of some macroeconomic variables on SMEs growth in the Czech Republic for the period 2007–2022. In order to assess the impacts on selected macroeconomic variables (rate of unemployment, economic growth, inflation rate, and real effective exchange rate) on SMEs growth, there were used suitable econometric methods.

The paper is organized in four parts. The first is the introduction; in the second, literature review which shows who dealt with similar research topic before; and the methodology section includes the hypotheses; in the third section the results are analysed and discussed in details, and finally the conclusions included implications and recommendations for practice, and also suggestions for future research.

2. Literature Review and Data

2.1 Literature Review

The topic of relationship between SME and some economic variables has been analysed by many authors. The importance of SME role in the development of global and regional economies is rising as well. The authors Ayyagari et al. (2007) describe the contribution of the SME to the employment and per capita Gross Domestic Products of 55 countries worldwide. They examine factors determining the size of the SME, including the ease of market entry and exit, labor legislation, access to bank crediting, and support of aid programs (including EU assistance). The similar thoughts and conclusion we can find in the paper of Ayyagari et al. (2007).

Research into the role and significance of the SME sector was also conducted by Beck et al. (2005), who explored the relationships between the nature of SME industrial enterprises and growth of per capita GDP as well as changes of income inequalities and relief of poverty. They demonstrated the existence of such a relationship.

Schiffer and Weder (2001) conducted research in companies from OECD countries and countries such as Latin America and the Caribbean, Eastern Asia and the Pacific, South Asia and Africa. The companies were asked to assess the following variables to their development: inflation, currency rates, functioning of the judiciary, corruption, street crime, organized crime, anti-corruption government practices.

Hallberg (2001) also wrote about the relationship of the SME to the employment and the GDP. Similar research was conducted by Pruša (2010) showing that in the Czech Republic, small and medium enterprises produce one-third of Gross Domestic Product, about 53% of gross value added and employ nearly two-thirds of all employees. The influence of SMEs on the growth and development of economy and on other macroeconomic variables was described by many authors like Taiwo et al. (2012) or Opafunso and Adepoju (2014). Many authors e.g. Kuteyi (2013), Taiwo et al. (2012)) revealed a distinct effect of SMEs on their country's development as they create employment and contribute to the GDP.

2.2 Data and Methods

The data for the period from 2007 to 2022 were used for the calculations. The Czech Statistical Office was the primary data source. The description of individual variables and the expected relationship are shown in Tab. 1. All values are considered in logarithmic terms. The selection of variables was done according to Osakwe et al (2015) and Halim et al (2017).

Table 1: Description of Variables

SME	The number of SME subjects.
GDP	Gross domestic product at current prices in billions of CZK. Higher GDP growth means higher sales growth and it could be positive for businesses. For this reason, the number of SME subjects is expected to be higher with higher GDP.
UNE	Unemployment rate (%). A negative long-term and short-term relationship is assumed.
INF	Inflation rate (%). There is assumed that the rise in price indices (inflation growth) will cause an decrease in the number of SME subjects.
REE	Real Effective Exchange Rate (2020=100). The unambiguous impact on this variable on the number of SME subjects is not expected.

Source: CZSO (2023), https://www.czso.cz/csu/czso/hmu_cr

The following hypotheses were formulated to fulfil the main aim. The core of this paper is to analyse these hypotheses concerning the relationship between the number of SME subjects and selected macroeconomic variables in the Czech Republic.

H1: There is a long-term relationship between the SME and the GDP, the rate of unemployment, the inflation rate, and real effective exchange rate, respectively in the Czech Republic.

H2: There is a short-term relationship between the SME and the GDP, the rate of unemployment, the inflation rate, and real effective exchange rate, respectively in the Czech Republic.

The hypotheses were confirmed or rejected through statistical methods such as VEC model, Granger causality.

The vector error correction model was used for this purpose to determine both long-term and short-term causal relationships. To create the resulting model, the econometric methodology was used, namely unit root tests, Granger causality for the determination of statistically significant relationships, information criteria, and the Johansen cointegration test. The methods of the cointegration analysis are described in articles Hendy and Juselius (2000), (2001).

The procedure for selecting a suitable method is shown below ('Unit root test'). Firstly, it is necessary to determine whether the variable is stationary by using the unit root test. Methods used to analyse stationary time series and non-stationary series are different. If all the variables are stationary, the methodology is simple. In such a case, ordinary least square (OLS) or vector autoregressive (VAR) models can be used. If all the variables are non-stationary, the ARDL model can be used. When the variables used in the analysis are of mixed type, i.e., some are stationary and others are non-stationary, we can use a similar procedure, outlined below (where OLS – ordinary least squares, VAR – vector autoregressive, ARDL – autoregressive distributed lags, ECM – error correction model).

Unit root test:

1. All variables stationary \Rightarrow OLS/VAR models
2. All variables non-stationary:
 - a) Johansen test:
 - a1) No cointegration
 - a2) Cointegration \Rightarrow ECM, causality test
 - b) ARDL models:
 - b1) No cointegration

- b2) Cointegration \Rightarrow ECM, causality test
3. Mixed variables \Rightarrow ARDL models: a) No cointegration
b) Cointegration \Rightarrow ECM, causality test.

3. Empirical Results

3.1 Stationarity of the Variables

The test results for all variables are provided in Table 2. The Dickey-Fuller test (ADF) was used to test stationarity. The model type of testing the unit root was used model with intercept. The second column contains the calculated T-statistics, and the following column contains the corresponding level of statistical significance. The last column includes the result of testing: N = non-stationary (H0 not rejected), S = stationary (H0 rejected).

Table 2: ADF Tests

Variable	T-stat	p-value	Result	Variable	T-stat	p-value	Result
<i>SME</i>	-2.833	0.102	N	<i>D(SME)</i>	-2.191	0.031**	S
<i>GDP</i>	1.324	0.997	N	<i>D(GDP)</i>	-3.421	0.028**	S
<i>UNE</i>	-1.704	0.404	N	<i>D(UNE)</i>	-2.834	0.085*	S
<i>INF</i>	-0.361	0.893	N	<i>D(INF)</i>	-3.511	0.077*	S
<i>REE</i>	-1.879	0.329	N	<i>D(REE)</i>	-4.231	0.007***	S

Statistical significance at the 0.01 level (***), at the 0.05 level (**), at the 0.1 level (*).

Source: Own calculations, Eviews.

All of variables exhibit the properties of first-order non-stationarity, i.e. I(1); therefore, long-run co-integration relationships may exist between these variables (at the statistical level 1%). Most of these tests (FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion, and LR: likelihood ratio) recommend a delay order of 1. VAR(1) model was chosen for further considerations.

3.2 Cointegration analysis

The next step is to test the number of cointegration relationships in VAR(1) model for the endogenous variables (*GDP*, *UNE*, *INF*, *REE*, *SME*) using the Johansen's method, as shown in Johansen (1995). Tab. 3 confirms the existence of 1 cointegration relationship for VECM(1). This is a model that includes limited level constant and does not include trend component.

Table 3: Cointegration analysis

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None *	0.715	75.641	60.061	0.0002
At most 1	0.425	39.759	40.174	0.0790
At most 2	0.354	21.282	24.275	0.2470
At most 3	0.185	6.488	12.3211	0.4790
At most 4	0.005	0.289	4.129	0.8183

* denotes rejection of the hypothesis at the 0.05 level

Source: Own calculations, Eviews.

The test in Tab. 3 confirms existence of one cointegration relationship. We have following cointegration equation (1).

$$SME = 1.806^{**} \cdot GDP - 2.073^{**} \cdot INF - 1.956^{**} \cdot UNE + 1.245^{*} \cdot REE \quad (1)$$

The cointegration equation shows that the number of SME subject is positively affected in the long term by GDP. GDP growth causes an increase in the number of SME objects in the long run, which is in line with the stated assumption. The negative relationships between the number of SME objects and the unemployment rate and the inflation rate are in line with the stated assumption. There is a positive relationship between the number of SME subjects and the real effective exchange rate.

The VECM is a tool for examining short-term deviations needed to achieve a long-term equilibrium between two variables. The VECM estimation for the cointegration relationship found is in Table 4. There is also a positive relationship between the number of SME subjects and the GDP, the rate of unemployment, and the real effective exchange rate and the other hand a negative relationship is between the number of SME subjects and inflation rate.

Table 4: Estimates VECM: D(SME)

	Coefficient	Std.error	Sign.
D(GDP(-1))	1.546	0.858	0.0315**
D(UNE(-1))	0.021	0.035	0.312
D(INF(-1))	-0.468	0.257	0.023**
D(REE(-1))	0.087	0.263	0.712
EC1	-0.098	0.474	0.041**
CONST	0.002	0.004	0.523

Statistical significance at the 0.01 level (**), at the 0.05 level (*), at the 0.1 level (*).

Source: Own calculations, Eviews.

Causality is captured by the statistically significant value EC1 (-0.098), which indicates that this variable will be modified by 9.8% within 1 quarter in case of long-term instability of the number of SME objects. In other words, complete elimination of instability would last approximately 10.2 quarters (1/0.098) and it is more than two years.

3.3 The Assumptions of the Model

The Table 5 shows testing results of the assumptions of the model. Doornik–Hansen test does not reject the null hypothesis of normality of residues. Ljung–Box test does not reject the null hypothesis of absence of autocorrelation. ARCH–LM test does not reject the null hypothesis of absence of heteroscedasticity. The tests were performed at the significance level of 0.05.

Table 5: The assumptions of the model

	Autocorrelation	Heteroscedasticity	Normality
Null hypothesis	H ₀ : absence of autocorrelation	H ₀ : absence of heteroscedasticity	H ₀ : normality of residues
Test	Ljung – Box	ARCH – LM	Doornik – Hansen
Significance	0.254	0.069	0.072

Source: Own calculations, Eviews.

The residual component is not correlated; residual component heteroscedasticity and residual component non-normality were not demonstrated.

3.4 Granger Causality

The Granger causality test is a statistical hypothesis test for determining whether one time series is useful in forecasting another (Granger, 1969). The results we can find in the Table 6. Using the term “causality” is a misnomer, as Granger-causality is better described as “precedence” (Leamer, 1985), or as Granger later claimed “temporally related” (Granger and Newbold, 1977). Rather than testing whether Y causes X, Granger causality tests whether Y forecasts X (Hamilton, 1994). It is necessary to work with the stationary time series.

Table 6: Pairwise Granger causality tests (lag 4)

	Statistic	Sign.
D(<i>SME</i>) does not Granger Cause D(<i>GDP</i>)	4.52	0.031**
D(<i>GDP</i>) does not Granger Cause D(<i>SME</i>)	3.75	0.044**
D(<i>SME</i>) does not Granger Cause D(<i>UNE</i>)	1.54	0.125
D(<i>UNE</i>) does not Granger Cause D(<i>SME</i>)	3.12	0.051*
D(<i>SME</i>) does not Granger Cause D(<i>INF</i>)	1.15	0.184
D(<i>INF</i>) does not Granger Cause D(<i>SME</i>)	3.92	0.041**
D(<i>SME</i>) does not Granger Cause D(<i>REE</i>)	4.12	0.038**
D(<i>REE</i>) does not Granger Cause D(<i>SME</i>)	2.75	0.062*

Statistical significance at the 0.01 level (**), at the 0.05 level (*), at the 0.1 level (*).

Source: Own calculations, Eviews.

Changes in the *SME* Granger cause changes in the *GDP* with one-year delay, and vice versa. Change in the *UNE* cause changes in the *SME*. The time series of the real effective exchange rate (*REE*) affects the number of *SME* objects, and vice versa in Granger's sense. Short-term relationships between these variables were confirmed. A short-term relationship between the inflation rate and the number of *SME* objects was not identified and the series are not related.

4. Conclusion

This article analyses the relationship between the number of *SME* objects and selected macroeconomic variables such as the *GDP*, the rate of unemployment, the inflation rate, and real effective exchange rate in the Czech Republic. There were two hypotheses. The first hypothesis was confirmed for all variables. It means there is a long-term relationship between the *SME* and the *GDP*, the rate of unemployment, the inflation rate, and real effective exchange rate in the Czech Republic. And in the case of short-term there is relationship between the *SME* and the *GDP*, the unemployment rate, and the inflation rate in the Czech Republic.

Inflation can also impact *SMEs*, particularly those that rely on imported goods or materials. Higher inflation rates can lead to higher costs for these businesses, which can reduce their profitability and potentially lead to closures. However, moderate inflation can also be beneficial for *SMEs*, as it can help stimulate consumer spending and economic growth.

Interest rates can also impact *SMEs*, particularly those that rely on borrowing to finance their operations or invest in new projects. Lower interest rates can make it easier for these businesses to access credit, while higher rates can make it more difficult and expensive.

The study reveals that *SMEs* play a vital role in job creation. There is a negative relationship between the number of *SME* objects and the unemployment rate. This study can be beneficial to both practitioners and academics. Further research may focus on strategies related to *SMEs* to create employment opportunities.

The successful operation of *SMEs* in the Czech Republic or their expansion into foreign markets is largely dependent on a functional and supportive business environment that considers all types of *SMEs*. The key will be to create a favourable business environment and to raise the entrepreneurial culture to increase the motivation to establish new innovative enterprises, remove obstacles to the growth of enterprises and stimulate their dynamic development. Start-ups and existing businesses often do not require direct support from the state, but need to operate in a stable and predictable environment that is conducive to entrepreneurial activity, allows the development of new ideas, and does not burden them with bureaucracy and various regulatory requirements, which ultimately hinder growth and competitiveness. Only in such an environment, individuals will be motivated to think creatively and innovatively, to implement their ideas, to start companies and to expand into domestic and foreign markets.

The Czech Republic and the EU are undergoing several changes that have an impact on the labour market and the requirements placed on entrepreneurs and employees. At the same time, innovation and technological progress associated with the digital transformation mean several new opportunities and business sectors, but sufficient attention must also be paid to creating the conditions that will allow these new opportunities to be exploited.

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USING MACHINE LEARNING TECHNIQUES TO REDUCE PAIRWISE COMPARISON MATRIX INCONSISTENCIES

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Abstract

This paper presents a new approach to the problem, the so-called inconsistency reduction in comparison matrices. Pairwise comparison matrices are used primarily in multi-criteria decision-making methods such as AHP (Analytic Hierarchy Process), where the problem of ensuring consistency of assessment regarding many different parameters also arises in these techniques. In this paper, selected algorithms from the machine learning family were used to reduce inconsistencies. The results of iterative inconsistency reduction algorithm (Szybowski), which effectiveness has already been sufficiently described and studied, were used as learning and testing data for the algorithms. The significance of the algorithms for the new data was also evaluated in terms of the following criteria: preservation of the original priority vector and the so-called object ranking, original preferences in the form of a pairwise comparison matrix, and preservation of the most significant number of unchanged positions of the original comparison matrix. The appropriateness of using such techniques for the presented problem is also discussed, as well as a comparison of results.

Keywords: machine learning, pairwise comparison, inconsistency reduction, analytic hierarchy process, ahp

JEL codes: C44, D81, C02

1. Introduction

In multi-criteria decision-making methods such as AHP, pairwise comparison matrices are used to evaluate and rank different parameters. However, the problem of ensuring consistency in the assessments of multiple criteria arises, which can lead to inaccurate decision-making. To address this issue, this paper presents a new approach to inconsistency reduction in comparison matrices which uses selected algorithms from the machine learning family to reduce inconsistencies in the pairwise comparison matrix. The effectiveness of the iterative inconsistency reduction algorithm (including Szybowski's used in this approach) has already been studied, and its results were used as learning and testing data for the algorithms in this study. The proposed approach was evaluated based on the preservation of the original priority vector, object ranking, pairwise comparison matrix, and unchanged positions of the original matrix. At this time, the authors are not aware of any other attempts to solve this problem in pairwise comparison matrices using the techniques indicated. This paper discusses the appropriateness of using such techniques for the presented problem and compares the results with existing methods for inconsistency reduction.

The paper is organized as follows. Section 2 provides an overview of pairwise comparison matrices and the problem of inconsistency reduction, along with a description of the Szybowski algorithm. Section 3 describes the machine learning techniques used in this study, including decision tree regression, multiple linear regression, k-nearest neighbors regression, and multi-layer perceptron regression. Section 4 details the methodology of the research, including data collection and preprocessing, application of machine learning techniques for inconsistency reduction, and evaluation criteria for the effectiveness of the proposed approach. Section 5 presents the results of the study and a discussion of their implications, including an evaluation of the effectiveness of the proposed approach and a comparison with existing methods. Finally, Section 6 provides a summary of the study's findings and its potential applications.

2. Pairwise comparison matrices

Pairwise comparison matrices are a useful tool in decision-making, where a set of entities are evaluated based on certain criteria. As Mazurek (2023) describes it - the matrix records the preferences of one entity over another, which allows for the relative importance of each entity to be evaluated (1).

$$a_{ij} = \frac{1}{a_{ji}}, \forall i, j \in \{1, 2, \dots, n\} \quad (1)$$

To construct a pairwise comparison matrix for a set of n entities, all possible pairwise comparisons are recorded in an $n \times n$ matrix (2). It's crucial for the values in the matrix to satisfy certain conditions, such as the property of reciprocity, which ensures that the pairwise comparisons are reciprocal. This property is necessary for establishing multiplicative pairwise comparisons.

$$\begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{pmatrix} \quad (2)$$

A prioritization method is a procedure that derives a priority vector from an $n \times n$ pairwise comparison matrix. The priority vector is a vector of weights of all n compared objects and is used to compare and rank the entities based on their relative importance (3).

$$\sum_{i=1}^n w_i = 1 \quad (3)$$

The values in the priority vector can be used to establish a ranking of the entities, with higher values corresponding to higher priority or greater relative importance. Ties in the ranking are also possible, indicating that multiple entities have the same level of importance with respect to the criteria being evaluated. The goal of pairwise comparison methods is to rank the compared objects from best to worst based on the derived priority vector. By using pairwise comparison matrices and prioritization methods, decision-makers can systematically evaluate and compare entities based on various criteria.

2.1 Problem of inconsistency reduction and inconsistency reduction algorithms

The consistency of a given $n \times n$ PC matrix A is commonly evaluated using Saaty's (1977) consistency index (CI) and consistency ratio (CR). To compute $CI(A)$, one needs to calculate the largest positive eigenvalue of A denoted by λ_{max} and use it in equation (4):

$$CI(A) = (\lambda_{max} - n) / (n - 1). \quad (4)$$

On the other hand, $CR(A)$ is defined as the ratio of $CI(A)$ to $RI(n)$, which is the random consistency index. $RI(n)$ is the mean of randomly generated PC matrices of a given order using Saaty's scale that is dependent on n (5):

$$CR(A) = \frac{CI(A)}{RI(n)}. \quad (5)$$

The possibility of errors in human perception and judgment can lead to inconsistency in PC matrices, making it difficult to pinpoint the exact location of these errors, described by Kuraś (2023). To tackle this issue, various methods and algorithms have been developed to identify and rectify erroneous data in matrix A, with the ultimate goal of minimizing the inconsistency ratio. Two main categories of algorithms exist for reducing inconsistency in pairwise comparison matrices: non-iterative and iterative methods as Mazurek (2023) mentioned in his work.

Mazurek et al. (2021) tested iterative algorithms, including those proposed by Cao et al. (2008), Szybowski (2018), and Xu & Wei (1999). While there are other known algorithms in the literature [87], the Kou et al. (2014) algorithm was considered unstable and inefficient, and the Mazurek et al. (2020) algorithm was found to not always converge to zero inconsistency. According to that research, the algorithm of Szybowski's kept the most matrix entries unchanged during inconsistency reduction. For this reason, it was also chosen as the algorithm used as a source of learning and test data, as will be described later in the paper.

2.2.1 Szybowski algorithm

Szybowski (2018) proposed an inconsistency reduction algorithm that aims to reduce inconsistencies in matrices. The algorithm works on the observation that if a matrix is inconsistent, there must be a violation of the transitivity property between at least one pair of elements. The Szybowski algorithm aims to identify and correct these violations systematically.

To start the algorithm, the initial CI and CR values of the input matrix are computed. Then, a series of modifications are made to the matrix until the CR falls below the given threshold. These modifications involve finding the largest e_{ij} value, which is the ratio of the i -th element to the j -th element, and using it to modify the matrix. The algorithm selects a pair of elements, (i, j) , where e_{ij} is the largest value in the matrix, and sets the value of the (i, j) element to be equal to the geometric mean of the i -th and j -th elements. The value of the (j, i) element is set to be equal to the reciprocal of the (i, j) element. After each modification, the CI and CR values of the modified matrix are recomputed, and the algorithm checks if the CR is below the threshold. If the CR is still too high, the process is repeated with the modified matrix until the desired level of consistency is achieved.

2.2 Measures of preference preservation

The aim is to minimize the difference between the original and modified matrices while reducing inconsistency. The algorithm for inconsistency reduction is defined as an algorithm that transforms the original pairwise comparison matrix into a modified one with a lower measure of inconsistency. Various measures of preference preservation have been proposed in the literature, including δ and σ by Xu & Wei (1999), the total number of deviation points by Pereira & Costa (2018), and measures of compromise by Abel et al. (2018). In this paper, the following measures of preference preservation will be used as mentioned in Mazurek et al. (2021):

- the average change in the priority vector (6),
- Kendall's tau distance (7),
- the distance between two matrices (8), and
- the number of changed elements in matrix after the inconsistency reduction (9).

$$d(w, w') = \frac{1}{n} \sum_{i=1}^n |w_i - w'_i| \quad (6)$$

$$K_d(A_{ij}, A'_{ij}) = \sum_{\{i,j\} \in P, i < j} \bar{K}_{i,j}(\tau_1, \tau_2) \quad (7)$$

$$D(A, A') = \|A - A'\| = \sum_{i=1}^n \sum_{j=1}^n |a_{ij} - a'_{ij}| \quad (8)$$

$$N = |a_{ij}; a_{ij} \neq a'_{ij}, \forall i, j| \quad (9)$$

Lower values for these measures indicate better preservation of the original preferences.

3. Machine learning techniques

Machine learning involves certain algorithms to make decisions and provide results to users. It is a subfield of artificial intelligence and is used for complex data classification and decision-making. As Eberbach & Strzałka (2022) mentioned machine learning algorithms enable systems to learn and make necessary decisions, and they are employed in a range of computing tasks where explicit algorithm design and programming is not feasible. Some examples of machine learning applications include spam filtering, OCR, search engines, and computer vision.

There are three main categories of machine learning methods and tasks: supervised learning, un-supervised learning, and reinforcement learning. Supervised learning involves mapping input objects to desired output values, while un-supervised learning involves defining a function to describe hidden structure from unlabeled data. Reinforcement learning deals with how software agents should take actions in an environment to maximize cumulative reward.

3.1 Machine learning algorithms used in a research

Supervised machine learning is a process that trains a model to predict outcomes based on given evidence while considering uncertainty as Nasteski (2017) mentioned. This technique requires known inputs and outputs to train the model to predict new data. If known output data is available, supervised learning is the appropriate method to use, as it is in the case of this research paper.

Classification and regression techniques are utilized in supervised learning to develop machine learning models. Classification techniques are used to predict discrete responses, such as classifying an email as spam or legitimate, or determining if a tumor is benign or cancerous. On the other hand, regression techniques are used to predict continuous responses, such as the state of battery charge, load on the electrical grid, or the price of financial assets. If the data range is broad or if the nature of the response is a real number, regression techniques should be used. This research paper employs four regression algorithms from this branch of machine learning techniques as described by Czajkowski and Kretowski (2016): decision tree regression, multiple linear regression, k-nearest neighbors regression, and multi-layer perceptron regression.

3.1.1 Decision tree regression

A tree-like structure is used by decision trees to construct regression or classification models. The dataset is divided into progressively smaller subsets, while simultaneously developing an associated decision tree. The resulting tree contains decision nodes and leaf nodes. A decision node has multiple branches, each corresponding to values of the attribute being tested. The leaf node denotes the decision on the numerical target. The root node, which corresponds to the best predictor, is the topmost decision node in the tree. Decision trees can handle both categorical and numerical data.

3.1.2 Multiple linear regression

Multiple linear regression (MLR) is a statistical technique for developing a model that depicts the linear connection between a dependent target and one or more independent variables. Several assumptions must be met for MLR to be accurate, such as a normal distribution of errors with a mean of zero and a constant variance. Unbiased estimators have an expected value equal to the true value of the parameter, efficient estimators have a smaller variance than any other estimator, and consistent estimators have biases and variances that approach zero as the sample size approaches infinity.

3.1.3 K-nearest neighbours regression

The K-nearest neighbours (KNN) algorithm is a straightforward method that retains all available cases and makes predictions for numerical targets by utilizing a similarity measure, such as distance functions. KNN has been employed as a non-parametric technique in statistical estimation and pattern recognition since the early 1970s. To perform KNN regression, one simple implementation involves calculating the mean of the numerical target for the K-nearest neighbours. Another approach involves

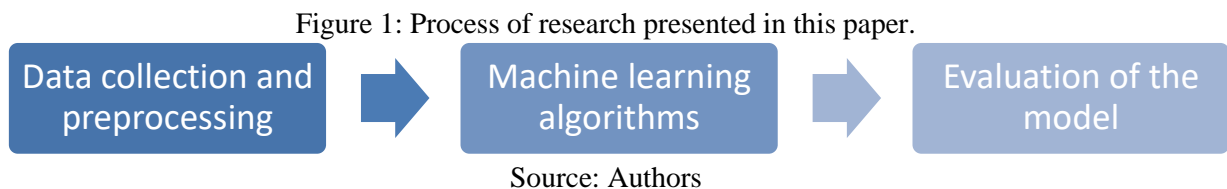
computing an inverse distance weighted average of the K-nearest neighbours. The distance functions used in KNN classification are also utilized in KNN regression.

3.1.4 Multi-layer perceptron regression

A multi-layer perceptron (MLP) artificial neural network is made up of three or more layers of perceptrons. These layers consist of a single input layer, one or more hidden layers, and a single perceptron output layer. The data in this network travels exclusively forward, beginning at the input layer and progressing via the hidden layers to the output layer. The MLP uses backpropagation to enhance its prediction accuracy, which entails getting feedback on flaws in its output and then modifying its weights accordingly.

4. Methodology of research

The entire process of testing the effectiveness of using machine learning techniques to reduce inconsistencies in the pairwise comparison matrices described in the next section can be visualized using the diagram in Figure 1.



4.1 Data collection and preprocessing

The 100,000 generated 4x4 pairwise comparison matrices from the PC MATRICES GENERATOR tool published by Kuraś & Gerka (2023) were used as input learning and test data for the machine learning algorithms presented in this paper in Sections 3.1.1 to 3.1.4. This tool was used because it allowed for the generation of a matrix with a high degree of inconsistency, thanks to the possibility of selecting the ranges of the CR factor. The matrices with $0.30 < CR < 0.80$ were chosen. To obtain the output, all 100,000 matrices were reprocessed using the Szybowski (2018) algorithm, described in Section 2.1.1, reducing the non-compliance rate using this algorithm to less than 0.10, which is considered sufficiently compliant. This algorithm was implemented within the REDUCE library and tool developed by Kowal et al. (2021). As the data from this tool contained additional columns, they were cleaned of redundant columns and the data ultimately contained the fields seen in Table 1, which is an extract from the CSV file.

Table 1: Data used for training algorithm, after processing by Szybowski (2018) algorithm

A11	A12	A13	A14	A21	A22	A23	A24	A31	A32	A33	A34	A41	A42	A43	A44	CR
1.0	0.5	0.25	0.12	2.0	1.0	1.0	0.2	4.0	1.0	1.0	0.14	8.27	5.0	7.0	1.0	0.051
1.0	4	9.0	0.2	0.2	1.0	5.0	0.11	0.11	0.2	1.0	0.04	5.0	9.0	22.35	1.0	0.05
1.0	0.33	6.0	0.33	3.0	1.0	9.0	0.3333	0.1667	0.11	1.0	0.125	3.0	3.0	8.0	1.0	0.0925
...
1.0	1.02	1.57	5.0	0.9	1.0	0.44	4.0	0.63	2.2	1.0	6.0	0.2	0.2	0.16	1.0	0.051

Source: Authors

The data were then segmented into 20,000 matrices each - the learning and test sets, respectively. Only such data could be processed by machine learning algorithms and create models, the implementation of which is described in detail in the next subsection. After separating this into the four algorithms used, the remaining 20,000 matrices were used for the final algorithm evaluation analyzed in this research paper.

4.2 Machine learning techniques application for inconsistency reduction

The code to execute machine learning tasks is a Python which uses several libraries including pandas, numpy, and scikit-learn to perform a range of operations including data loading, data splitting, training and testing different machine learning models, and calculating CR. The script first loads two datasets (X and y) from CSV files, where X is the input and y is the output. It then splits the datasets into training and testing sets using the `train_test_split` function from scikit-learn. The script creates a list of machine learning models to be used, including linear regression, k-nearest neighbors, decision tree regression, and multi-layer perceptron regression. It then trains each model using the training dataset and predicts the output using the testing dataset. The script uses 10-fold cross-validation to estimate the performance of each model, and the resulting scores are stored in the `self.scores` list. Finally, the script calculates the actual CR for each predicted output using the `calc_cr` function from the `helpers.py` file (shown in Figure 2) and stores the results in CSV files for each model (Figure 3). A diagram of how the algorithm works is shown in Figure 4.

Figure 2: Script calculating CR from matrix

```
import numpy as np
from CR_calc import CrCalc

def calc_cr(data):
    # A11,A12,A13,A14,A21,A22,A23,A24,A31,A32,A33,A34,A41,A42,A43,CR
    m1 = [data["A11"], data["A12"], data["A13"], data["A14"]]
    m2 = [data["A21"], data["A22"], data["A23"], data["A24"]]
    m3 = [data["A31"], data["A32"], data["A33"], data["A34"]]
    m4 = [data["A41"], data["A42"], data["A43"], data["A44"]]
    m = np.matrix([m1, m2, m3, m4])
    max_vals = self.max_eigenvalue()
    ci = (max_vals - self.SIZE) / (self.SIZE - 1)
    ri = self._select_ri(self.SIZE)
    cr = ci / ri
    return cr()
```

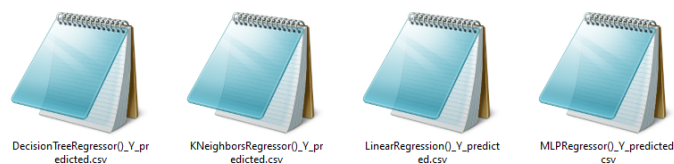
Source: Authors

4.3 Evaluation criteria for the effectiveness of the proposed approach

Since, as can be seen in Figure 3, the CR value is also involved in shaping the machine learning model, the fact that it is correctly predicted is, in our case, the first factor that allows us to determine the correctness of the operation of the chosen regression type at its most basic level. It will also allow us to reject some of the models for further analysis. Then, on the matrices that remain, the average change in the priority vector, Kendall's tau distance, the distance between two matrices, and the number of changed elements in the inconsistency reduction will be calculated, which are described in section 2.2 of this research paper.

Figure 3: Results in CSV files

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	A11	A12	A13	A14	A21	A22	A23	A24	A31	A32	A33	A34	A41	A42	A43	A44	CR	cr_real	
2	0.10	1.3289	7.0	6.0	0.7525	1.0	9.0	8.0	0.1429	0.1111	1.0	0.3333	0.1667	0.125	3.0	1.0	0.0593	0.059301299084693546	
3	1.10	3.0	5.0	0.25	0.3333	1.0	4.0	0.1429	0.2	0.25	1.0	0.0932	4.0	7.0	10.7293	1.0	0.0567	0.05671999392557785	
4	2.10	5.0	0.5	8.0	0.2	1.0	0.2367	0.8427	2.0	4.2243	1.0	6.0	0.125	1.1867	0.1667	1.0	0.0573	0.057291868028171315	
5	3.10	1.6147	0.125	0.25	0.6193	1.0	0.25	0.4597	8.0	4.0	1.0	1.0019	4.0	2.1755	0.9981	1.0	0.0822	0.08224385014179886	
6	4.10	0.3333	0.3333	3.993	3.0	1.0	0.3333	5.0	3.0	3.0	1.0	5.6499	0.2504	0.2	0.177	1.0	0.084	0.08402581521556074	
7	5.10	0.2	1.0	0.3333	5.0	1.0	3.0	1.0496	1.0	0.3333	1.0	0.971	3.0	0.9527	1.0299	1.0	0.064	0.06404620571016444	
8	6.10	0.3333	7.0	3.0	3.0	1.0	7.0	5.0	0.1429	0.1429	1.0	0.248	0.3333	0.2	4.0326	1.0	0.0717	0.07169744228296317	
9	7.10	3.5515	1.0852	1.0	0.2816	1.0	0.1429	0.125	0.9215	7.0	1.0	2.321	1.0	8.0	0.4308	1.0	0.0731	0.07313046448776156	
10	8.10	3.1321	3.0	7.0	0.3193	1.0	0.5	0.5	0.3333	2.0	1.0	3.0	0.1429	2.0	0.3333	1.0	0.0962	0.09617655928225537	
11	9.10	0.0892	0.2	0.1111	11.2142	1.0	7.0	2.0	5.0	0.1429	1.0	0.1667	9.0	0.5	6.0	1.0	0.0789	0.07896304926369001	
12	10.10	9.0	3.0	1.8744	0.1111	1.0	0.25	0.1429	0.3333	4.0	1.0	0.2	0.5335	7.0	5.0	1.0	0.0634	0.06342834543137425	
13	11.10	2.3523	4.0	0.2546	0.4251	1.0	4.0	0.2	0.25	0.25	1.0	0.1429	3.928	5.0	7.0	1.0	0.0689	0.06888474691211753	
14	12.10	10.7666	3.6071	4.0	0.0929	1.0	0.2	0.1667	0.2772	5.0	1.0	2.4924	0.25	6.0	0.4012	1.0	0.0665	0.06651946437210768	
15	13.10	1.0649	0.1429	1.0926	0.939	1.0	0.25	4.0	7.0	4.0	1.0	9.0	0.9153	0.25	0.1111	1.0	0.0632	0.0631918446969819	
16	14.10	8.0	4.0	9.1779	0.125	1.0	1.6118	3.0	0.25	0.6204	1.0	4.0661	0.109	0.3333	0.2459	1.0	0.0779	0.07797779891239674	
17	15.10	0.3333	4.4475	0.8049	3.0	1.0	9.0	7.0	0.2248	0.1111	1.0	0.5	1.2423	0.1429	2.0	1.0	0.0606	0.06058268778337995	
18	16.10	0.1111	7.0	1.0	9.0	1.0	17.8728	5.0	0.1429	0.056	1.0	0.25	1.0	0.2	4.0	1.0	0.0547	0.05485277462990698	
19	17.10	1.0	0.2146	0.2	1.0	1.0	0.2	0.5	4.6597	5.0	1.0	3.4944	5.0	2.0	0.2862	1.0	0.0657	0.06570545756617438	
20	18.10	0.2792	6.0	0.25	3.5813	1.0	8.0	0.4819	0.1667	0.125	1.0	0.091	4.0	2.0749	10.9924	1.0	0.0513	0.051329401232897094	
21	19.10	4.1994	2.0	3.0	0.2381	1.0	0.1429	0.25	0.5	7.0	1.0	3.6003	0.3333	4.0	0.2778	1.0	0.0928	0.09278212475371346	
22	20.10	6.0	1.0	0.5	0.1667	1.0	0.1667	0.1111	1.0	6.0	1.0	1.5197	2.0	9.0	0.658	1.0	0.0482	0.04819824233249391	



Source: Authors

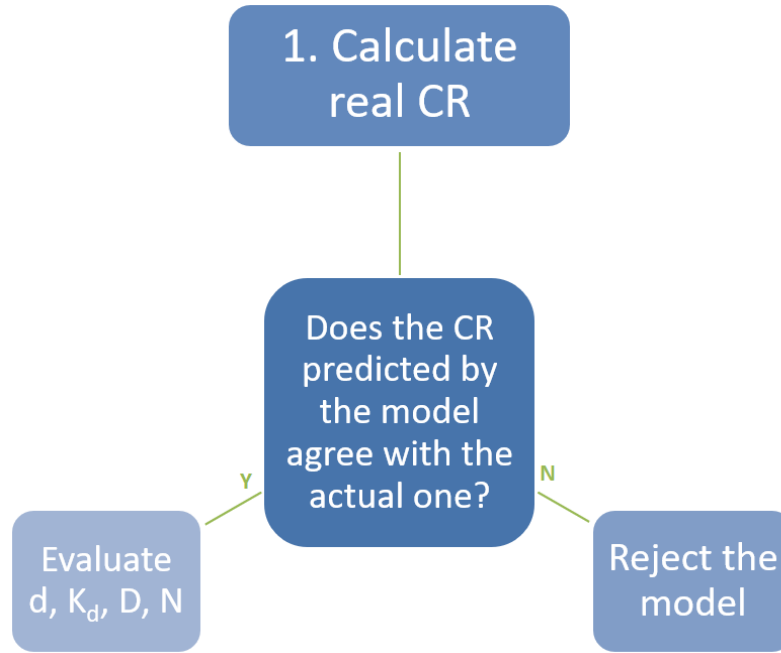
Figure 4: Algorithm operation diagram.



Source: Authors

The final step will be to compare the results obtained with those obtained by iterative 'classical' pairwise comparison matrix inconsistency reduction algorithms. The whole process can be illustrated by the diagram shown in Figure 5.

Figure 5: Evaluation of the models.



Source: Authors.

Figure 6: Comparing CR predicted value with real CR value – orange fields are not matching, green are equal or almost equal

	A	B	C	D	E	F	G	H
1	Decision Tree Regression		K-Neighbours Regression		Linear Regression		MLP Regression	
2	CR	cr_real	CR	cr_real	CR	cr_real	CR	cr_real
3	0,0593	0,0593	0,06102	0,081721025	0,06668082481970666	-0,1815437522656399	0,05531259003746078	-0,6441869360562806
4	0,0567	0,0567	0,0658	0,083414797	0,06498310628713201	-0,3466652414701778	0,05644714728090024	0,10809365071506916
5	0,0573	0,0573	0,06338	0,125922859	0,06485094102104841	-0,4068496229021497	0,05718706490969436	-0,09092668886103072
6	0,0822	0,0822	0,0733	0,150013554	0,06650971936339503	1,7733163372813425	0,07070880012585617	-0,1487415054524579
7	0,0840	0,0840	0,0821	0,096944889	0,06536691996232516	-0,4659175667646214	0,05913807325041734	-0,5706257312219398
8	0,0640	0,0640	0,05488	0,182202352	0,06446807537210893	0,3709091659464023	0,0642232367984813	0,13884050349726745
9	0,0717	0,0717	0,07076	0,100923195	0,06643511529577315	-0,2622324421477864	0,05869411736407466	0,2998302675352131
10	0,0731	0,0731	0,08876	0,269157551	0,06512591197201831	-0,22640845163799142	0,05318130745468309	0,3774515619750699
11	0,0962	0,0962	0,05242	0,243743367	0,0642571089673979	1,1750058375248462	0,05884960878718341	0,39846768947070915
12	0,0789	0,0790	0,06266	0,091078251	0,0665088340436724	-0,15511237204838307	0,0696566122432507	0,01749514266340363
13	0,0634	0,0634	0,05092	0,073636116	0,06460364231073536	-0,4895347548128841	0,05359245191795626	-0,696001956612555
14	0,0689	0,0689	0,07938	0,118899135	0,06579420557371973	-0,18273647232050333	0,05396179636127214	-0,6034628513456628
15	0,0665	0,0665	0,0728	0,19883065	0,06616396771650308	-0,014059788311759252	0,05649348768758669	0,7066801184301746
16	0,0632	0,0632	0,05804	0,113480298	0,06660240818292772	-0,1538955467695304	0,05832734558550039	0,39938325407186753
17	0,0779	0,0780	0,06406	0,34270915	0,06518297211321623	-0,07465119307672279	0,05869999955459624	0,5545045385312118
18	0,0606	0,0606	0,06052	0,102749509	0,06563632284639982	-0,2260999295472858	0,05192621005142665	0,24112078585175198
19	0,0547	0,0549	0,05236	0,11563917	0,06484143161810733	-0,37432722402214474	0,05687651286475145	-0,18801789501846342
20	0,0657	0,0657	0,07822	0,164282201	0,06321375850190067	0,44830024597323803	0,05256014903776385	0,39475877094573497
21	0,0513	0,0513	0,06624	0,181891312	0,06666214774714405	1,678606553498413	0,06654492015461816	0,7987959026742121
22	0,0928	0,0928	0,07138	0,14418268	0,0661493988855437	0,7531203119978424	0,0600638151589593c	0,5795352277229816
23	0,0482	0,0482	0,06788	0,150423693	0,06522661537522256	-0,2536900846090026	0,04989692284575744	0,1143545682103039
24	0,0778	0,0778	0,06894	0,083098067	0,06849787444559985	0,36132883674587385	0,06956542223297164	0,7216301519440642
25	0,0800	0,0801	0,06784	0,099554128	0,06741970420636793	-0,18413801378810268	0,05990059800447824	0,5541772669691913
26	0,0704	0,0704	0,05724	0,094864616	0,06436433046733488	-0,48783571479342575	0,06481167459093655	0,4615159667562106
27	0,0558	0,0558	0,07394	0,145755823	0,06642909240112047	1,661315176012057	0,0565068355288055c	-0,07671246624553281
28	0,0414	0,0414	0,05356	0,063193113	0,06559907193172457	-0,30862680432573	0,06354175886849237	-0,8497009315418899

Source: Authors

5. Results and Discussion

5.1 Evaluation of the effectiveness of the proposed approach in terms of the evaluation criteria

As mentioned in Section 4.3, the first step was to investigate which algorithms correctly learned to perform inconsistency reduction, as evidenced by the correspondence between the learned CR and the actual one calculated using equation (2). As can be seen in Figure 6, unfortunately, only one of the algorithms - decision tree regression - was able to cope with this test, so only it will be considered for further calculations.

Then, taking the original, non-reduced matrix together with the matrix reduced by an algorithm using decision tree regression, we are able to count the values of the average change in the priority vector, Kendall's tau distance, the distance between two matrices, and the number of changed elements in the inconsistency reduction, and determine the average values of these coefficients, as can be seen in Table 2.

Table 2: Average preference preservation parameters after decision tree regression

Avg. change in priority vector (d)	Kendall's tau distance (K_d)	Distance between two matrices (D)	Number of changed elements (N)
0.1946	0.3290	37.72	11.5

Source: Authors

5.2 Comparison of the proposed approach with existing methods for inconsistency reduction in pairwise comparison matrices

In a study by Mazurek et al. (2021), several iterative incompatibility reduction algorithms for pairwise comparison matrices were tested against measures of preference preservation to compare their effectiveness. Taking these studies into account, the results obtained in the study from this paper were compared with the results obtained in the mentioned study and grouped in Table 3.

Table 3: Comparing results with iterative methods of reducing inconsistency for initial value $0.30 < CR < 0.80$. Green fields are the best (lowest) value, red – the worst (highest).

	(d)	(K_d)	(D)	(N)
This paper	0.1946	0.3290	37.72	11.5
Cao et al.	2.132	0.191	11.67	12
Cao et al. II	1.552	0.147	14.44	12
Mazurek et al.	5.341	0.595	8.74	4.62
Szybowski	5.827	0.638	9.97	3.84
Xu and Wei	0.567	0.039	14.47	12
Xu and Wei II	0.723	0.049	12.12	12

Sources: Mazurek J. et al (2021): A Numerical Comparison of Iterative Algorithms for Inconsistency Reduction in Pairwise Comparisons; and Authors.

5.3 Discussion of the results and their implications

The model shows great potential - it even proved to be the best within one of the indicators - that is, the average change in the priority vector. In addition to this, against iterative algorithms, it showed an average Kendall's tau distance at a level not out of line with others, and a number of unchanged elements close to 12 (in other words, only the ones on the diagonal are retained) - which would be the worst value, but is also a feature of other algorithms, e.g. Xu and Wei (1999) and Cao (2008). Unfortunately, in terms of the distance between two matrices, the value presented by the model deviates significantly from other values.

Interestingly, no correlation can be seen between the results obtained with Szybowski's algorithm and the model on which it was based. This gives room for further analysis of decision trees in terms of inconsistency reduction, which will certainly be subject to future research.

6. Conclusion

This publication presents an attempt to use machine learning algorithms to solve the problem of pairwise comparison matrix inconsistency reduction. In the presented study, decision tree regression algorithms obtained results that indicate further potential for research in this area, which will certainly be done. Certainly, the entire family of machine learning algorithms should not be definitively discarded, which was initially one of the assumptions of the experiment, but the results proved promising enough that it may initiate a whole new branch of research on the topic of pairwise comparisons and the inconsistency reduction problem.

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A COMPARISON OF EXISTING RISK ANALYSIS METHODS USED IN INFORMATION SECURITY SYSTEM AUDITS AND THE POTENTIAL FOR THEIR DEVELOPMENT

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Abstract

This paper provides a comparison of existing risk analysis methods used in information security systems audits. Specifically, it examines the strengths and weaknesses of the risk analysis process, including the use of structured questionnaires, quantitative risk analysis, internal control reviews, threat and vulnerability assessments, and other risk assessment techniques. It also discusses the importance of understanding the specific risks associated with the system being audited in order to properly assess a system's security posture. Finally, it provides recommendations on how to use risk analysis methods in a comprehensive audit process, and indicates the potential for the development of such methods, with a particular focus on the direction of the potential use of solutions analogous to those used in decision-making techniques using pairwise comparison matrices (such as AHP), with an indication of such desirable features as multi-criteria or reduction of the inconsistency of expert opinion that such methods provide.

Keywords: risk analysis, information security, threat and vulnerability assessments, structured questionnaires, pairwise comparison matrices

JEL codes: C61, C63, C83

1. Introduction

The requirement for comprehensive risk analysis in information security system audits has gotten more and more important as the significance of information security keeps rising. Any audit process must include risk analysis because it enables auditors to recognize and assess the dangers that the information security system of an organization faces.

This study compares the various risk analysis methodologies now in use for information security systems audits, such as structured questionnaires, quantitative risk analysis, internal control reviews, threat and vulnerability assessments, and other risk assessment methods. This paper seeks to offer a full overview of the risk analysis procedure and its potential for improvement by exploring the advantages and disadvantages of different methodologies. In addition to evaluating existing methods, this paper also explores the potential for the development of new risk analysis methods. Specifically, it focuses on the use of solutions analogous to those used in decision-making techniques using pairwise comparison matrices, such as the Analytical Hierarchy Process (AHP). The paper proposes a new method,

PCM-RISK, which uses pairwise comparison matrices to improve the consistency and accuracy of expert opinions and to provide a more comprehensive assessment of risks.

2. Information security system audits

Information security audits are essential for organizations to protect against data breaches and privacy violations. By examining company systems and services, an auditor can pinpoint security weaknesses and determine if the practices comply with laws like the GDPR. The primary goal of such process is to identify vulnerabilities that could result in a data breach and assess the compliance posture. As Sabilillon (2022) presented in his work, audits should be performed by a qualified third party auditor, and the results of the assessment verify to management and stakeholders that the defenses methods are adequate. A thorough assessment provides a comprehensive overview of systems and insights on the best way to address vulnerabilities. Conducting an information security audit mitigates the risk of a data breach, which can result in significant financial damage and leave customers and suppliers less confident in the organization. According to a number of guidelines companies and organizations should conduct a cyber security audit at least once a year, but more frequent audits may be necessary only for organizations with a larger number of employees or potential sources of data security breaches as concluded by Slapničar et al. (2022). Conducting a cyber security audit is advisable when significant operational changes are made, or, for example, a new version of a compliance standard, or norm like ISO/IEC 27001 is released.

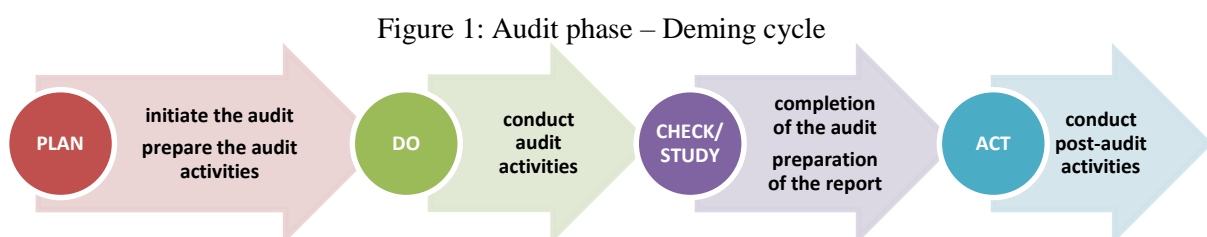
2.1 Structure of information security audits in accordance with ISO/IEC 27001

The security audit is a very complex and time-consuming process. Conducting it properly requires meeting a number of requirements, which are formulated in ISO/IEC 27001 (2017). A key element that determines the reliability of an audit is the qualifications and work method of the audit team members. External auditors have a much broader view of the organization. Auditors should have full independence and in addition, auditors should be guided by a number of principles that will facilitate the audit itself and provide the most reliable and credible information possible about the state of the organization.

Among these principles are: integrity (doing the job honestly, conscientiously, and responsibly), fair presentation of audit results (findings, conclusions, and audit reports should be based on the auditor's actual actions), due diligence (diligence, reasonableness, and the ability to exercise sound judgment), confidentiality (ensuring the security of systems and the information they contain), independence (acting independently, impartially and free from bias), fact-based approach (obtaining reliable and reproducible conclusions based on the audit activities carried out), risk-based approach (considering the risks and opportunities of the audit and ensuring that the audit focuses on issues important to the organization).

The sound and thorough audit requires adequate planning and preparation. The scope of the audit program should be based on the size and nature of the organization, as well as the functionality, complexity, type of risks and opportunities of the management systems to be audited. Special attention should be paid to where the most important decisions are made and who is responsible for them in the management system. Where there are multiple locations/facilities, or where important functions are outsourced and performed under the direction of another organization, special attention should be paid to the design, planning and approval of the audit program. For smaller or less complex organizations, the audit program can be scaled accordingly.

The representation of the audit phase using the Deming (1986) cycle is as follows on Figure 1.



Source: Authors

The ISO/IEC 27001 standard outlines guidelines for an information security management system (ISMS), the role of the organization and its management in establishing the system, and how to use it. The audit should be conducted in accordance with the ISO standard, while the conclusions and post-audit activities should follow the guidelines (ISO 27001).

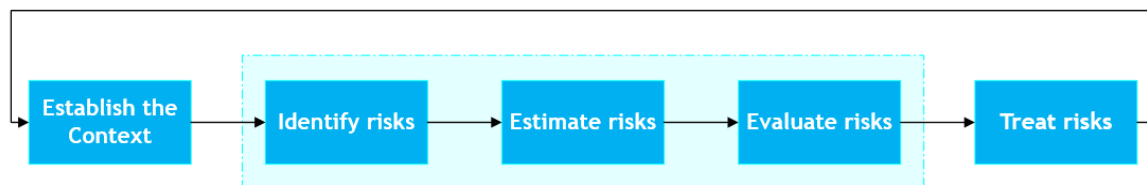
2.2 Risk analysis (risk assessment)

Risk assessment, which is mentioned in ISO/IEC 27001 and described also in Beckers et al., (2014), is a very important step in ensuring information security in an organization. Thanks to the risk assessment procedure, it is possible to identify any undesirable and harmful factors for the organization, both internal and external, and to develop appropriate methods for preventing undesirable phenomena and eliminating their effects.

The risk assessment process consists of five consecutive steps detailed by Hosseinpour et al. (2021), which are in accordance with ISO 31000 (2018), and these are: establishing the context, identifying the risk, estimating the risk, evaluating the risk and treating the risk (Figure 2).

Establishing the context includes establishing the scope and focus of the analysis, identifying the assets for which risks are identified, and determining the criteria for risk assessment. The purpose of the analysis is defined at the desired level of abstraction using precise and well-understood notation. The documentation produced during the establishment of the context is then used as input and basis for the subsequent risk assessment. Risk assessment involves three steps: risk identification, risk estimation and risk evaluation. Risk identification involves identifying and documenting undesirable events along with the threats and vulnerabilities that could cause them. Risk estimation involves estimating the likelihood and consequences of undesirable incidents. To facilitate risk estimation and identify the most important sources of risk, probabilities are also estimated for threats and threat scenarios. Risk evaluation involves comparing identified risks with risk assessment criteria and determining which risks are unacceptable. Finally, risk treatment involves identifying measures to mitigate unacceptable risks.

Figure 2: Risk assessment procedure



Source: Authors

2.2.1 Structured questionnaires

Structured questionnaires are documents that include a predetermined set of questions and precise language for gathering information from respondents. In a structured questionnaire can be use both open-ended and closed-ended questions. Questionnaire design is closely related to the quality of the data collected. Francis Galton (1883) was a pioneer in the use of structured questionnaires. He was using this method in social research, but it is still very common in the collection of research data today.

Structured questionnaires can be a useful method for conducting risk analysis as part of information security systems audits, used by example as Brief Risk Questionnaire Method (BRQ) published by Jones et al. (2015). These questionnaires typically contain a series of questions that are designed to assess the security posture of an organization, system or application.

Structured questionnaires offer several advantages, including cost-effective and relatively quick data collection from a large group of respondents, user-friendly design, ease of quantification, and reduced interviewer bias due to standardized questions. Moreover, data quality evaluation is easier compared to other methods due to its transparency. However, there are some drawbacks to consider, such as potential issues in data analysis arising from a large portion of respondents selecting "don't know" or refusing to answer, the accuracy of results being reliant on participants' honesty, and the limitation that structured questionnaires are not comprehensive risk analysis methods on their own, necessitating their use in conjunction with other methods.

Overall, structured questionnaires can be an effective risk analysis method in information security systems audits, helping auditors to identify potential security risks and vulnerabilities, however they should be used only as part of a comprehensive approach that includes other risk analysis methods.

2.2.2 Internal control reviews

Internal controls are used to avoid or minimize losses within an organization. COSO defines internal control as "the process performed by an entity's board of directors, management and other personnel to provide reasonable assurance regarding the achievement of objectives related to operations, reporting and compliance" as mentioned in Janvrin et al. (2012).

The internal control review identifies the objectives of such control relevant to the company. Policies and procedures in place and documentation standards are reviewed. In order to perform an internal control review, it is necessary to isolate the processes occurring within the tasks performed. A checkpoint is adopted for each process, which consists of the input data, how it is processed and the final product. The question for each process checkpoint is whether it meets the formal and legal requirements and whether we have all of the necessary information at the start of the process. If any of these are missing, it should be determined how this deficiency will affect task execution and whether the process should be continued or terminated.

In this manner, it is necessary to go "step by step" through all of the processes in place within the organization. It should also be determined whether the company has taken corrective action in response to the risks identified. As Geiger et al. (2004) mentioned as advantages of internal control reviews we could count potential to be an early warning system to identify and correct deficiencies early (i.e. before external, regulatory or compliance audits). Also, fact that internal controls make the organization more process-oriented than people-oriented, reducing the risk of over-reliance on specific key personnel and they can identify redundancy in operational and compliance procedures, providing opportunities to simplify operations make them very useful tool in risk analysis.

However, ICRs can lead to slower processes and for a complex level of internal control review or extensive procedures within an organization, and it can generate high costs and be time-consuming which was noticed by Walton et al. (2021).

2.2.3 Threat and vulnerability assessments

One of main purpose of the audit is to reduce vulnerability and counter the effects of threats. Threat and vulnerability assessments is the first step to improving safety. As part of the assessment of potential threats, their impact and vulnerability, is to review current security state, procedures and identify potential threats and vulnerabilities.

Threats can occur in various forms and the results can cause both financial and reputational losses. Inadequate security measures in data processing can lead to the leakage of personal data, which may result in legal consequences. Threats can stop or slow down processes or damage infrastructure that is critical to operations. Each of these forms of threat must be countered and their potential effects reduced. As Renfroe & Smith (2010) described, the threat assessment should include modules such as: a review of potential security threats, an assessment of the effectiveness of current security measures (e.g. procedures, technical security) and analysis of the potential effects of the threats. The analysis of the factors described is intended to support the development of a security strategy that includes the possible best methods to prevention and mitigate threats by reducing vulnerability and their potential consequences.

2.2.4 Comparison of most common risk assessment methods

Each risk assessment method offers unique benefits and challenges within the ISO 27001 cybersecurity audit process (Table 1). Structured questionnaires provide a consistent and cost-effective approach, while internal control reviews ensure alignment with the standard. Threat and vulnerability assessments offer the most comprehensive identification of potential risks, but require significant technical expertise and resources. Organizations should carefully consider their specific needs and resources when selecting the most appropriate risk assessment method.

Table 1: Comparison of most common risk assessment methods

Feature	Structured Questionnaires	Internal Control Reviews	Threat and Vulnerability Assessments
Ease of Implementation	High	Medium	Low
Cost	Low	Medium	High
Technical Expertise Required	Low	Medium	High
Identification of New Threats	Medium	Low	High
Consistency Across Audits	High	Medium	Low
Alignment with ISO 27001	Medium	High	High

Source: Authors

2.2.5 Other risk assessment techniques

Risk mapping proposed by Scandizzo (2005) can help organizations prioritize their risk management efforts by providing a comprehensive understanding of their risk exposure. Scenario planning from Lindgren & Bandhold (2003) can help organizations anticipate and prepare for unexpected events, whereas the Delphi method (Crisp et al., 1997) can provide insights from a diverse range of perspectives, and CSA based on Collie & Sissenwine (1983) can help organizations identify and address vulnerabilities before they become major risks.

3. Potential of development of risk analysis methods

The development of risk analysis methods using pairwise comparison matrices holds great potential for providing a systematic and quantitative evaluation of the relative importance of various factors in a given risk scenario. This approach can help decision-makers identify critical risk factors and prioritize their actions based on their potential impact on key objectives.

With the flexibility and adaptability of pairwise comparison matrices, this methodology can be utilized in various fields, such as finance, healthcare, and especially information security audits which are the main subject of this paper - to evaluate and manage risks effectively. The advances in technology and data analysis tools have further enhanced the development and analysis of pairwise comparison matrices, allowing for more accurate and comprehensive risk assessments.

3.1 Pairwise comparisons

Pairwise comparison matrices described in Mazurek (2023) book, are an effective tool for decision-making processes that involve evaluating a set of entities based on specific criteria. These matrices systematically compare the preferences of one entity over another and record them in a matrix, which helps evaluate the relative importance of each entity with respect to the others. They take the form as in equation (1).

$$\begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{pmatrix} \quad (1)$$

To create a pairwise comparison matrix, a dataset is established, representing the set of n entities to be compared. The preferences of the i -th entity over the j -th entity are recorded in the entry a_{ij} of the pairwise comparison matrix. It's important to note that the values of a_{ij} must be non-negative and satisfy the property of reciprocity, as expressed in equation (2). This ensures that the pairwise comparisons are reciprocal and the PCM can be used to assess the relative importance of each entity and inform decision-making processes.

$$a_{ij} = \frac{1}{a_{ji}}, \forall i, j \in \{1, 2, \dots, n\} \quad (2)$$

A prioritization method is any procedure that derives a priority vector $w = (w_1, \dots, w_n)$ - a vector of weights of all n compared objects - from an $n \times n$ pairwise comparison matrix. The priority vector w is associated with the pairwise comparison matrix A or derived by a priority generating method based on the pairwise comparison matrix A . The priority vector is often normalized, as shown in equation (3), to interpret it as a set of weights used to compare and rank the entities based on their relative importance.

$$\sum_{i=1}^n w_i = 1 \quad (3)$$

The ultimate goal of pairwise comparison methods is to rank the compared objects from best to worst based on the derived priority vector $w = (w_1, \dots, w_n)$. The values of the priority vector w can be used to establish a ranking of the entities, with higher values corresponding to higher priority or greater relative importance. By using pairwise comparison matrices and prioritization methods, decision-makers can systematically evaluate and compare entities based on various criteria and use the resulting rankings to inform their decision-making processes as mentioned by Kuraś (2023).

3.1.1 Problem of inconsistency and algorithms for its reduction

Pairwise comparison matrices are a popular tool for decision-making processes that involve evaluating a set of entities based on specific criteria. However, a potential issue with using pairwise comparison matrices is inconsistency, which occurs when the pairwise comparison matrix violates the transitive property. The transitive property is a fundamental property of pairwise comparisons, which states that if entity A is preferred to entity B, and entity B is preferred to entity C, then entity A should also be preferred to entity C. In other words, the preferences among entities should be transitive.

Inconsistency can arise when the pairwise comparisons recorded in the matrix are not transitive. This can happen when different evaluators have different interpretations of the criteria or different levels of experience and knowledge, leading to conflicting opinions about the relative importance of the entities. In such cases, the pairwise comparisons made by the evaluators may be inconsistent with each other, leading to an inconsistent pairwise comparison matrix.

$$CI(A) = (\lambda_{max} - n)/(n - 1) \quad (4)$$

The inconsistency in a pairwise comparison matrix, described by Saaty (1984) can be quantified by using various methods, such as the consistency index (4) and the consistency ratio (5). The inconsistency index measures the degree of inconsistency in the matrix by calculating the maximum eigenvalue of the matrix, while the consistency ratio compares the inconsistency index with an average random inconsistency (RI) to determine whether the inconsistency is significant.

$$CR(A) = \frac{CI(A)}{RI(n)} \quad (5)$$

To address inconsistency in pairwise comparison matrices, various techniques can be used, such as identifying and resolving conflicts in the pairwise comparisons or adjusting the weights of the criteria to reduce inconsistency. One commonly used technique is the Analytical Hierarchy Process (AHP) presented by Saaty (1988), which involves decomposing the problem into a hierarchy of sub-problems, allowing for a more consistent and structured evaluation process.

Identifying the source of these errors can be challenging, so various methods and algorithms have been developed to detect and correct erroneous data in matrix A, with the goal of minimizing the inconsistency ratio. Two main groups of algorithms exist for reducing inconsistency in pairwise comparison matrices: non-iterative and iterative. In particular, iterative algorithms proposed by Cao et al., Szybowski, and Xu and Wei were tested in the work of Mazurek et al. (2021). Several non-iterative algorithms are also worth mentioning, as presented in references.

3.2. Decision-making techniques using pairwise comparison matrices

Multi-criteria decision making (MCDM) is a decision-making approach that evaluates and selects alternatives based on multiple criteria. MCDM methods provide a structured approach for evaluating and ranking alternatives based on different criteria. One popular MCDM method is the

Analytical Hierarchy Process (AHP), which enables decision-makers to quantify the relative priorities for a given set of alternatives on a ratio scale based on their judgments. The AHP approach breaks down complex problems into smaller, more manageable components, allowing decision-makers to make decisions based on a logical, step-by-step process. AHP also allows group decision-making, which can be achieved using dedicated software, eliminating the problem of "groupthink" or dominance by a strong member of the group. Other MCDM methods include the Best-Worst Method (BWM) method described by Rezaei (2015), the TOPSIS from Lai et al. (1994), and the VIKOR method proposed by Opricovic (1998) as well as many others.

3.2.1 Process of working with Analytical Hierarchy Process (AHP) framework

The Analytical Hierarchy Process (AHP) is a decision-making tool that uses the judgment of decision-makers to arrive at a structured and systematic solution. The AHP process described by Saaty (1987) involves six steps – from defining problem and establish objective to last issue where consistency of judgments is determined by calculating the consistency index (CI) using the eigenvalue (λ_{max}).

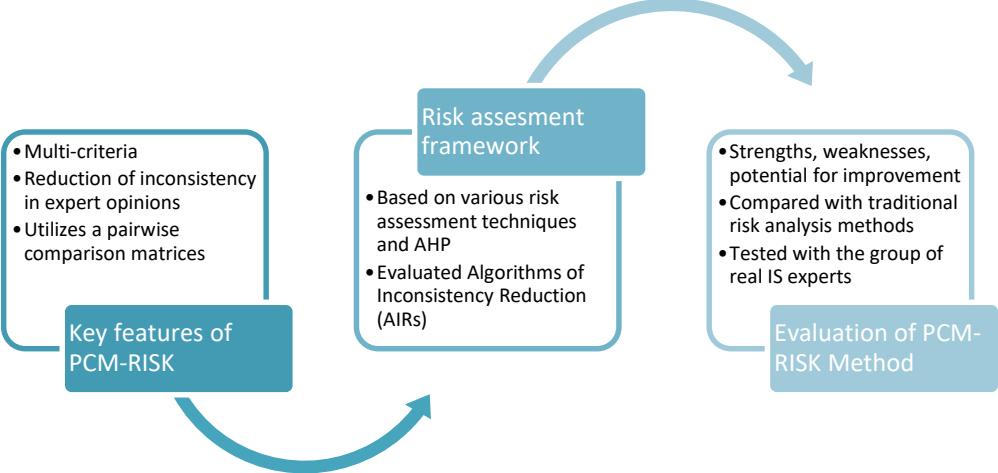
The AHP enables group decision making by allowing group members to deconstruct problems into a hierarchy and solve them by following the AHP steps. Brainstorming and exchanging ideas and insights lead to a more comprehensive understanding of the issues at hand. Using AHP dedicated software, reduces the problem of "group-think" or dominance by a strong member of the group mentioned by Saaty (1989). During a group session, the group can modify a pre-prepared hierarchy to suit their understanding of the problem. If the group achieves consensus on a judgment, only that judgment is inputted. If the group is unable to reach consensus, they may use a voting technique or choose to take the "average" of the judgments.

3.3. Proposal for a new method using pairwise comparison matrices for risk analysis – PCM-RISK

This proposal introduces the PCM-RISK method, a new approach to risk analysis in information security auditing that utilizes a pairwise comparison matrix which allows it to achieve features such as multi-criteria and to ensure that the problem of inconsistency of the opinions of the evaluating experts is reduced, thanks to the pairwise comparison matrix inconsistency reduction algorithms presented and studied by Mazurek et al. (2021). The research team will integrate various risk assessment techniques to create a decision-making framework for assessing risk (Figure 3).

The surveyed group of independent anonymous experts will be gathered (i.e. from Polish Institute of Internal Control or other several leading certification bodies) and the final auditing scenario will be conducted in accordance with the ISO/IEC 27001 guidelines for information security management systems.

Figure 3: Proposal of PCM-RISK method and research procedure



Source: Authors

3.3.1 PCM-RISK method structure and steps

- Step 1: **Identify the main criteria for risk assessment.** The criteria considered in this system include asset value, threat likelihood, vulnerability severity, and control effectiveness.
- Step 2: **Create a pairwise comparison matrix.** A matrix is created for the main criteria, where experts input their opinions in the form of pairwise comparisons. These values typically range from 1/9 (least important) to 9 (most important). The matrix will be in a form like the one shown in Table 2.

Table 2: Pairwise comparison matrix for the main criteria

	Asset value	Threat likelihood	Vulnerability severity	Control effectiveness
Asset value	1			
Threat likelihood		1		
Vulnerability severity			1	
Control effectiveness				1

Source: Authors

- Step 3: **Expert opinions from various risk assessment techniques.** Expert opinions are gathered using diverse risk assessment techniques such as structured questionnaires, internal control reviews, and threat and vulnerability assessments. The experts' opinions are used to populate the pairwise comparison matrix.
- Step 4: **Application of AHP.** The Analytic Hierarchy Process is applied to derive the weights of the main criteria. This involves calculating the geometric mean for each row, normalizing the geometric mean values, and calculating the consistency ratio (CR) to ensure the expert opinions are consistent.
- Step 5: **Application of IR algorithms.** Inconsistency Reduction algorithms are employed to identify and resolve inconsistencies in expert opinions. The pairwise comparison matrix is updated with the adjusted values.
- Step 6: **Calculation of final weights.** The AHP process is repeated with the updated pairwise comparison matrix, ensuring the updated CR falls within the acceptable threshold.
- Step 7: **Aggregation of results.** The derived weights are used to calculate a weighted score for each risk, and the risks are ranked based on their weighted scores to prioritize risk mitigation efforts.

3.3.2 Exploring the potential application of the PCM-RISK method

A group of 15 auditors with experience in cybersecurity audits were selected for the study. They were given a comprehensive introduction to the integrated multi-criteria risk assessment system, including its methodology and potential benefits. Following the introduction, the auditors were asked to complete a survey consisting of both closed-ended and open-ended questions (the hyperlink to the survey is the first position in the references to this paper). The survey aimed to assess their opinions on the potential application of the method in their work, as well as any concerns or challenges they foresee.

The auditors' experience in cybersecurity audits ranged from 3 to 15 years, with an average of 8 years. 20% of the auditors were familiar with the AHP and IR algorithms, while 80% were not familiar with these techniques. The usefulness of the proposed system in improving consistency in cybersecurity audits was rated at an average of 4.1 on a scale of 1 to 5. The usefulness of the proposed system in providing a more comprehensive risk evaluation was rated at an average of 4.0 on a scale of 1 to 5. The main benefits of implementing the integrated multi-criteria risk assessment system, as perceived by the auditors, included improved consistency (73%), comprehensive risk evaluation (53%), and better decision-making (53%).

The concerns and challenges foreseen by the auditors in implementing the integrated multi-criteria risk assessment system were the complexity of the method (40%), time and resource constraints (33%), and expertise requirements (27%). 53% of the auditors believed the integrated multi-criteria risk assessment system would be easy to implement in their current work environment, while 47% thought it would be challenging. The auditors also identified several resources and support required for effective

implementation, such as training sessions (80%), user-friendly software tools (67%), and organizational support (40%). 73% of the auditors considered adopting the PCM-RISK in their future cybersecurity audits, while 27% were unsure or hesitant.

The suggestions and recommendations for PCM-RISK included providing more examples and case studies (27%), and developing a software tool for automation (20%).

4. Conclusions

In this paper, we have reviewed the techniques of risk analysis methods and presented perspectives on their development using patterns drawn from methods using so-called pairwise comparison matrices. Multi-criteria decision making (MCDM) is a method of choosing between alternatives by weighing them against a number of different factors. An effective MCDM technique is the Analytical Hierarchy Process (AHP), which enables decision-makers to quantify the relative priority for a given set of choices on a ratio scale based on their assessments.

Our proposal offers the PCM-RISK method, a novel method for risk analysis in information security auditing that makes use of a pairwise comparison matrix to solve the issue of evaluating expert opinions' incompatibility. The research team will combine different risk assessment methods to develop a framework for making decisions about risk. We strongly believe that the new method, which will be examined in the forthcoming work of the research team, will contribute to improving the efficiency of safety audits in organizations and companies. The new method would, of course, also be used in other fields of science, the effectiveness and usefulness of which we will also seek to prove in the near future.

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DIVERSE APPROACHES NEEDED TO DEVELOP COMPANY'S ETHICS INTERNALLY: SMALL VS. MEDIUM-SIZED SLOVAK ENTERPRISES

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Abstract

This paper draws on the results of an extensive multi-method and multi-phase research project on the development of business ethics in the Slovak business environment, which was carried out in the years 2017 – 2021 on a representative sample of Slovak companies regarding their size and regional location. It focuses specifically on two categories of companies - small (n = 413) and medium-sized companies (n = 294) and identifies significant differences between them regarding the perceived barriers to ethical development and the development needs of these companies in the field of internal company ethics. The results point to substantial differences, both in the barriers and the development needs of small and medium-sized enterprises, which indicates that when it comes to internal company ethics, the size of the company matters significantly, and it is necessary to approach its development in a fundamentally different way.

Keywords: business ethics, company size, Slovakia, SMEs

JEL codes: M14

1. Introduction

Small and medium-sized enterprises (SMEs) are often regarded as a single category, as one *block* of companies sharing and tackling similar problems in the business environment. The mainstream business literature usually does not make any fundamental distinction between small and medium-sized enterprises and rather concentrates on examining the differences between small and large enterprises and various aspects of their sometimes uneven and somewhat troubling relationship (e.g., Buyl and Roggeman, 2019; Jaegersberg et al., 2017; Özar, 2009; Tran and Jeppesen, 2016). In addition, also official statistical reports in national or international overviews usually do not distinguish between small and medium-sized enterprises.

It is somewhat surprising that the term “SMEs” and a kind of automatic grouping of small and medium-sized enterprises into one category is commonly used, although clearly, the size of the enterprise (in terms of the number of employees) is a fundamental factor that determines the approach to management and organization. For instance, while in smaller companies the burden of governance and control lies on the shoulders of the owner (e.g., Spence, 1999; Spence and Rutherford, 2001) and informal processes prevail that depend largely on people’s personalities, skills, and experience, in larger companies there is a greater degree of professionalization of management and formalization of processes operating largely independently of people. Notably, smaller businesses have limited resources, which creates pressure on instant adaptability and less forward planning (Lepoutre and Heene, 2006). The influence of the owner-manager, his/her perspective, experience, and personal network are absolutely crucial (e.g., Chuang et al., 2007; Jenkins, 2006; Quinn, 1997), whilst the decision-makers in larger organizations have the comfort of concentration of professionals and their wider networks. Various fractions or subcultures evolve over time in larger companies that can bring in more diverse perspectives and solutions, whereas the culture in smaller companies is based on the personality of the owner-manager and can impose a certain degree of anticipated conformity (e.g., Feltham et al., 2005). It could be hypothesized that for managers of small businesses, there is a greater risk of slipping into an information bubble, building on his/her own opinions and those of the closest circle of associates and

excluding contradictory or differing information that challenges the already made judgment (Lobonțiu and Lobonțiu, 2014).

Prior literature on business ethics and CSR pays sufficient attention to business ethics in large companies as well as to the contrasts between SMEs and large companies (e.g., Baumann-Pauly et al., 2013; Graafland et al., 2003; Longenecker et al., 2006; Perrini et al., 2007; Russo and Tencati, 2009), but a deeper examination of the differences *within* the SMEs category is lagging. So far, research has determined for example that CSR in SMEs is rather implicit or “silent” (Jenkins, 2004; Lund-Thomsen et al., 2014), meaning that small owners-managers often do not have a precise understanding of the true meaning and application of CSR, the CSR activities are informal, ad hoc, intuitive, and small-scale local, without recognizing the full range of the company stakeholders (Lee et al., 2016). Small entrepreneurs tend to perceive CSR narrowly as philanthropic activities focused on recipients who stand close to the entrepreneur in terms of psychological or physical proximity (e.g., Gao et al., 2007; Mickiewicz et al., 2016), although there is evidence that SMEs can undertake a more structured and holistic approach to CSR in different institutional contexts (e.g., Ameashi et al., 2016).

Perhaps the greatest challenge for small owners-managers is to cope with the profit maximization pressure that is usually attributed to large companies. According to Lähdesmäki (2012), it is particularly difficult and confusing for small entrepreneurs to reconcile altruistic and instrumental expectations. Another challenge follows from a stereotypical assumption that ethics is a matter of the inner world of a small entrepreneur and belongs more to the person than to the firm (e.g., Fassin et al., 2012). This belief might then imply that there is little or no room for ethics elements (e.g., code of ethics, ethics training, CSR program) in the company, which feeds into a certain uninformed ignorance of otherwise beneficial methods of purposeful ethics management. Other attitudinal barriers to ethics in small companies include the belief that ethics and business do not mix, it does not pay to be ethical, if it is legal then it is also ethical, and that this company (the small owner’s company) is enough ethical (Russell, 1993, acc. to Tilley, 2000). Prior literature also acknowledges that smaller companies exhibit greater sensitivity to the level of perceived institutional fairness of the larger environment in which the company operates (e.g., Ji et al., 2019), although, at the same time, small businesses have only a limited possibility to overcome these unfavorable conditions.

In the Slovak business environment, the responsibility for developing company ethics in SMEs is perceived as a sovereign competence of owners-managers, who should serve as ethical role models for their employees and manage employee ethical behavior via rewarding for exemplar behavior and disciplining for non-compliant conduct (Lašáková et al., 2021). Smaller Slovak companies perceive the business environment as substantially more hostile in terms of unethical business practices (Remišová et al., 2021). This might be one of the reasons why small entrepreneurs find it demanding not to adapt and, on the contrary, to go against the stream in the matter of acting on the market as a responsible and honest player. In this case, the market represents an opportunistic force that, as small businessmen believe, can drive out those actors who try to operate responsibly in an otherwise unethical business arena. Owners-managers feel trapped in an institutionally impoverished environment, where they constantly have to fight with large companies and with the government issuing legislation insensitive and unfair toward small firms (Remišová and Lašáková, 2020). Thus, they tend to abandon their own responsibility for the ethical development of the business environment and condition their ethical conduct by changes at the macro-societal level of the government and the state. This kind of attitude makes it particularly demanding to leverage internal company ethics in SMEs because the implementation of ethics infrastructure components is largely dependent owners-managers’ discretion. Moreover, previous literature on ethics in SMEs did not delve into the differences between small and medium-sized firms and thus little is known about their potential distinctions in this respect.

In light of the aforementioned, the main *research question* is whether there is a significant difference between small and medium-sized Slovak companies in their perception of internal barriers to ethical development and in their needs for ethical development. More specifically, we explore which barriers and development needs are the main differentiating points in this respect. The practical background of this question lies in understanding whether, and in what ways, it is necessary to adapt the approach to internal ethics development in small and medium-sized companies.

2. Research Methodology

This paper presents partial results of a large multi-phase and multi-method research project comprehensively assessing the state of business ethics in Slovakia carried out during the years 2017-2021. One of the research streams was designed as a quantitative survey on a representative sample of Slovak companies regarding their size and regional location. The sampling strategy was based on the method of stratified random sampling by proportional allocation (Stankovicova and Frankovic, 2020). Within the criterion “company size”, we worked with four categories: micro (1 – 9 employees), small (10 – 49), medium-sized (50 – 249), and large companies (250+), whilst the criterion „company regional location“ was based on NUTS2 system and included Bratislava region, West Slovakia, Central Slovakia, and East Slovakia. Data acquisition took six months and resulted in obtaining $n = 1295$ responses in total. For the purposes of this paper, we focus on a subset of small ($n = 416$) and medium-sized companies ($n = 294$).

Data were gathered via a questionnaire. Potential research participants were identified based on contacts included in the FinStat and Cribis databases comprising companies operating in Slovakia. Due to the considerable challenges with obtaining specific numbers of companies of a particular size and regional location, company owners and higher rank managers were asked to participate based on the research teams’ individual contacts and mailing lists. In addition, generous help with building the internal contacts database was provided by prominent Slovak business associations. In the last months of this lengthy and difficult data acquisition process, business conferences were visited that offered space to inform conference participants about the undergoing research and ask them to take part.

As for the composition of the final sample, within the subset of small companies, 97% was populated with private-owned companies, 16% was foreign-owned, 39% was organized via membership in professional associations, and 85% reported being profitable in the last three years. As for the sector/industry, 14% were construction firms, 17% operated in industrial production, mining and quarrying, and other related industries, 19% operated in wholesale, retail, transport, storage, accommodation, and catering services, and 23% belong to other (not specified) services. The subset of medium-sized companies included 86% of private-owned and 26% foreign-owned companies, 48% declared membership in professional associations, and 87% reported profitability during the last three years. Furthermore, 13% of the medium-sized companies operating in the sector of public administration, defense, education, health, and social assistance, 16% in services (unspecified), 19% in wholesale, retail, transport, storage, accommodation, and catering services, and 25% in the sector of industrial production, mining and quarrying and related industries. The company location in both subsamples was proportional across the four Slovak regions (Bratislava, West, Central, East), thus covering representatively the whole country.

Findings presented in this paper derive from two sections of the respective quantitative survey that dealt with perceived barriers and needs regarding ethics development within companies. The content of both sections was based on the fusion of prior literature on organizational ethics development and results from a preceding qualitative phase of the project that included interviews and focus groups with diverse stakeholders (e.g., representatives of major Slovak business associations, NGOs, SMEs). The large volume of obtained qualitative materials was reduced by qualitative content analysis in several rounds. As the original survey was larger and included various aspects of business ethics in Slovakia, only the most significant ethics development barriers and needs according to the qualitative findings were included in the questionnaire. Its content was subject to critical discussion among the team members, and afterward, the pilot version was tested in several focus groups including 32 participants in total (company owners, directors, and top managers) to ensure the final survey tool was clear, understandable, and unambiguous.

The survey section on internal barriers to company ethics development included nine items (e.g., obstacles due to financial costs associated with ethics, lack of time, fear of change; for the full list of examined barriers see Figure 2) and respondents were asked to ascertain on a five-point scale the extent to which these factors are considered an obstacle to the development of ethics in their companies. The section on development needs included nine items (e.g., code of ethics, ethics education, ethics hotlines; for the full list of examined needs see Figure 3) and respondents were instructed to indicate on a five-point scale to what extent their company would need help and consultations targeted on the respective ethics management elements. Reliability analysis indicated high internal consistency of both measures

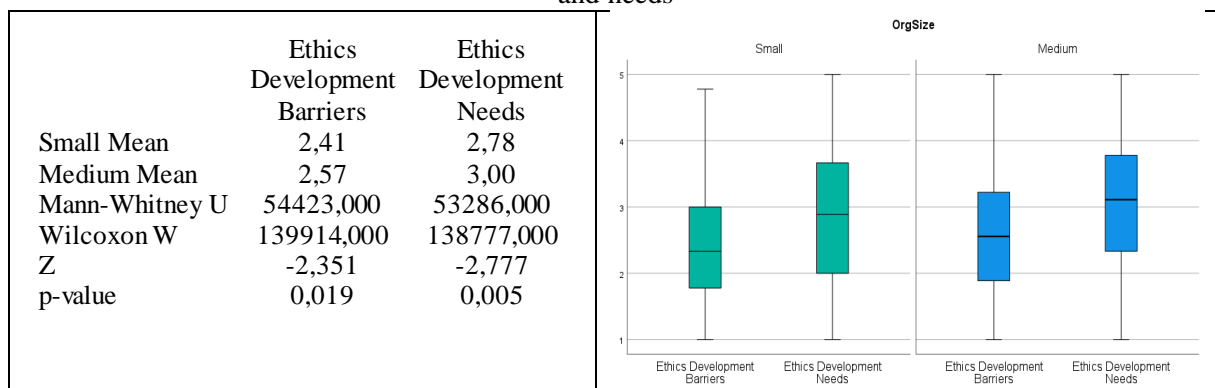
($\alpha = 0,814$ for ethics development barriers, and $\alpha = 0,924$ for ethics development needs). The correlation between the two measures was medium and positive ($r = 0,513$, $p < 0,001$), supporting the theoretical idea of certain interconnectedness between the perceived difficulty of cultivating the company's internal environment (barriers) with the felt necessity for its ethical development (needs). For the purposes of this study, the data analysis utilized a non-parametric method of the Mann-Whitney U test.

3. Results and Discussion

The development of an infrastructure for internal company ethics in Slovakia lacks legal specification and thus evolves rather spontaneously. Although there are some actual exceptions (valid legislation related to the protection of whistleblowers, legislation pieces related to verification of 3rd parties that are in the state of preparation), there are no general legislation pieces in place that would prescribe Slovak businesses institutionalization of the ethics function, deploying its infrastructural elements like committees, directives, processes, communication, etc. In addition, there is no tradition in Slovakia related to the profession of business ethics experts, but also when it comes to connecting values with the management of a business. In general, Slovak businesses do not link entrepreneurship with values, partially due to the dynamically changing conditions of the business environment, and partially due to the lack of a long and continuous tradition of private enterprising (Lašáková et al., 2022). It became, therefore, one of the ambitions when conducting this survey, to elaborate on the existence of barriers that Slovak businesses perceive when it comes to the development of business ethics internally, as well as concrete needs they feel in the course of this development.

Figure 1 shows boxplots and results of the Mann-Whitney U test for statistically significant differences between small and medium-sized companies in perceived ethics development barriers (composite, including nine items, see Figure 2) and ethics development needs (composite, including nine items, see Figure 3). The p-value was 0,019 (barriers) and 0,005 (needs). Results indicate that compared to medium-sized organizations (mean = 2,57, measured on a 5-point scale), small companies (mean = 2,14) perceive the existence of internal barriers to the development of ethics at a much lower level. In connection with that, their development needs are at a significantly lower level (mean = 2,78) than in medium-sized companies (mean = 3,00).

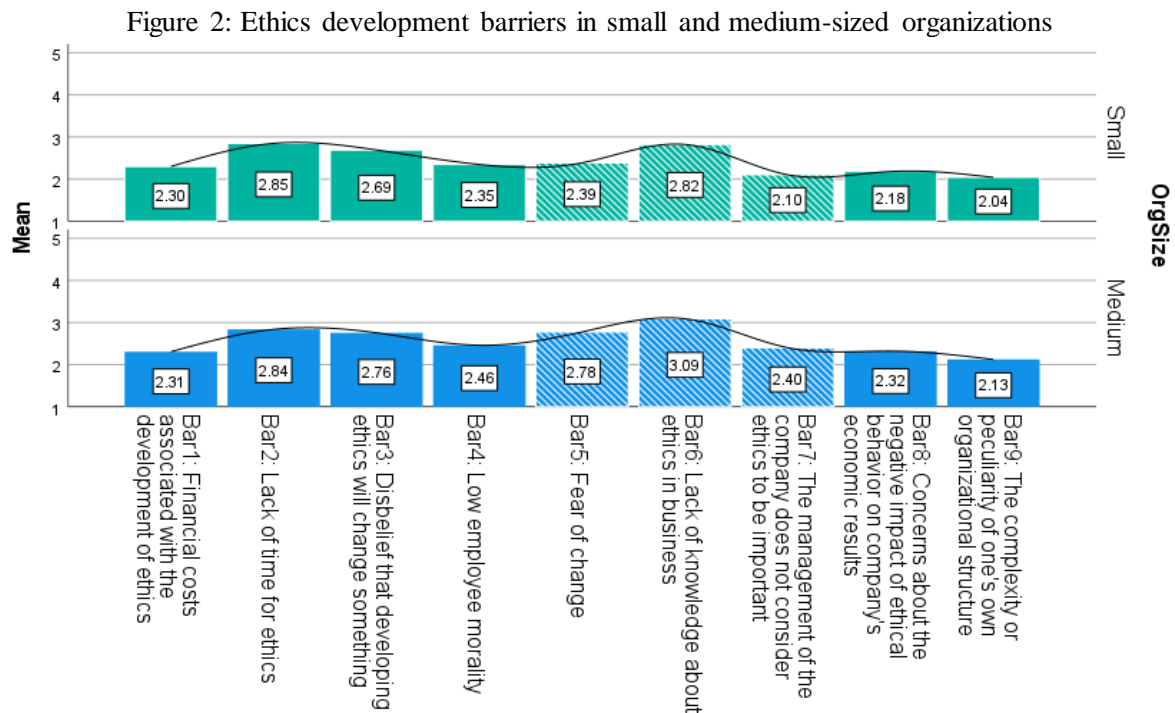
Figure 1: Difference between small and medium-sized organizations in ethics development barriers and needs



Source: authors' calculations

For a deeper understanding of systematic differences in internal barriers to ethics development in small and medium-sized companies, we employed the Mann-Whitney U test for the nine barriers (individual items from the composite measure). Figure 2 displays the mean values (on a 5-point scale) for the individual barriers, and Table 1 shows results for Mann-Whitney U test correspondingly. Out of the nine barriers, significant differences were identified in three of them, namely in *Fear of change related to ethics development* ($p = 0,000$, mean Small = 2,39, mean Medium = 2,78), *Lack of knowledge about ethics in doing business* ($p = 0,011$, mean Small = 2,82, mean Medium = 3,09), and *Management of the company ascribing little importance to ethics* ($p = 0,013$, mean Small = 2,10, mean Medium =

2,40). In all three cases, small companies perceive these barriers as significantly less present than medium-sized companies do.



Source: authors' calculations

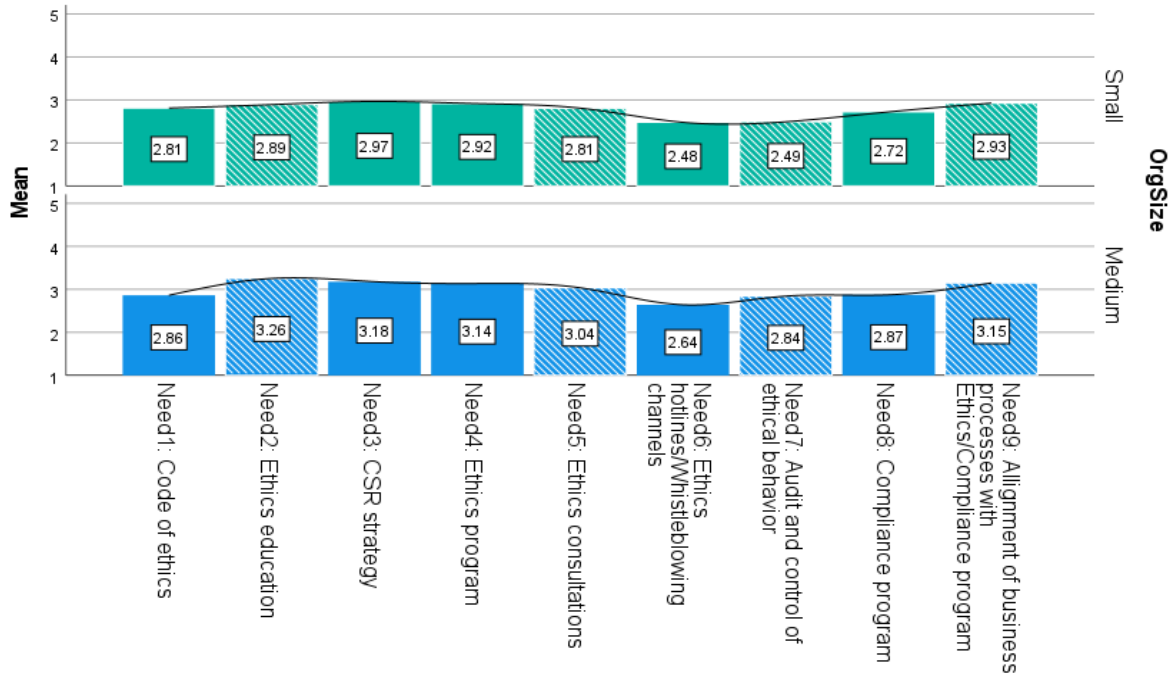
Table 1: Mann-Whitney U test - Barriers

	Bar1	Bar2	Bar3	Bar4	Bar5	Bar6	Bar7	Bar8	Bar9
U	59907,50	60541,00	58844,00	57233,00	50875,50	54079,00	54419,00	56568,00	57650,50
W	145398,5	103906,00	144335,0	142724,00	136366,50	139570,00	139910,00	142059,00	143141,50
Z	-0,314	-0,065	-0,718	-1,347	-3,790	-2,552	-2,491	-1,615	-1,206
p	0,754	0,948	0,473	0,178	0,000	0,011	0,013	0,106	0,228

Source: Authors' calculations

Figure 3 and Table 2 show the results of comparing small and medium-sized companies based on their ethics development needs. Based on the Mann-Whitney U test, findings indicate that out of the nine individual developmental needs, in four cases significant differences were found. Specifically, small and medium-sized companies differed substantially in their need for *Ethics education for employees* (mean Small = 2,89, mean Medium = 3,26), *Ethics consultations to current ethical issues in the company* (mean Small = 2,81, mean Medium = 3,04), *Ethics auditing and control of ethical behavior* (mean Small = 2,49, mean Medium = 2,84), and *Alignment of business processes with elements of Ethics/Compliance program* (mean Small = 2,93, mean Medium = 3,15). Similar to the case of developmental barriers, small companies express significantly less interest in developmental needs than medium-sized enterprises do.

Figure 3: Ethics development needs in small and medium-sized organizations



Source: Authors' calculations

Table 2: Mann-Whitney U test - Needs

	Need1	Need2	Need3	Need4	Need5	Need6	Need7	Need8	Need9
U	59723,50	52121,50	55806,00	55639,00	55213,00	56277,00	51899,50	56771,50	55355,00
W	145214,5	137612,50	141297,00	141130,00	140704,00	141768,00	137390,50	142262,50	140846,00
Z	-0,380	-3,325	-1,889	-1,947	-2,116	-1,707	-3,381	-1,509	-2,056
p	0,704	0,001	0,059	0,052	0,034	0,088	0,001	0,131	0,040

Source: authors' calculations

At first glance, our findings are somewhat surprising. Why is it that small companies perceive the existence of ethics development barriers and needs *at a lower level* than medium enterprises? Significantly different perceptions of ethical development barriers and related development needs, as declared by Slovak small versus medium-sized companies, can be interpreted in *two ways*. First, the internal environment in small companies truly enables and supports ethical development much more than in medium-sized organizations, and ethics is already so highly developed in small companies that these organizations do not feel the need for further ethical development as much as medium-sized companies do. However, considering a spectrum of specificities of small companies and their complicated position in the market, an *alternative interpretation* of our findings can be considered.

CUMULATION OF ROLES AND RELATED REDUCED SPACE FOR ETHICAL CONSIDERATIONS IN SMALL COMPANIES

We propose that a general difference might follow from dissimilar governance and organizational structure-related characteristics of small and medium enterprises, leading to medium companies having more awareness and sensitivity to the topic of organizational ethics, its tools, and benefits, than is the case with small companies. As a rule, the smaller company, the simpler structure is in place. Simple structure in a commercial organization typically means organizational design with little departmentalization, wide spans of control, authority centralized in a single person of an owner-manager, as well as a low level of formalization, whilst with medium-sized businesses, fair distribution of functions and responsibilities becomes visible. Therefore, governance of small businesses is very much based on centralization, where leadership and strategic management role frequently appears to be cumulated with any kind of control and support functions and to be personified by the owner, statutory representative, or the manager responsible for the entire business operations. This might leave *less room*

for the small owner-manager to deliberately reflect on ethics management processes that might be installed in the company. Prior literature (e.g., Arend, 2013; Spence, 1999) noted that small entrepreneurs are often under pressure and overwhelmed by multi-tasking which limits their capacity to think about ethics.

INCREASED ETHICAL AWARENESS IN MEDIUM COMPANIES DUE TO THE DIVERSE REQUIREMENTS AND MANDATORY STANDARDS

Due to specific industry regulations, holding requirements, or other obligatory standards (e.g. ISO standards for quality management, environmental protection, compliance management necessary to follow in order to meet customer requirements), this business segment obviously deals with topics of risk management, legal compliance, culture and leadership topics, where the competence to cover these topics is spread among several carriers within the organization. On the other side, the call for utmost organizational synergies in order to maintain (achieve) organizational agility conditioned by strong cost efficiency remains valid at the same level as with small businesses. From this perspective, we can assume that *medium businesses with a higher likelihood possess the necessary knowledge* about reasons why business ethics should be developed internally and which potential benefits it can bring to the organization's success. This point could, from a very high-level perspective, explain both why small businesses perceive the barriers to the development of business ethics and the concrete needs to develop it, on a significantly lower level compared to medium-sized companies. In addition, *medium enterprises with more intensity face concrete requirements* when it comes to legal safety, risk management, and business ethics, and, in addition, need to provide a certain level of assurance on the adequate grasping of these topics to their external stakeholders (customers, financing subjects/capital market, authorities). This urge certainly is less frequent in the segment of small businesses. The effect can be multiplied by the fact that the obvious barriers to investing resources into organizational ethics development are more present in the small enterprise segment. As Weltzien and Mele (2009) note, the limited financial resources and related insufficient personnel or skills capacity are one of the reasons why it is complicated for smaller companies to deal with ethics on a professional basis.

LIMITED KNOWLEDGE AND EXPERIENCE WITH ETHICS IN SMALL OWNERS-MANAGERS

As noted above, managers in small enterprises usually cumulate diverse responsibilities with less comprehensive management education. Without having clear guidelines, standards, and examples, *they obviously do not have a concrete idea about the implementation of an internal ethics program* in a relatively simple organization with a flat structure and only up to several individuals having the power and competence to set principles to be applied in the organization, its overall strategy as well as behavioral patterns expected from the rest of the team. In other words, small owners-managers have lower awareness of organizational ethics and might believe, as Tilley (2000) noted, that their company is ethically enough advanced and does not need any further ethics development. This points to certain ignorance of the newest management knowledge, and reluctance for keeping up with the current trends in organizational ethics. In this context, for instance, Fernandez and Camacho (2016) also maintain that ethics formalization and the use of ethics management tools are lagging in smaller companies. Lack of understanding with respect to business ethics and CSR in small businesses was supported by previous literature (e.g. Gao et al., 2007; Mickiewicz et al., 2016; Petts et al., 1999), and this might be well extended also to the sphere of internal company ethics.

DISTRUST THAT ETHICS CAN MAKE A CHANGE

Another possible explanation for our findings is that ethics development needs in small firms might be suppressed by the conviction *such development would have no real impact and therefore would become useless in the end*, because unethical conduct on the market is driven by players with much mightier impact. So, hypothetically, there can be a segment of small businesses who as respondents to our survey took the "It is not us" position, i.e. a position of a minor, impact-less component of the larger system. What in principle those respondents say is that it is possible (and potentially beneficial) to elaborate on the topic of integrity and ethics in small organizations, however, the real impact is missing,

as they are a too fragile system component to drive the societal change. This is in line with previous findings (e.g., Curran et al., 2000; Smith et al., 2022) regarding a certain gap in the felt responsibility of smaller companies toward the ethical standards of the wider society.

DISBELIEF THAT ETHICS WORKS IN FAVOR OF A SMALL COMPANY

Due to somewhat complicated and thorny survival on the market (e.g., Enderle, 2004; Remišová and Lašáková, 2020), particularly small companies might feel that *up-scaling ethical standards within their organization might not have any positive consequence*, and in fact, it might endanger their existence. Connected with that, an important factor contributing to the gap between small and medium-sized companies might represent the *attention of small companies' management more on fundamental business constraints* they must primarily focus on in the course of daily business than on the ethical organization. All these matters might cause a strong defocus of these companies' managers from the topic of ethical business conduct and, secondarily, result in low sensitivity being declared when it comes to both barriers of ethical development and concrete development needs. Companies can be afraid that pursuing ethics within their organizations can have significant business impacts. This fear, with high probability, is more intense with small businesses, as they are in general more sensitive to business disruptions. For instance, if, according to enhanced ethical standards, small businesses would discontinue several business opportunities in their business pipeline, this might have devastating consequences for their abidance in the competitive fight. Medium enterprises, contrary, usually have more business diversification in place and the adverse effect of losing some of the business opportunities might be satisfactorily compensated by external trustworthiness, the undisputable fruit of their potential ethical efforts.

4. Conclusion

Results imply an *invisible dividing line* that exists in internal company ethics between small and medium-sized enterprises. Thus, although SMEs are generally regarded in the economics and business literature as one block, this assumption *does not hold when it comes to organizational ethics*. Results suggest significant differences in perceptions of barriers and related needs in ethical development in small versus medium-sized companies. As for the particular barriers, the gap widens especially in the fear of change related to ethics development, the lack of knowledge about ethics in business, and the lower management focus materialized in managers ascribing little importance to ethics. These translate then into substantial differences in developmental needs, especially in the need for employee ethics education, ethics consultations to extant ethical issues in the company, ethics auditing and control of ethical behavior as well as in alignment of business processes with elements of the Ethics/Compliance program.

Interestingly, our results seem counterintuitive, as small companies report a lower level of barriers as well as developmental needs in all examined areas. We propose a series of possible explanations for this surprising result while attributing it not to a higher ethical developmental level of small firms compared to medium-sized businesses but to the somewhat problematic attitude of small businesses to organizational ethics. This may be caused by several factors, including the cumulation of roles and related reduced space for ethical considerations in small companies, increased ethical awareness in medium-sized companies due to the diverse requirements and mandatory standards, limited knowledge and experience with ethics in case of small owners-managers, distrust that ethics can make a change, and disbelief that ethics could work well for a small company. Since these theses represent the authors' logical assumptions, it seems appropriate to test them in additional research.

In our view, this analysis might provide a fair basis for further investigation of organizational variables predicting differences in perceptions of ethical development in small and medium-sized companies. In addition, our findings can form a basis for modeling concrete, targeted measures, and solutions to enhance ethical development in small and medium organizations. In this context, it appears vital to further research on the span of ethical components implemented in small and medium enterprises, as well as on the overall maturity and effectiveness of ethics programs in place. On top of that, results can help raise small entrepreneurs' awareness of the positive impacts and benefits of particular ethics components that can evolve within the organization. However, since the average

perception still appears to be below legitimate expectations also in medium-sized enterprises, it will probably be necessary to focus on this group of enterprises as well. There is a huge potential to cultivate the Slovak business environment and remains a challenge for institutions active in legislation/regulation, and education. business financing, as well as for Slovak business and professional associations.

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CREATING AND USING MODELS AND IT TOOLS ALLOWING FOR A REALISTIC ASSESSMENT OF THE RISK OF SARS-COV-2 INFECTION

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Abstract

The paper presents tools for the analysis and visualisation of statistical data on the dynamics of the spread of the SARS-CoV-2 virus in the southern region of Poland which are placed on the dedicated website covid.wsi.edu.pl. The use of innovative means of content transmission and effective social communication channels allows for effective dissemination of information about the threat of a pandemic to a wide audience. In the light of the results obtained from Twitter's metrics showing the degree of user involvement in the content published on the covid.wsi.edu.pl website, it cannot be clearly stated whether the methods used to transfer information positively affect the level of safety in the reported regions of Poland.

Keywords: Covid-19, data visualisation, statistical analysis

JEL codes: C02, C63, I19, Y10

1. Introduction

The Covid-19 pandemic exposed many social and economic problems of the modern world mentioned by Smolaga (2019) which hit primarily the physically and economically weakest layers of society. The market situation that developed during the pandemic in Poland destroyed intergenerational solidarity and threatened the existence of pensioners and people struggling with long-term unemployment. It strongly undermined one of the pillars of the European concept of social market economy (Mączyńska and Pysz, 2020). According to the statistics of the Central Statistical Office, the proportions between the generation that is fully professionally active and people at their retirement age, which have been deteriorating in Poland for years, have additionally increased dramatically in 2020-2021 as a result of the Covid-19 pandemic. The fact is that despite numerous scientific and technological achievements, the period of the coronavirus pandemic had a negative impact on the economic and social situation of an average Polish family. Again, according to Mączyńska and Pysz (2020), the main reason for this state of affairs is the inefficient system of organising socio-economic life in Poland and political decisions taken at the global level, which are often made contrary to the real needs of Poles. The biggest challenge, however, is the need to change the awareness of citizens who, operating in a highly competitive market economy, lose their human characteristics and, faced with the threat posed by the Covid-19 pandemic, become aggressive, selfish and discriminate against the weak. A change of views and lifestyle for many who are used to excessive consumption and comfort in the face of the state of nationwide quarantine becomes an unacceptable situation, even at the cost of their own health and life. The predictability of the world and the security they felt before irretrievably disappear and the present and the future appear difficult and uncertain (Długosz, 2021). In a situation of uncertainty, social divisions are deepening and anarchist movements are gaining ground, blaming the authorities, the media and public health institutions for the whole situation.

1.1 The purpose of the study and related works

Nowadays, access to any interesting information is no longer a problem. Users of modern information and communication technologies are increasingly suffering from the effects of the phenomenon popular on the Internet today, known as information noise (Tadeusiewicz, 2018). It is difficult to find sites that are substantively accurate, devoid of ads and unnecessarily distracting

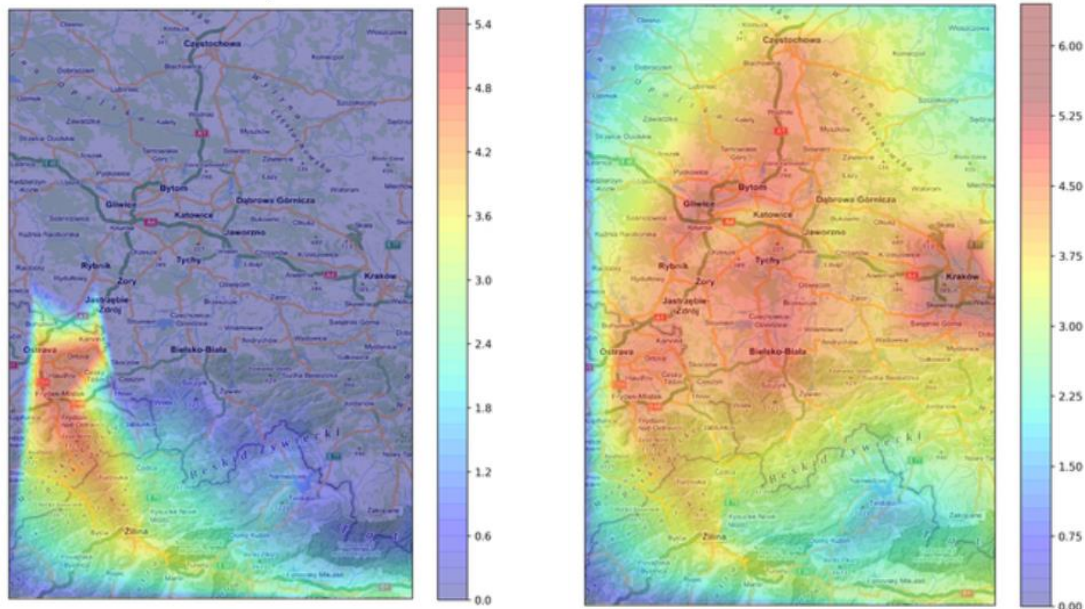
chaotic content. Unrelated and unchecked messages cause confusion in various areas of knowledge for an uninitiated recipient, having a negative impact on their perception of reality. Since the production of information on the web is currently a mass process, it also favours the formation of groups that manipulate this information which is processed in such a way as to serve the interests of these groups (Dennis et al., 2021). The period of the Covid-19 pandemic proved the harmful impact of the phenomenon of information overload, coming from sources of dubious quality on the ethical and moral values of an individual, promoting an ignorant attitude towards the knowledge of professionals and authorities in the field searched for (Duszyński et al., 2020). In such conditions, it is difficult for the average Internet user to distinguish between true and false information (Hopp, 2022). According to the announcement placed on the website of the European Commission, the fight against disinformation, especially during the Covid-19 pandemic, seems to be a priority and duty of all governmental institutions and scientific communities that should get involved in it for the benefit of the entire society. The University of Information Technology and Management, being an institution with rich scientific traditions, educating engineering specialists in five IT areas, meeting the challenges of our times, created and then made available in the first phase of the pandemic (2020) to a wide community and institutions of southern Poland, in particular the region of Silesia and border areas, i.e. Moravskoslezský kraj (the Czech Republic) and northern Slovakia, a scientifically supported metric with a tool for visualizing the state of SARS-CoV-2 infection threat located at covid.wsi.edu.pl. Just like other online platforms of this type, e.g. COVID-HUB-PL (<https://covidhub.psnc.pl/>), COVID-19 GIS Hub (<https://coronavirus-resources.esri.com/#get-apps>), or COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU) (<https://gisanddata.maps.arcgis.com/apps/dashboards/bda7594740fd40299423467b48e9ecf6>), the purpose of the covid.wsi.edu.pl website was to provide information in a visual form, legible for an average Internet user, showing the spread of the SARS-CoV-2 infection threat in the region of southern Poland and border areas, along with "actionable items", i.e. practical actions that can be taken to significantly reduce this risk. There is no doubt that this form of presenting numerical data is more understandable and engaging, and above all, more suited to the needs of a modern mass recipient. However, the problem is the varied quality and consistency of the collected data, obtained from government statistical reports, which may significantly hinder their global comparison.

1.2 Data visualisation on the COVID-19 dedicated website

Modern platforms dedicated to COVID-19 statistics, using information and communication technologies and an innovative approach to data visualisation, allow you to effectively inform the public about the current threat and support decision-makers in taking intervention measures at the regional and national level. Data visualisation is not limited only to dashboards containing time courses or network diagrams with aesthetic info-graphics, but engages the recipient, giving them the opportunity to explore data, detect correlations and see trends. Today's programming tools let us analyse large data sets quickly and effectively giving them a visual form that is easier to remember and that affects the recipient (Walker and Sharma, 2021). The covid.wsi.edu.pl website was created for an average Internet user who, due to the deficit of knowledge about the dynamics of the disease in the chosen region of southern Poland, is unable to act rationally in a situation of health threat caused by the state of the pandemic. Local sanitary and epidemiological institutions provided data on the number of new cases, healings and deaths in the numerical form, illegible for the recipient of these data. From the point of view of the recipient's perception, it becomes important to plan the information space in such a way as to draw their attention to the most important issues and maintain their interest for a longer period of time. In this case, the author of the website should demonstrate the ability to manage the time and space of the project and build a cause and effect path to achieve the goals he set himself. Since there are many ways to illustrate different types of data, it is important to choose the type of chart which can represent the desired information in a reliable way (Kalamaras, et al., 2022). Typically, heatmaps are developed by grouping data for individual areas on the map into classes which are coloured in such a way as to obtain a scale that allows for easy reading of the spatial variability of the presented phenomenon. An important element of each heatmap, which determines the degree of its detail, is the so-called field of reference, the choice of which is mainly related to the depicted phenomenon. For this reason, the type of heatmap chart used in data visualisation on the

covid.wsi.edu.pl website where individual values (number of confirmed infections) are presented in a colour scale for several dozen points (cities/rural areas) on the map of southern Poland. It is immediately noticed that this type of data visualisation lets us illustrate areas where the degree of epidemic threat is the highest thanks to the differences in the implemented colours. (Figure 1).

Figure 1: Heatmaps showing the level of epidemic threat in southern Poland, on a daily basis - November 24, 2020 (number of new infections on the left side), on a weekly basis (np7 on the right side)



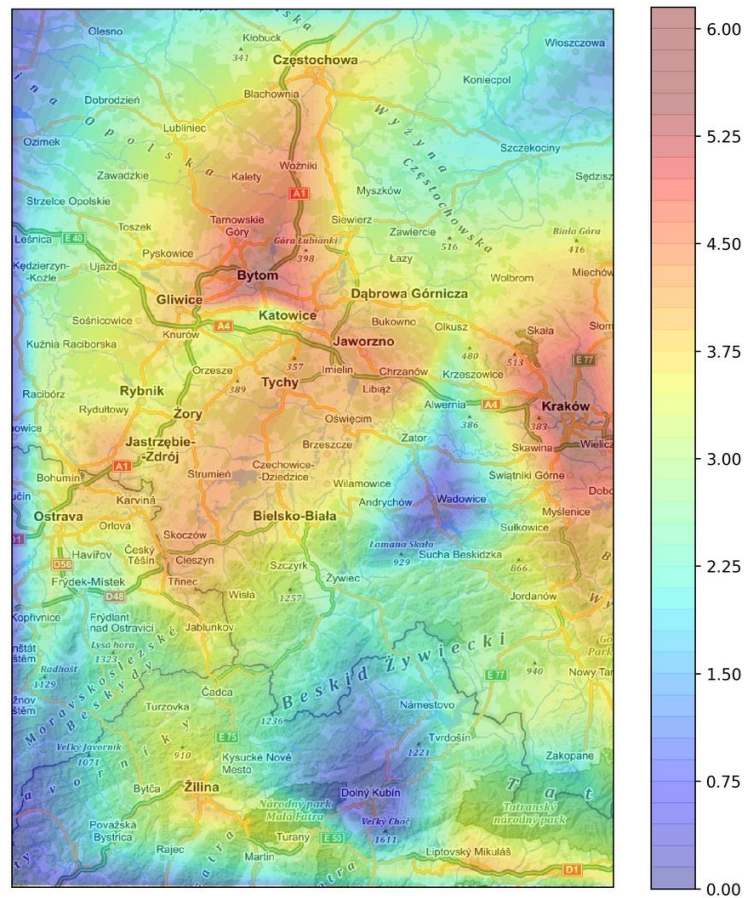
Source: covid.wsi.edu.pl

On the heatmap shown in Figure 1, the reference field is marked by the points where the district sanitary and epidemiological stations are located in southern Poland. Although we are unable to read information on the spread of the epidemic in individual areas, except for the Śląskie Voivodship and the entire country, from a map made at this level of detail, it is possible to obtain a local image where the information is presented in a more detailed way in the maps shared by official government websites. Considering the above and the assumptions of the covid.wsi.edu.pl project, it should be clearly stated that the information contained in the maps presented on the website should be treated as a practical source of information on the scale of the Covid-19 pandemic risk for recipients living in individual municipalities of Silesia. However, looking at maps on official government websites where the voivodship was used as a reference field, it is difficult to draw similar conclusions.

2. Data sources and their statistical analysis

As it has already been mentioned the source of data for the covid.wsi.edu.pl website were numerical data on the number of new cases, healings and deaths, provided daily on the websites of district sanitary and epidemiological stations of the Śląskie Voivodship and partly of the Lesser Poland Voivodship, with particular emphasis on the city of Cracow. In order to correctly illustrate the statistical data graphically, the data had to be divided into several groups called classes, according to the increasing value of the presented parameter. The number of colours used in the chart also depended on the number of classes. In the discussed case, due to the large differences between the minimum and maximum values, it was decided to use a logarithmic scale for the presented data, which was grouped into 9 classes and the method of equal spans was used to determine them (Pieniążek et al., 2014). The colour scale used on the maps allowed for the correct assignment of the basic fields to individual classes and a clear distinction for the recipient of areas with a higher and lower epidemic risk (Figure 2).

Figure 2: A colour scale consisting of 9 classes with a fixed range of values – number of new infections on November 17, 2020

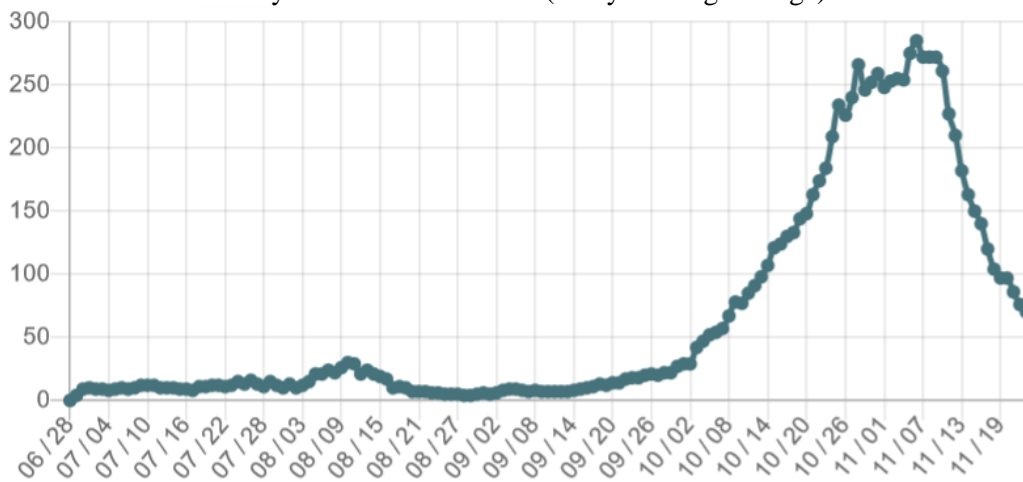


Source: covid.wsi.edu.pl/#/map/557

The essential condition that guarantees proper understanding of the heatmap is the colour scale correctly implemented in which the sequence of colours illustrates the direction of change in the features of the depicted phenomenon. By default, lighter colours are assumed to correspond to lower values on the scale while darker shades are reserved for higher values of this scale. Disruption of this rule may lead to incorrect reading of the information contained in the heatmap for the recipient. On the maps of the covid.wsi.edu.pl website (Figures 1 and 2), a colour scale was used in which the following classes of values were assigned colours from cool to warm so that the purple colour means zero cases, and the orange-red a large number of cases, i.e. a colour with a value of "4" on the scale means 50 cases, and a colour with a value of "6" means 400 cases. The use of such a colour scale increases the contrast in the map area and makes it possible to increase the readability of details in areas particularly at risk of epidemics, with a large percentage of infected people. In addition to heatmaps, the covid.wsi.edu.pl website includes line charts presenting the daily number of infections and the daily number of people in quarantine for individual map points (Figure 3).

In the analysis of epidemiological data presented in the exemplary chart (Figure 3), a simple moving average was used which is one of the basic indicators of most technical analyses. The use of a moving average of a certain length enables an objective assessment of the observed phenomenon. It allows to discover the trend in its dynamics and eliminate one-off deviations that do not affect the development of the situation over time. In this service example, a 7-day moving average was used, which means that the value for each day was obtained as the arithmetic average of the last seven days.

Figure 3: Sample number of infections per day for Frýdek-Místek.
Daily number of infections (7-day moving average)



Source: covid.wsi.edu.pl/#/stats/232

Thanks to this, the anomalies that took place during the first phase of the pandemic and resulted from the inefficiency of the reporting system (i.e. errors in the reported number of daily infections, lack of data) were largely removed from the analysis and did not distort the real picture of the epidemic. Thanks to the use of a simple moving average, it was possible to recognize the existing or changing trend of the epidemic phenomenon in a small area, covering one commune. On this basis, it was possible to draw conclusions about the degree of Covid-19 infection risk, which greatly facilitated taking preventive measures to limit the spread of the epidemic in the region of southern Poland and in the border areas on the Czech and Slovak sides.

3. The impact of the covid.wsi.edu.pl website on shaping public opinion

Today's popular social media platforms are an excellent information space where creators of content, both scientific and commercial, shares it with the recipients, influencing their moods and behaviour. While all social networking sites have seven basic functionalities (Michalak, 2017): identity building, presence, communication, content sharing, relationship building, reputation building and community building, the main idea of Twitter is to inform a wide audience about current events, products and scientific research results in short and concise messages. Due to its popularity among politicians and researchers, the microblogging format of Twitter has contributed to the improvement of scientific communication between scientists who willingly share their work with colleagues and other interested in research topics (Zhichao, 2021). The dissemination of scientific research results via Twitter has a positive effect on raising public health awareness, especially in the field of preventive health care. Therefore, it is hardly surprising that Twitter was chosen as an instrument of social communication to raise awareness of the threats related to the spread of the SARS-CoV-2 virus in the region of southern Poland. The content published through it was intended to convey knowledge in a simple and clear way, supported by the results of scientific research, regarding the way the virus spreads in society, in order to effectively shape pro-health attitudes in various social groups, regardless of their cultural differences and adopted stereotypes. Using the full potential of Twitter, the authors of the covid.wsi.edu.pl website have developed a communication strategy in which they involved people from the world of science, politics and journalists in the joint creation of content regarding the state of the pandemic in southern Poland. According to (Zhichao, 2021), the dissemination of knowledge and scientific research on Twitter is possible thanks to the involvement of the portal community, which usually manifests itself in various types of interactive behaviour of a group of users in a short period of time after the publication of a new tweet. Most of the interactions observed on the account where data from the covid.wsi.edu.pl website were published focused either on the content of the tweet itself or on links to scientific sources it contained. The addresses in the content of the tweet leading to the cited scientific sources were a perfect complement to the published information, which resulted in building trust to the author in the tweet himself as well as in the covid.wsi.edu.pl website. In a short time, a

community was created around the covid.wsi.edu.pl website, which showed its commitment to the fight against the pandemic in a manner characteristic of Twitter by numerous likes, retweets and comments on the content published by the portal. As shown by the data provided by Twitter's basic statistics (Figure 4), in the period from July 2 to September 30, 2020, tweets received 687.1K views with an average engagement rate of 2%. A year later, in the period from October 2 to December 30, 2021, a higher engagement rate of 3.3% was recorded, with the number of tweet views falling almost six times to 123.7K.

Figure 4: Basic engagement metrics from July 2 - September 30, 2020



Source: twitter.com/pmarecki2

Although the information on the level of epidemic threat in the area of southern Poland disseminated via Twitter undoubtedly caused a wave of interest from the Twitter community, it is still unclear whether they had any specific impact on reducing the level of SARS-CoV-2 virus threat in this area. In this case, it can only be assumed that the awareness of the existence of tools for constant monitoring of the current degree of threat in the active phase of the Covid-19 pandemic allows the recipient to take conscious actions aimed at protecting their own health and that of the closest environment by eliminating behaviours that may threaten it.

4. Conclusion

The modern digital world and modern technologies offer unlimited possibilities of accessing information on health and its prevention. However, it is scientifically supported that facts and reliable knowledge obtained from proven sources are a unique value for shaping proper pro-health attitudes. For a modern mass recipient, the form of content transfer is also an important element that determines the degree of assimilation of information. Therefore, it is hardly surprising that the authors of the Internet system discussed in the thesis the use of innovative forms of content transfer, legible for a modern Internet user, and social communication channels to provide up-to-date information on the dynamics of the state of the pandemic and shaping appropriate behaviours to prevent Covid-19 infection. Despite the fact that the authors themselves tracked the metrics of recipients' involvement in the information on Covid-19 statistics published on Twitter on a daily basis, it is difficult for them to clearly determine whether they had an impact on the health situation in the reported areas. Considering the above, it is necessary to conduct further research and analyses that would allow for an unambiguous qualitative and quantitative determination of the impact of the tools created by the

authors on the change in the Covid-19 threat in southern Poland as well as adjacent regions of neighbouring countries.

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SOME NOTES ON THE ASSESSMENT OF INCONSISTENCY IN DECISION MAKING BASED ON PAIRWISE COMPARISON

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Abstract

Decision making processes, or judgements in general, are often susceptible to inconsistency inherent to human mind. Usually, low degrees of inconsistency are undesirable since they might lead to unreliable or incorrect decisions. The aim of our paper is to assess inconsistency of pairwise comparisons via Monte Carlo simulations. We focus on four inconsistency indices: consistency ratio (CR), Koczkodaj's inconsistency index (KI), Peláez-Lamata's index (PLI) and triads geometric consistency index (T-GCI). First, we apply Monte Carlo method to generate 50,000 random pairwise comparisons matrices of the order $n = \{3, 4, 5, 6, 7, 8, 9, 10\}$ with elements drawn from Saaty's fundamental scale $\{1/9, 1/8, \dots, 1, 2, \dots, 9\}$, and then we estimate their inconsistency with respect to aforementioned four inconsistency indices. Our results indicate that the pairs (CR, T-GCI), (CR, PLI) and (PLI, T-GCI) closely correlate (with Pearson's correlation coefficient exceeding 0,9) and that correlation among indices is rather stable with respect to a matrix size. Finally, we provide percentile tables for all four indices that can be used to assess whether a given pairwise comparisons matrix (a set of judgements) is tolerably inconsistent, or not.

Keywords: decision making, inconsistency, inconsistency index, Monte Carlo simulations, pairwise comparisons.

JEL codes: C13, C15, C88.

1. Introduction

Pairwise comparisons (PCs) form a fundamental part of many multiple criteria decision making (MCDM) methods, such as the AHP/ANP, BWM, ELECTRE, MACBETH, PAPRIKA, or PROMETHEE, see e. g. (Bana e Costa et al., 2005, Figueira et al., 2005, Ramík, 2020, Saaty, 1980).

One particular problem associated with pairwise comparisons is their (potential) inconsistency. For example, if an object A is judged to be four times better than an object B, and an object B is two times better than an object C, then the object A should be precisely 8 times better than C. However, decision makers, or experts, are seldom completely consistent in their judgments due to the lack of knowledge, time pressure, a large number of comparisons to be made, or other reasons. Therefore, many inconsistency indices, which are functions measuring the degree of inconsistency, were proposed in the recent decades, see e. g. (Brunelli, 2016, Brunelli, 2018, Mazurek, 2018, Mazurek, 2022, Pant et al., 2022).

As mentioned before, decision making processes, or judgments in general, are often susceptible to inconsistency inherent to human mind. Usually, low degrees of inconsistency are tolerated, while

relatively high degrees of inconsistency are undesirable since they might lead to unreliable or incorrect decisions.

The aim of this paper is to assess inconsistency of pairwise comparisons via Monte Carlo simulations and provide a decision maker with information necessary for deciding whether a given set of judgments (in the form of pairwise comparisons arranged into a pairwise comparisons matrix) is acceptably inconsistent, or not. Also, we examine the four inconsistency indices in terms of their correlation in order to ascertain their (dis)similarities.

The presented study belongs into a broad set of simulation studies on pairwise comparisons, see e.g. (Alonso and Lamata, 2006, Brunelli et al., 2013, Cavallo, 2017, Cavallo, 2020, Kowal et al., 2021, Mazurek and Kulakowski, 2020, Vargas, 2008). However, percentile tables with indices' values for randomly generated pairwise comparisons matrices are still missing in the literature. This paper fills this gap for four selected inconsistency indices: CR , KI , PLI and $T - GCI$. (It should be noted that percentile tables for the consistency ratio CR were already published in (Vargas, 2008) however, they slightly differ from our results, see Section 4.

The paper is organized as follows: Section 2 provides a brief review of inconsistency indices, details of Monte Carlo simulation are described in Section 3 followed by the results in Section 4. Section 5 illustrates a practical application of percentile tables and Conclusions close the article.

2. The indices

Hereinafter, we provide definitions of four inconsistency indices applied in this numerical study (Aguarón et al., 2020; Brunelli, 2018; Koczkodaj, 1993; Mazurek, 2018; Mazurek, 2023; Peláez and Lamata, 2003; Saaty, 1980).

Definition 1. The consistency index CI of a PC matrix A of the order n is defined as follows:

$$CI(A) = \frac{\lambda_{max} - n}{n - 1}, \quad (1)$$

The consistency ratio CR is defined as:

$$CR(A) = \frac{CI(A)}{RI(n)}, \quad (2)$$

where $RI(n)$ in the definition above denotes the random consistency index (the arithmetic mean of randomly generated PC matrices of a given order with Saaty's scale) dependent on n , and λ_{max} is the largest right (positive) eigenvalue of A .

Definition 2. Koczkodaj's inconsistency index KI of an $n \times n$ ($n > 2$) reciprocal matrix $A = [a_{ij}]$ is given as:

$$KI(A) = \max_{i,j,k \in \{1,\dots,n\}} \left\{ \min \left\{ \left| 1 - \frac{a_{ij}}{a_{ik}a_{kj}} \right|, \left| 1 - \frac{a_{ik}a_{kj}}{a_{ij}} \right| \right\} \right\} \quad (3)$$

Definition 3. Peláez-Lamata index (PLI/CI^*). Let $A_{n \times n} = [a_{ij}]$ be a pairwise comparisons matrix. Then the PLI index is defined as follows:

$$PLI(A) = \frac{6}{n(n-1)(n-2)} \cdot \sum_{i=1}^{n-2} \sum_{j=i+1}^{n-1} \sum_{k=j+1}^n \left(\frac{a_{ik}}{a_{ij}a_{kj}} + \frac{a_{ij}a_{kj}}{a_{ik}} - 2 \right) \quad (4)$$

Definition 4. The triads geometric consistency index ($T - GCI$). Let $A_{n \times n} = [a_{ij}]$ be a pairwise comparisons matrix. The triads geometric consistency index $T - GCI$ is defined as follows:

$$T - CGI(A) = \frac{2 \sum_{i < j < k} (\log(a_{ij} a_{jk} a_{ki}))^2}{n(n-1)(n-2)} \quad (5)$$

3. Monte Carlo simulations

To find percentile tables for the four selected indices Monte Carlo simulations were performed. For each matrix size $n = \{3,4,5,6,7,8,9,10\}$ 50,000 random (reciprocal) pairwise comparisons matrices were generated with elements drawn (uniformly) from Saaty's fundamental scale $\{1/9, 1/8, \dots, 1, 2, \dots, 8, 9\}$. Uniform distribution guarantees that each value from the scale is represented 'fairly', that is with the same probability as other values. Subsequently, percentiles tables were calculated.

The code for numerical simulations was written in Python and both the code and its outputs are accesible at Github repository (Smalara et al., 2022).

The *Inconsistency matrix generator repository* with Saaty's scale consists of several python functions for matrix initialization. The following code shows the initialization of a matrix of any size.

```
def create_matrix(size):
    matrix = [[0 for x in range(size)] for y in range(size)]
    for n in range(size):
        for m in range(size):
            if n == m:
                matrix[n][m] = 1
    return matrix
```

The following python code allows to create a matrix of any size according to the Saaty scale.

```
def fill_matrix(matrix):
    choice_list = [1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9]
    size = len(matrix)
    for n in range(size):
        for m in range(size):
            if n > m:
                matrix[n][m] = random.choice(choice_list)
    for n in range(0, size):
        for m in range(0, size):
            if n < m:
                matrix[n][m] = 1/matrix[m][n]
    return matrix
```

In the code above, instead of 'create.matrix', the 'numpy.eye' function can be considered as well.

Pearson's correlation coefficients between all pairs of inconsistency indices were calculated via CORREL function in MS Excel. The results are shown in Figure 1 in the next section.

4. Results

Results of Monte Carlo simulations are provided in Table 1. As can be seen, *PLI* index acquired highest values, followed by the $T - GCI$ index. In general, with increasing matrix size the percentile values grow as well.

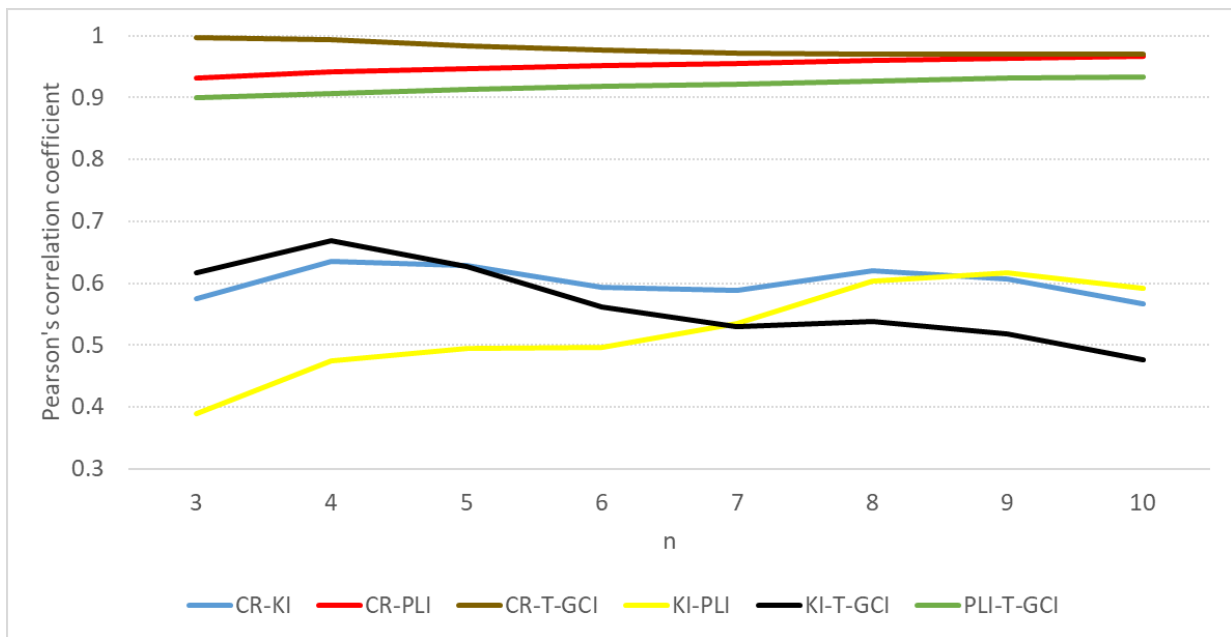
The (linear) correlation between inconsistency indices is shown in Figure 1. As can be seen, the pairs $(CR, T - GCI)$, (CR, PLI) and $(PLI, T - GCI)$ closely correlate (with Pearson's correlation coefficient exceeding 0.9) and that correlation among indices does not change significantly with respect to a matrix size. From a practical point of view it means that *CR*, *PLI* and $T - GCI$ indices can be used interchangeably.

Table 1: Percentiles for CR, KI, PLI and $T - GCI$ indices with respect to the matrix size n ; 50,000 randomly generated cases for each n with matrix elements drawn from Saaty's scale. $\tilde{x} = median$.

CR/Perc.	0.001	0.005	0.01	0.02	0.03	0.04	0.05	0.10	0.20	0.25	0.50 (\tilde{x})
n = 3	0	0	0	0.001	0.002	0.004	0.007	0.028	0.095	0.129	0.415
n = 4	0.011	0.033	0.051	0.076	0.097	0.116	0.131	0.197	0.319	0.385	0.853
n = 5	0.074	0.127	0.157	0.196	0.226	0.253	0.277	0.376	0.558	0.644	1.003
n = 6	0.163	0.229	0.274	0.331	0.371	0.408	0.439	0.557	0.712	0.771	1.011
n = 7	0.252	0.349	0.403	0.465	0.513	0.547	0.573	0.673	0.792	0.836	1.008
n = 8	0.370	0.461	0.511	0.574	0.610	0.638	0.663	0.741	0.833	0.868	1.005
n = 9	0.464	0.555	0.595	0.645	0.676	0.701	0.719	0.785	0.863	0.891	1.006
n = 10	0.552	0.624	0.660	0.703	0.729	0.765	0.765	0.820	0.884	0.908	1.004
KI/Perc.	0.001	0.005	0.01	0.02	0.03	0.04	0.05	0.10	0.20	0.25	0.50 (\tilde{x})
n = 3	0	0	0	0.1	0.125	0.167	0.222	0.4	0.611	0.667	0.857
n = 4	0.375	0.571	0.667	0.719	0.75	0.786	0.800	0.857	0.917	0.933	0.983
n = 5	0.786	0.844	0.875	0.900	0.917	0.926	0.937	0.963	0.982	0.986	0.994
n = 6	0.906	0.938	0.952	0.967	0.975	0.979	0.982	0.989	0.993	0.994	0.996
n = 7	0.958	0.976	0.984	0.988	0.990	0.991	0.992	0.994	0.995	0.996	0.997
n = 8	0.984	0.990	0.992	0.993	0.994	0.994	0.995	0.996	0.996	0.997	0.997
n = 9	0.991	0.993	0.994	0.995	0.995	0.996	0.996	0.996	0.997	0.997	0.998
n = 10	0.994	0.995	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.998	0.998
PLI/Perc.	0.001	0.005	0.01	0.02	0.03	0.04	0.05	0.10	0.20	0.25	0.50 (\tilde{x})
n = 3	0	0	0	0.011	0.018	0.033	0.064	0.267	0.960	1.333	5.143
n = 4	0.125	0.362	0.578	0.878	1.142	1.392	1.600	2.564	4.594	5.812	20.41
n = 5	0.914	1.647	2.102	2.747	3.256	3.719	4.181	6.360	12.01	15.34	33.16
n = 6	2.278	3.393	4.273	5.626	6.652	7.725	8.678	12.85	19.43	22.35	36.45
n = 7	3.903	6.262	7.826	9.906	11.54	12.91	13.94	18.27	24.17	26.72	37.82
n = 8	6.820	9.890	11.82	13.99	15.64	16.91	17.98	21.78	27.04	29.11	38.43
n = 9	9.991	13.20	15.03	17.21	18.74	19.92	20.88	24.39	29.00	30.87	38.85
n = 10	13.25	16.20	17.99	20.02	21.40	22.48	23.36	26.48	30.59	32.22	39.15
T-GCI/Perc.	0.001	0.005	0.01	0.02	0.03	0.04	0.05	0.10	0.20	0.25	0.50 (\tilde{x})
n = 3	0	0	0	0.004	0.006	0.011	0.021	0.087	0.297	0.402	1.262
n = 4	0.041	0.115	0.178	0.260	0.329	0.391	0.440	0.654	1.027	1.221	2.403
n = 5	0.266	0.440	0.535	0.663	0.754	0.833	0.904	1.186	1.633	1.830	2.633
n = 6	0.565	0.757	0.886	1.041	1.149	1.234	1.314	1.589	1.939	2.075	2.632
n = 7	0.813	1.076	1.198	1.356	1.457	1.539	1.602	1.831	2.109	2.217	2.641
n = 8	1.106	1.336	1.449	1.589	1.672	1.735	1.794	1.979	2.204	2.291	2.638
n = 9	1.323	1.523	1.621	1.742	1.820	1.878	1.923	2.083	2.276	2.346	2.635
n = 10	1.516	1.690	1.773	1.881	1.943	1.990	2.031	2.167	2.330	2.392	2.636

Source: Own

Figure 1: Correlation between indices.



Source: Own

5. Illustrative example

A manager of a small company has to select an electricity supplier; she has four options. She invites two experts (A and B) who provide pairwise comparisons of the four suppliers, see pairwise comparisons matrices A and B below. Before the manager uses the AHP or other method to find the best supplier, she checks consistency of judgments of both experts.

$$A = \begin{bmatrix} 1 & 2 & 4 & 5 \\ 0.5 & 1 & 3 & 2 \\ 0.25 & 0.33 & 1 & 2 \\ 0.2 & 0.5 & 0.5 & 1 \end{bmatrix},$$

$$B = \begin{bmatrix} 1 & 2 & 4 & 1 \\ 0.5 & 1 & 0.25 & 2 \\ 0.25 & 4 & 1 & 3 \\ 1 & 0.5 & 0.33 & 1 \end{bmatrix}.$$

The manager calculates the inconsistency index PLI for both matrices:

$$PLI(A) = 0.44, PLI(B) = 4.88.$$

From the percentile Table 1 it can be seen that the inconsistency of the matrix A (of the order $n = 4$) is below 0.01 (1%) percentile, hence it can be considered acceptably inconsistent. However, the inconsistency of the matrix B is above 0.20 (20%) percentile, hence it can be considered too much inconsistent (recall Saaty's 10% rule of thumb for consistency ratio CR).

The manager may decide to ask the expert B to revise his judgments, or she may ignore expert's B opinion and proceed towards acquiring suppliers weights from the matrix A .

6. Conclusion

The aim of this paper was to facilitate decision making in the framework of pairwise comparisons methods by providing percentile tables for four selected inconsistency indices: CR , KI , PLI , and $T - GCI$. The tables can be used for assessing whether a given pairwise comparisons matrix is tolerably inconsistent, or not.

In addition, linear correlation between the indices was investigated in order to examine their (dis)similarity. Our results indicate that CR , PLI , and $T - GCI$ closely correlate with Pearson's correlation coefficient exceeding 0.90.

Simulation results are freely available at Github repository, see (Smalara et al., 2022). Further research will focus on other indices that can be found in (Mazurek, 2023).

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A TOOL FOR SOLVING MULTICRITERIA DECISION PROBLEMS

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Abstract

A variety of software products are available to aid in decision making. However, the main disadvantage of these products is their commercial nature, which makes them relatively expensive and inaccessible to small companies, students, and researchers. This paper introduces a new, free desktop tool called Fuzzy Multicriteria Decision Assistant for Microsoft Windows. This tool was designed to support users in making decisions with uncertain data in a multicriteria decision-making setting. The tool is a successor to an earlier software product called FDA, which required an internet connection and discouraged users from sending sensitive decision data to the server. The Fuzzy Multicriteria Decision Assistant can also be used by students to help them understand the basic principles of multicriteria decision making because it displays the results of all intermediate calculations and does not function as a black box. The proposed software package is demonstrated using a real-life decision problem: selecting the best mobile phone.

Keywords: analytic hierarchy process, fuzzy, multi-criteria decision making, pair-wise comparisons
JEL codes: C61, C63, C88.

1. Introduction

Decision making in situations with multiple options is an important research area in decision theory and has been extensively studied in various sources, including Fishburn (1971), Zhang and Ruan (2007), Ramik and Perzina (2006), Ramik and Perzina (2008), Ramik and Perzina (2014), Ramik (2016), Saaty (1991), Saaty (2001). A wide range of computer programs is available to assist decision makers in making effective decisions, such as Decisions Lens, Expert Choice, Mind Decider, MakeItRational, or Super Decisions. However, the main disadvantage of these programs is that they are commercial and relatively expensive, which makes them inaccessible to small companies and individual entrepreneurs. Another drawback is that they require installation on a computer or are only available for specific platforms or operating systems.

In this paper, we introduce a new desktop tool called FMDA, which stands for Fuzzy Multicriteria Decision Assistant. FMDA is an improved version of the author's earlier products, including DAME, which only supported crisp evaluations and was only available in Microsoft Excel (Ramik and Perzina, 2014), and an online tool called FDA (Perzina et al., 2018), which discouraged users from sending sensitive data to external servers. The primary advantage of the new FMDA tool is its ability to handle both crisp and fuzzy evaluations. Unlike other software products for solving multicriteria decision problems, FMDA is free, allows for easy data manipulation, and is available on any computer with a Microsoft Windows operating system. Users can structure their decision models into two levels, criteria, and variants. Standard pairwise comparisons are used to evaluate both criteria and variants, and an inconsistency index is calculated for each pairwise comparison matrix. The center of gravity method (Chen, 1992) is used to rank fuzzy weights.

2. Tool Description

The FMDA tool is compatible with all computers that run Microsoft Windows 7 or a later version. To download the installation files for the tool, users can visit the following website:

<http://www.opf.slu.cz/kmme/FMDA>. The tool was developed using the C# programming language and runs on the .NET framework. After the tool is installed and launched, users will see a form displayed on their screen, which allows them to input the key characteristics of a new problem, as shown in Figure 1.

Figure 1: New problem form

Basic settings:

Number of criteria ▾

Number of variants ▾

Other settings:

Evaluations Crisp Fuzzy

Criteria Comparison Pairwise Weights

Evaluation of variants according to individual criteria:

1. Pairwise Values max Values min

2. Pairwise Values max Values min

3. Pairwise Values max Values min

Source: Own

The top panel of the form contains the basic settings for the problem, which include specifying the number of criteria and variants. In the second panel, "Other settings," users can select whether they want to use crisp or fuzzy evaluations. This panel also allows users to choose how they want to compare criteria, either by using pairwise comparison matrices or by setting the weights directly. In the last panel, users can select how they want to evaluate variants based on individual criteria. There are three options: pairwise comparison, values max (for maximization criteria, where each variant is evaluated by a single value such as revenue), and values min (for minimization criteria, where each variant is evaluated by a single value such as cost). After confirming these settings, a new form is created where users can update the names of all elements and evaluate criteria and variants using pairwise comparison matrices, as illustrated in Figure 2.

Figure 2: Pairwise comparison matrix example

Criteria	Crit1	Crit2	Crit3	0,080	Weights
Crit1		3 ▾	3 ▾		0,594
Crit2			2 ▾		0,249
Crit3					0,157

Source: Own

Users need to enter values in the upper triangle of the pairwise comparison matrix. The lower triangle values are automatically calculated as reciprocals. To indicate that a criterion or variant in a row is more important than one in a column, values from 2 to 9 are used, with higher values indicating greater importance. Conversely, if a criterion or variant in a row is less important than one in a column, values from 1/2 to 1/9 are used, with lower values indicating lesser importance. If both criteria or variants in a row and column are equally important, a value of 1 or an empty cell is used. The inconsistency index is calculated in the top right corner, and it should be less than 0.1. If it is higher, the pairwise comparisons need to be reconsidered to achieve greater consistency. The weights of individual criteria or variants are calculated based on the pairwise comparison matrix values in the far-right column using Equation (1), and the evaluation method is selected.

3. Mathematical Background

In this section, we will provide a concise explanation of the mathematical concepts and formulas that are utilized in the calculations performed by FMDA.

3.1 Crisp Calculations

In case of crisp evaluations, i.e. when we can compare all pairs of criteria/variants exactly, we use geometric mean method for calculation criteria/variants weights w_k from pairwise comparison matrices, see e.g. [11], as follows.

$$w_k = \frac{\left(\prod_{j=1}^n a_{kj} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n a_{ij} \right)^{1/n}}, k = 1, 2, \dots, n, \quad (1)$$

where w_k is the weight of k -th criterion (variant), a_{ij} are values in the pairwise comparison matrix, and n is number of criteria (variants).

The inconsistency index is calculated using the formula (2).

$$GCI = \frac{2}{(n-1)(n-2)} \sum_{i < j} \log^2 \left(a_{ij} \cdot \frac{w_j}{w_i} \right) \quad (2)$$

When we enter values into individual pairwise comparison matrices all weights are recalculated, so that we obtain an immediate impact of each individual entry. The matrix of normalized values as well as the graph with total evaluation of variants is then shown at the bottom. The resulting vector of weights of the variants \mathbf{Z} is given by the formula (3).

$$\mathbf{Z} = \mathbf{W}_{32} \mathbf{W}_{21} \quad (3)$$

where \mathbf{W}_{21} is the $n \times 1$ matrix (weighing vector of the criteria), i.e.

$$\mathbf{W}_{21} = \begin{bmatrix} w(C_1) \\ \vdots \\ w(C_n) \end{bmatrix} \quad (4)$$

and \mathbf{W}_{32} is the $m \times n$ matrix

$$\mathbf{W}_{32} = \begin{bmatrix} w(C_1, V_1) & \cdots & w(C_n, V_1) \\ \vdots & \cdots & \vdots \\ w(C_1, V_m) & \cdots & w(C_n, V_m) \end{bmatrix} \quad (5)$$

where $w(C_i)$ is the weight of criterion C_i , $w(V_r, C_i)$ is the weight of variant V_r subject to the criterion C_i .

3.2 Fuzzy Calculations

In certain situations, decision makers may find it easier to express their evaluations using natural language phrases such as "possibly 3", "approximately 4" or "about 5" or make comparisons using phrases like "A is possibly weak preferable to B" as described in Saaty (1991). Fuzzy sets of real numbers, such as triangular fuzzy numbers, can be used to represent these evaluations. A triangular fuzzy number a is defined as $(a_L; a_M; a_U)$, where a_L is the lower number, a_M is the middle number, and a_U is the upper number, subject to the condition that $a_L \leq a_M \leq a_U$. If $a_L = a_M = a_U$, then a is a crisp number (i.e., a non-fuzzy number). Fuzzy numbers, vectors, and matrices are denoted by a tilde symbol, e.g., \tilde{a} . If all the elements of an $m \times n$ matrix \mathbf{A} are triangular fuzzy numbers, then \mathbf{A} is a triangular fuzzy matrix composed of triples of real numbers. In the case where \mathbf{A} is a pairwise comparison matrix, it is assumed to be reciprocal, with ones on the diagonal. To identify the "optimal" variant, we need to calculate the triangular fuzzy weights as evaluations of the relative importance of the criteria and evaluations of the variants based on individual criteria. We assume that there are vectors of triangular fuzzy weights $\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n$, $\tilde{w}_i = (w_i^L; w_i^M; w_i^U)$, $i = 1, 2, \dots, n$, which can be calculated using the formula (6) described in Ramik and Perzina (2006).

$$\tilde{w}_k = (w_k^L; w_k^M; w_k^U), k = 1, 2, \dots, n, \quad (6)$$

where

$$w_k^S = \frac{\left(\prod_{j=1}^n a_{kj}^S \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n a_{ij}^M \right)^{1/n}}, S \in \{L, M, U\} \quad (7)$$

The method of obtaining triangular fuzzy weights using equation (7) from a triangular fuzzy pair-wise comparison matrix is referred to as the *logarithmic least squares method* in Chen (1992). This method can be applied for determining both the relative importance of individual criteria and for obtaining relative triangular fuzzy values of the criteria for each variant from the pair-wise comparison matrices.

Next, we will use formula (8) to calculate the synthesis, which represents the aggregated triangular fuzzy values of the individual variants. This formula is applied to triangular fuzzy matrices.

$$\tilde{\mathbf{Z}} = \tilde{\mathbf{W}}_{32} \tilde{\mathbf{W}}_{21} \quad (8)$$

Here, for addition, subtraction and multiplication of triangular fuzzy numbers we use the fuzzy arithmetic operations mentioned earlier, see e.g. Ramik and Perzina (2006). The simplest method for ranking a set of triangular fuzzy numbers in (8) is the *center of gravity method*. This method is based on computing the x -th coordinates of the center of gravity of each triangle given by the corresponding membership functions of \tilde{z}_i , $i = 1, 2, \dots, n$. Evidently, it holds

$$z_i^g = \frac{z_i^L + z_i^M + z_i^U}{3}. \quad (9)$$

By (9) the variants can be ordered from the best to the worst. There exist more sophisticated methods for ranking fuzzy numbers, for a comprehensive review of comparison methods see Chen (1992).

4. Case Study – Crisp Evaluations

In this section, we demonstrate the application of the FMDA tool for a practical decision-making scenario involving the purchase of a mobile phone. The aim is to identify the best variant among three pre-selected options based on three criteria: visual appearance (pairwise), quality (pairwise), and price (minimization criterion). The figure below (Fig. 3) illustrates the parameter settings.

Figure 3: Case study – setting of parameters

Basic settings:

Number of criteria ▾

Number of variants ▾

Other settings:

Evaluations Crisp Fuzzy

Criteria Comparison Pairwise Weights

Evaluation of variants according to individual criteria:

1. Pairwise Values max Values min

2. Pairwise Values max Values min

3. Pairwise Values max Values min

Source: Own

Submitting the form by clicking on a “Generate” button there is generated a new form. First, we set the names of criteria (Visual, Quality and Price) and variants (Phone A, Phone B and Phone C), see Figure 4.

Figure 4: Case study – names of criteria and variants

Names of criteria:

Criterion 1

Criterion 2

Criterion 3

Names of variants:

Variant 1

Variant 2

Variant 3

Source: Own

Next, we compare each criterion to one another by utilizing a pairwise comparison matrix. The elements within this matrix indicate the relative importance of the criterion in the selected row compared to the criterion in the selected column. Please refer to Figure 5 for the comparison matrix.

Figure 5: Case study – criteria comparison

Criteria	Visual	Quality	Price	0,057	Weights
Visual		<input type="text" value="1/3"/> ▾	<input type="text" value="1/5"/> ▾		0,114
Quality			<input type="text" value="1"/> ▾		0,405
Price					0,481

Source: Own

The pairwise comparisons we made have resulted in an inconsistency index of 0.016, which is less than 0.1. This indicates that our comparisons are consistent. The weights of each criterion can be found in the last column of the table.

Finally, we evaluate the variants based on individual criteria. The first two criteria (visual appearance and quality) are evaluated using pairwise comparisons, while the third criterion (price) is evaluated based on the actual price of each variant in EUR. Please refer to Figure 6 for the evaluations.

Figure 6: Case study – evaluation of variants

Visual	Phone A	Phone B	Phone C	0,060	Weights
Phone A		1/2	3		0,320
Phone B			4		0,558
Phone C					0,122

Criterion: Quality

Quality	Phone A	Phone B	Phone C	0,000	Weights
Phone A		3	6		0,667
Phone B			2		0,222
Phone C					0,111

Source: Own

It can be observed that both pairwise comparison matrices are consistent as their inconsistency indices are below 0.1. The top right matrix displays the weights of each variant (rows) based on the individual criteria (columns). After computing the synthesis, the total evaluation of the variants is presented in the last table of Figure 7. Accordingly, Phone C is the best variant with a weight of 0.364, followed by Phone B with a weight of 0.329, and finally Phone A with a weight of 0.307.

Figure 7: Case study – total evaluation of variants

	M	COG	Rank
Phone A	0,307	0,307	3
Phone B	0,329	0,329	2
Phone C	0,364	0,364	1

Source: Own

5. Case Study – Fuzzy Evaluations

In certain decision-making scenarios, decision-makers may not be able to make precise comparisons between every pair of criteria or variants. In such situations, using fuzzy evaluations, such as triangular fuzzy numbers, may be more appropriate, as discussed in Ramik (2016). To further illustrate the use of FMDA, we will continue with the example from the previous section and demonstrate how fuzzy evaluations can be applied.

In the “New problem” section we select “Fuzzy” option under “Evaluations” in the “Other settings” section. All other options are the same as in the previous example, see Figure 8.

Figure 8: Fuzzy case study – New problem form

Basic settings:

Number of criteria ▾

Number of variants ▾

Other settings:

Evaluations Crisp Fuzzy

Criteria Comparison Pairwise Weights

Evaluation of variants according to individual criteria:

1. Pairwise Values max Values min

2. Pairwise Values max Values min

3. Pairwise Values max Values min

Source: Own

Once the "Generate" button is clicked, a new form is generated where the user can input all the required values. The first step is to fill in the importance of the criteria, which is given by the fuzzy pairwise comparisons. This is done using triangular fuzzy numbers, where each input for pairwise comparison is expressed by three numbers. This process is illustrated in Figure 9.

Figure 9: Fuzzy case study – criteria fuzzy comparison and their weights

Criteria	Visual	Quality	Price	0,143	Weights
Visual		<input type="text" value="1/2"/> ▾ <input type="text" value="1/3"/> ▾ <input type="text" value="1/5"/> ▾	<input type="text" value="1/3"/> ▾ <input type="text" value="1/5"/> ▾ <input type="text" value="1/6"/> ▾		0,090 0,114 0,155
Quality			<input type="text" value="1/2"/> ▾ <input type="text" value="1"/> ▾ <input type="text" value="3"/> ▾		0,281 0,405 0,693
Price					0,281 0,481 0,644

Source: Own

The next step involves incorporating fuzzy evaluations of the variants based on the individual criteria through two pairwise comparison matrices and a table containing triangular fuzzy prices, as shown in Figure 10. The use of fuzzy prices enables modeling of a realistic scenario where prices at the time of purchase may differ from those at the time of decision making.

Figure 10: Fuzzy case study – evaluation of variants

Criterion: Visual

Visual	Phone A	Phone B	Phone C	0,126	Weights
Phone A		1/4 ▾ 1/2 ▾ 2 ▾	2 ▾ 3 ▾ 4 ▾		0,222 0,320 0,558
Phone B			2 ▾ 4 ▾ 4 ▾		0,279 0,558 0,704
Phone C					0,111 0,122 0,176

Criterion: Quality

Quality	Phone A	Phone B	Phone C	0,189	Weights
Phone A		3 ▾ 3 ▾ 6 ▾	5 ▾ 6 ▾ 6 ▾		0,627 0,667 0,840
Phone B			1/2 ▾ 2 ▾ 4 ▾		0,111 0,222 0,280
Phone C					0,088 0,111 0,187

Criterion: Price

Price	Value			Weights
Phone A	680	699	710	0,048 0,017 0,000
Phone B	460	481	500	0,397 0,363 0,333
Phone C	305	320	330	0,643 0,619 0,603

Source: Own

The final aggregation of results is now automatically calculated and presented in the form of triangular fuzzy numbers, along with the center of gravity (COG) for each variant and their corresponding ranks, as shown in Figure 11.

Figure 11: Fuzzy case study – total evaluation of variants

	L	M	U	COG	Rank
Phone A	0,201	0,315	0,699	0,405	1
Phone B	0,150	0,328	0,558	0,346	3
Phone C	0,204	0,356	0,571	0,377	2

Source: Own

Comparison of the fuzzy case with the crisp case presented in Section 4 reveals that the introduction of fuzzy evaluations has led to a change in the ranking of variants. In the new case, the best variant is Phone A with a center of gravity of 0.405, followed by Phone C with a center of gravity of 0.377, and finally Phone B with a center of gravity of 0.346. However, in the crisp case, the best variant was Phone C, the second-best variant was Phone B, and the worst variant was Phone A.

3. Conclusion

This paper introduces a new desktop tool called FMDA - Fuzzy Multicriteria Decision Assistant for solving decision-making problems with both certain and uncertain data. In comparison to other decision support software products, FMDA is free, has the capability to process crisp or fuzzy evaluations, and is easy to manipulate data. Furthermore, it can run on any computer with Microsoft

Windows. We demonstrated the functionality of FMDA through two realistic case studies and showed that introducing fuzzy comparisons can change the rank of alternatives. This tool is highly recommended for students, researchers, small companies, or individuals interested in modern decision-making methods for various situations.

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WHY WE NEED DESIRABLE PROPERTIES IN MCDM?

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Abstract

Pairwise comparisons matrices (PCMs) are inevitable tools in some important multiple criteria decision making methods, e.g. AHP, TOPSIS, PROMETHEE, etc. In this paper we investigate some important properties of PCMs which influence the generated priority vectors for final ranking the given alternatives. The main subproblem of the Analytic Hierarchy Process (AHP) is to calculate the priority vectors, i.e. the weights assigned to the elements of the hierarchy (criteria, sub-criteria, and/or alternatives or variants), by using the information provided in the form of a pairwise comparison matrix. Given a set of elements, and corresponding pairwise comparison matrix, whose entries evaluate the relative importance of the elements with respect to a given criterion. Here, we investigate some important and natural properties of PCMs called the desirable properties, particularly, the non-dominance, consistency, intensity and coherence, which influence the generated priority vectors for final ranking of the given alternatives. The purpose is to calculate the priority vector characterizing the ranking of elements. There exist various methods for calculating the vector of weights, e.g. Saaty's Eigenvector Method, the Arithmetic Mean Method, Geometric Mean Method, Least Square Method and others. The properties are derived, discussed and some illustrating examples are presented.

Keywords: multi-criteria decision making (MCDM), Analytic Hierarchy Process (AHP), pairwise comparison matrix, consistency, intensity, coherence, priority vector

JEL codes: C44, C63

1. Introduction

Recently, each entrepreneurship is based on a modern information technology (IT). Each firm has its own personal computer(s), tablets, mobile phones, or other means. Moreover, there is an increasing popularity of methods for decision support solvable by the help of computers and IT. Multiple Criteria Decision Methods (MCDM) proved to be useful methods e.g. in the following areas: buying equipment (cars, machines, furniture), investment opportunities, services evaluations, etc. A fundamental problem of decision theory is how to derive the weights for a set of objects (alternatives, activities, etc.) according to their importance, which are usually judged in pairs according to several criteria. By these weights, the objects are then ordered. This is a process of multiple criteria decision making (MCDM) which is a theory of measurement in a hierarchical structure (AHP) consisting of the goal, the criteria (subcriteria), and the alternatives, see Saaty (1977), Vaidya and Kumar (2006).

The main subproblem of the Analytic Hierarchy Process (AHP) is to calculate the priority vectors, i.e. the weights assigned to the elements of the hierarchy (criteria, sub-criteria, and/or alternatives or variants), by using the information provided in the form of a pairwise comparison matrix. Given a set $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$ of elements, and corresponding $n > 1$, and an $n \times n$ pairwise comparison matrix, whose entries evaluate the relative importance of the elements with respect to a given criterion. Pairwise comparisons matrices (PCMs) are important tools in many other multiple criteria decision making methods, e.g. AHP, TOPSIS, PROMETHEE, etc. In this paper we investigate some important and natural properties of PCMs called the *desirable properties*, particularly, the non-dominance, consistency, intensity and coherence, which influence the generated priority vectors for final ranking of the given alternatives. The purpose is to calculate the priority vector characterizing the ranking of elements. There exist various methods for calculating the vector of weights, e.g. Saaty's Eigenvector

Method, the Arithmetic Mean Method, Geometric Mean Method, Lest Square Method and others, see Ramík (2017a, 2020).

Comparing to Ramík (2020), and Saaty and Vargas (1984), here, we propose newly reformulated desirable properties – the non-dominance, consistency, intensity, and coherence – of the priority vector and we also propose a method how to generate priority vectors with these desirable properties of the given pairwise comparison matrix.

2. Preliminaries

The reader can find the corresponding basic definitions, concepts and results, e.g. in Ramík (2017a). Here, we summarize some necessary concepts. For detailed information, we refer to Ramík (2020).

Let $\mathcal{G} = (G, \cdot, \leq)$ be a multiplicative alo-group over an open interval, $G =]0; +\infty[$ of the set of real numbers \mathbf{R} . Here, the division operation \div on G is an inverse operation to the multiplicative operation \cdot , for more details see Cavallo and D'Apuzzo (2009), or, Ramík (2020). Let $A = \{a_{ij}\}$ be an $n \times n$ matrix where each element a_{ij} belongs to G .

The matrix $A = \{a_{ij}\}$ is said to be *reciprocal* if the following condition holds for each $i, j \in \{1, \dots, n\} = \mathcal{N}$:

$$a_{ij} \cdot a_{ji} = 1. \quad (1)$$

If $A = \{a_{ij}\}$ is reciprocal, then $A = \{a_{ij}\}$ is called a *pairwise comparison matrix*, *PC matrix*, or, shortly, *PCM*.

Now, we turn to the concept of consistency of PC matrices.

Definition 1. A PC matrix $A = \{a_{ij}\}$ is said to be *consistent* if the following condition holds for each $i, j, k \in \{1, \dots, n\}$:

$$a_{ik} = a_{ij} \cdot a_{jk}. \quad (2)$$

The next proposition gives an equivalent condition for a PC matrix to be consistent, see, e.g. Ramík (2020). The proof of the following proposition is easy, or can be found in Ramík (2020).

Proposition 1. Let $A = \{a_{ij}\}$ be a PC matrix. Then A is consistent if and only if (shortly: iff) there exists a vector $w = (w_1, \dots, w_n)$ with $w_i \in G$, for $i \in \{1, \dots, n\}$, such that for each $i, j \in \mathcal{N}$, it holds:

$$a_{ij} \leq \frac{w_i}{w_j}. \quad (3)$$

The result of the pairwise comparisons method based on the PC matrix $A = \{a_{ij}\}$ is a rating of the set $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$ of the elements, i.e. a mapping that assigns real values to the elements (criteria or alternatives). Formally, it can be introduced as follows.

The *ranking function* for \mathcal{C} (or the *ranking* of \mathcal{C}) is a function $w: \mathcal{C} \rightarrow G$ that assigns to every element from $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$ a value from the linearly ordered set G of the alo-group $\mathcal{G} = (G, \cdot, \leq)$.

Here, $w(c)$ represents the ranking value for $c \in \mathcal{C}$. The function w is usually written in the form of a vector of *weights*, i.e. $w = (w(c_1), w(c_2), \dots, w(c_n))$, or, simply $w = (w_1, w_2, \dots, w_n)$, and it is called the *priority vector*. Also, we say that the priority vector w is associated with the PC matrix A , or that the priority vector w is generated by a priority generating method based on the PC matrix A .

The priority vector $w = (w_1, w_2, \dots, w_n) \in G^n$ is *multiplicatively normalized*, if

$$\prod_{i=1}^n w_i = 1. \quad (4)$$

The priority vector $u = (u_1, u_2, \dots, u_n)$ is *additively normalized*, if

$$\sum_{i=1}^n u_i = 1. \quad (5)$$

Notice that if $w \in G^n$ is multiplicatively normalized then

$$u = \left(\frac{w_1}{\sum_{i=1}^n w_i}, \dots, \frac{w_n}{\sum_{i=1}^n w_i} \right) \quad (6)$$

is additively normalized.

3. Priority vectors of PC matrices and their properties

We start with definitions of various concepts of priority vectors: non-dominant, consistent, intensity, and coherent ones.

Definition 2. Let $A = \{a_{ij}\}$ be a PC matrix on the alo-group $\mathcal{G} = (G, \cdot, \leq)$, let $w = (w_1, w_2, \dots, w_n)$, with $w_j \in G$, be a priority vector.

- (i) We say that the vector w is a *consistent vector* (CsV) of the PC matrix A if the following condition holds:

$$a_{ij} \leq \frac{w_i}{w_j} \quad \text{for all } i, j \in \mathcal{N}. \quad (7)$$

If there exists a consistent vector of the PC matrix A , then A is called a *consistent PC matrix*. Condition (7) is called the *consistent condition* (CsC).

- (ii) We say that the vector w is an *intensity vector* (InV) of the PC matrix A if the following condition holds:

$$a_{ij} > a_{kl} \quad \text{iff} \quad \frac{w_i}{w_j} > \frac{w_k}{w_l} \quad \text{for all } i, j, k, l \in \mathcal{N}. \quad (8)$$

If there exists an intensity vector of the PC matrix A , then A is called an *intensity PC matrix*. Condition (8) is called the *intensity condition* (InC).

- (iii) We say that the vector w is a *coherent vector* (CoV) of the PC matrix A if the following condition holds:

$$a_{ij} > 1 \quad \text{iff} \quad w_i > w_j \quad \text{for all } i, j \in \mathcal{N}. \quad (9)$$

If there exists a coherent vector of the PC matrix A , then A is called a *coherent PC matrix*. Condition (9) is called the *coherent condition* (CoC).

Remark 1. Notice that by the reciprocity property of the elements it is easy to see that w is a CsV of $A = \{a_{ij}\}$ if and only if

$$a_{ij} = \frac{w_i}{w_j} \quad \text{for all } i, j \in \mathcal{N}. \quad (10)$$

As will be shown in the following text of this chapter, some inconsistent pairwise comparisons matrices violate the non-dominant (ND) condition: the ‘best’ alternative is selected from the set of non-dominated alternatives, while this set is nonempty. Inconsistent PCMs that violate this natural condition should be viewed as logically flawed and should not be used for the derivation of weights of alternatives or other objects in MCDM. Other PCMs may violate the coherent condition (CoC), or the intensity condition (InC), in Bana e Costa and Vansnick also called POIP condition, see Bana e Costa and Vansnick (2008). PCMs in these two categories are in fact very frequent (Mazurek and Ramík, 2019), so they might be considered acceptable for derivation of weights of alternatives or criteria in practice. However, a decision maker should be aware of their logical limitations.

Furthermore, a new non-linear optimization problem is proposed for generating a priority vector (weights of alternatives, criteria, or other alternatives). The method is designed to find a priority vector so that all of the aforementioned properties are satisfied, hence providing a more logical solution than the classical eigenvalue (EV), or the geometric mean (GM) methods.

Definition 3. Let $A = \{a_{ij}\}$ be the PC matrix based on the set of alternatives $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$. We say that an alternative c_i *dominates* alternative c_j , and we write $c_i \succcurlyeq c_j$, or, equivalently, that an alternative c_j is *dominated* by alternative c_i , if

$$a_{ij} > 1. \quad (11)$$

If a given alternative is not dominated by any other alternative, then such alternative is called the *non-dominated alternative*. The set of all non-dominated alternatives in \mathcal{C} with respect to matrix A is denoted by $\text{ND}(A)$.

By (11) we obtain

$$\text{ND}(A) = \{c_j \in \mathcal{C} \mid \text{there is no } i \in \mathcal{N} : c_i \succcurlyeq c_j\}. \quad (12)$$

The following proposition gives a sufficient condition for the existence of a non-dominated alternative in \mathcal{C} . This property is well known in the theory of graphs (see e.g. Bollobas (2002)).

Proposition 2. Let $A = \{a_{ij}\}$ be the PC matrix based on the set of alternatives $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$. If there is no cycle of pairs of indexes:

$$(k_1, k_2), (k_2, k_3), \dots, (k_{n-1}, k_n), (k_n, k_1),$$

where $k_i \in \{1, \dots, n\}$, such that $\{k_1, k_2, \dots, k_n\}$ is a permutation of $\{1, \dots, n\}$ with

$$c_{k_i} \succcurlyeq c_{k_{i+1}}, \quad i \in \{1, \dots, n-1\}, \quad \text{and} \quad c_{k_n} \succcurlyeq c_{k_1}, \quad (13)$$

then $\text{ND}(A)$ is non-empty.

Definition 4. Let $A = \{a_{ij}\}$ be the PC matrix based on the set of alternatives $\mathcal{C} = \{c_1, c_2, \dots, c_n\}$. Assume that $\text{ND}(A)$ is non-empty.

Let $w = (w(c_1), \dots, w(c_n))$ be the priority vector (i.e. vector of weights) associated to A . We say that the *non-dominated condition (NDC)* is satisfied with respect to A and w , if the maximal weight of the priority vector is associated with a non-dominated alternative.

Equivalently, we say that w satisfies the NDC with respect to A , if for some $i^* \in \{1, \dots, n\}$:

$$c_{i^*} \in \text{ND}(A) \quad \text{and} \quad w(c_{i^*}) = \max \{w(c_j) \mid j \in \{1, \dots, n\}\}. \quad (14)$$

Alternatively, we say that A satisfies NDC with respect to w .

The following example demonstrates a ‘sufficiently’ consistent PCM where Saaty’s consistency index is less than 0.1, but the NDC and CoC conditions are, however, not met, see Ramík (2017a, 2017b).

Example 1. Consider the set of four alternatives $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$, and the corresponding PC matrix A given as follows:

$$A = \begin{pmatrix} 1 & 1.5 & 2 & 2 \\ 0.67 & 1 & 4 & 4 \\ 0.5 & 0.25 & 1 & 1 \\ 0.5 & 0.25 & 1 & 1 \end{pmatrix},$$

From the first row of PC matrix A , alternative c_1 clearly dominates the other three alternatives. Hence, c_1 is non-dominated. Saaty's consistency index CI and consistency ratio CR are: $CI = 0.052$, $RI = 0.089$, $CR = CI/RI = 0.058$. According to Saaty, see Saaty (1991), for a 4×4 PCM, here, inconsistency is acceptable if $CR < 0.08$ (for an $n \times n$ PCM, $n > 4$: $i < 0.1$). Hence, inconsistency of A is acceptable and the priority vector (additively normalized) is generated by EVM as follows:

$$w_{EV} = (0.350, 0.396, 0.127, 0.127).$$

The weights of all alternatives (the priority vector w additively normalized) derived by GMM are as follows:

$$w_{GM} = (0.344, 0.396, 0.130, 0.130).$$

According to both EVM and GMM, the alternative with the highest weight is alternative c_2 . This alternative is, however, dominated by alternative c_1 , which is the only non-dominated alternative. Therefore, both w_{EV} and also w_{GM} violate NDC with respect to A , even though the consistency ratio $CR = 0.058$ is below Saaty's threshold of 0.08.

Moreover, the Co condition is violated, too, as $a_{12} = \frac{3}{2} > 1$ and $\frac{w_1}{w_2} = \frac{0.344}{0.396} = 0.866 < 1$.

The following proposition says that the CoC is stronger than the NDC, i.e. CoC condition implies NDC. The opposite assertion does not hold as it is demonstrated in Example 1.

Proposition 3. Let $A = \{a_{ij}\}$ be a PC matrix, and let $w = (w_1, \dots, w_n)$ be a PV associated to A . If A satisfies the CoC with respect to w , then A satisfies the NDC with respect to w .

Proof. Assume that c_{i_0} is non-dominated, and w_{j_0} is the maximal weight, $i_0 \neq j_0$. If c_{j_0} is non-dominated, then the proposition holds. On the other hand, if c_{j_0} is dominated, then there is a c_{k_0} which dominates c_{j_0} , so $a_{k_0 j_0} > 1$. By the Co condition we have $w_{k_0} > w_{j_0}$, a contradiction with the assumption that w_{j_0} is a maximal weight. Hence, the ND condition is satisfied. ■

Remark 2. From definition it is clear that the In condition is stronger than the Co condition. In other words, if the In condition is satisfied, then the Co condition is satisfied, too.

Remark 3. Let $A = \{a_{ij}\}$ be a consistent pairwise comparison matrix, and let $w = (w_1, \dots, w_n)$ be a priority vector associated with A satisfying (10). Then it is obvious that ND, Co and In conditions are satisfied. Moreover, for a consistent pairwise comparison matrix, it is clear that the priority vector satisfying (10) can be generated by either EVM or by GMM.

A PC matrix A from Example 1 violates the Co condition with respect to priority vector w generated by the GM method. The following proposition gives a sufficient conditions that any PC matrix satisfies the Co and In conditions with respect to a vector generated by the GM method.

Example 2. Consider the set of four alternatives $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$, and the corresponding PC matrix:

(a) Consider a PC matrix $B = \{b_{ij}\}$ as follows:

$$B = \begin{pmatrix} 1 & 1.33 & 1.5 & 1.5 \\ 0.75 & 1 & 2 & 2 \\ 0.67 & 0.5 & 1 & 1 \\ 0.67 & 0.5 & 1 & 1 \end{pmatrix},$$

and the priority vector (obtained by GM method, additively normalized):

$$w^{(B)} = (0.317, 0.317, 0.183, 0.183). \quad (15)$$

Clearly, $w_1 = 0.317$ is the maximal weight and c_1 is the non-dominated alternative, hence the ND condition is met. Moreover, inconsistency of B is acceptable as $CR = 0.016 < 0.08$.

Here, $b_{12} = \frac{4}{3} > 1$, however, $\frac{w_1}{w_2} = \frac{0.317}{0.317} = 1.000$, therefore the Co condition is not met.

(b) Consider a PC matrix D given as follows:

$$D = \begin{pmatrix} 1 & 1 & 2 & 2 \\ 1 & 1 & 3 & 2 \\ 0.5 & 0.33 & 1 & 2 \\ 0.5 & 0.5 & 0.5 & 1 \end{pmatrix},$$

and the priority vector (obtained by the GM method, multiplicatively normalized):

$$w^{(D)} = (1.414, 1.565, 0.760, 0.595). \quad (16)$$

We obtain that $w_2 = 1.565$ is the maximal weight and c_2 is non-dominated alternative, hence the ND condition is met. Moreover, inconsistency of D is acceptable as $CR = 0.044 < 0.08$.

As it can be easily demonstrated, Co condition is satisfied:

$$\begin{aligned} d_{13} = 2, \quad \frac{w_1}{w_3} = \frac{1.414}{0.760} > 1.000, \quad d_{14} = 2, \quad \frac{w_1}{w_4} = \frac{1.414}{0.595} > 1.000, \\ d_{23} = 3, \quad \frac{w_2}{w_3} = \frac{1.565}{0.760} > 1.000, \quad d_{24} = 2, \quad \frac{w_2}{w_4} = \frac{1.565}{0.595} > 1.000, \\ d_{34} = 2, \quad \frac{w_3}{w_4} = \frac{0.760}{0.595} > 1.000. \end{aligned}$$

On the other hand, the In condition is not met, e.g.:

$$d_{23} = 3 > d_{14} = 2, \quad \text{and} \quad \frac{w_2}{w_3} = \frac{1.565}{0.760} = 2.060 < \frac{w_1}{w_4} = \frac{1.414}{0.595} = 2.378.$$

It is highly desirable that for a given PC matrix, A , possibly inconsistent, we are able to generate a priority vector w such that the ND, Co and In conditions are satisfied. For this purpose we shall formulate a special optimization problem whose solution will generate the desirable priority vector associated with the PC matrix A satisfying all above stated conditions, see also Kułakowski et al. (2019).

4. Deriving priority vectors of PC matrices with the desirable properties

In this section, we propose a method for calculating the priority vector of an $n \times n$ PC matrix $A = \{a_{ij}\}$ satisfying the desired properties (i.e. non-dominancy, consistency, intensity, and/or coherence).

4.1. (Problem 0)

It was shown in Section 3, Example 1, that the calculation of a priority vector by the EV or GM methods from an inconsistent pairwise comparison matrix may result in violating the desirable conditions NDC, CoC, or InC. Therefore, an alternative approach to the derivation of a priority vector for PCMs may be formulated in terms of satisfying the ND, Co and In conditions.

Let $A = \{a_{ij}\}$ be a PC matrix. Based on this PCM, we need the following two sets of indexes:

$$I^{(2)}(A) = \{(i, j) \mid i, j \in \{1, \dots, n\}, a_{ij} > 1\}, \quad (17)$$

$$I^{(4)}(A) = \{(i, j, k, l) \mid i, j, k, l \in \{1, \dots, n\}, a_{ij} > 1, a_{kl} > 1, a_{ij} > a_{kl}\}. \quad (18)$$

Let

$$\delta: (x, y) \in \mathbf{R}_+ \times \mathbf{R}_+ \rightarrow \delta(x, y) \in \mathbf{R}_+$$

be a *distance function*, i.e. a function with the following well known properties for all $x, y, z \in \mathbf{R}_+$:

- $\delta(x, y) \geq 0$,
- $\delta(x, y) = 0$ iff $x = y$,
- $\delta(x, y) = \delta(y, x)$,
- $\delta(x, z) \leq \delta(x, y) + \delta(y, z)$.

Let $w = (w_1, \dots, w_n)$ be a priority vector associated with A . An $n \times n$ matrix of distances, $\Delta(A, w)$, is defined as:

$$\Delta(A, w) = \{\Delta_{ij}\} = \left\{ \delta \left(a_{ij}, \frac{w_i}{w_j} \right) \right\},$$

and a *matrix aggregation function*, Φ :

$$\Phi: X \in \mathbf{R}_+^n \times \mathbf{R}_+^n \rightarrow \Phi(X) \in \mathbf{R}_+,$$

as an idempotent and increasing function (in each variable), where $X = \{x_{ij}\}$ is an $n \times n$ PC matrix.

An *error function*, \mathcal{E}_A , of $w = (w_1, \dots, w_n)$ is defined as follows:

$$\mathcal{E}_A: w \in \mathbf{R}_+^n \rightarrow \mathcal{E}_A(w) \in \mathbf{R}_+,$$

$$\mathcal{E}_A(w) = \Phi(\Delta(A, w)). \quad (19)$$

The problem of finding a priority vector satisfying the ND, Co and In conditions can be formulated in terms of the following optimization problem, where $A = \{a_{ij}\}$ is a given PC matrix and $w = (w_1, \dots, w_n)$ is an unknown priority vector with variables $w_1, \dots, w_n \in G$:

(Problem 0)

$$\mathcal{E}_A(w) \rightarrow \min; \quad (20)$$

subject to

$$\prod_{r=1}^n w_r = 1, \quad w_r > 0 \quad \forall r, \quad (21)$$

$$w_r > w_s \quad \forall (r, s) \in I^{(2)}(A), \quad (22)$$

$$\frac{w_r}{w_s} > \frac{w_t}{w_u} \quad \forall (r, s, t, u) \in I^{(4)}(A). \quad (23)$$

The objective function in (20) minimizes the distance between the elements of PC matrix A and corresponding elements of the PCM $W = \left\{ \frac{w_i}{w_j} \right\}$, measured by distance function δ . By constraint (21), the weights are positive and (multiplicatively) normalized. By (22), the Co condition is secured and by (23) the In condition is satisfied.

4.2. Transformation to (Problem ϵ)

Unfortunately, (Problem 0) is not in the form of a standard optimization problem that is appropriate for solving by existing numerical methods. Here, variables w_i are required to be strictly

positive and some inequality constraints, (22), (23), are strict, hence the set of feasible solution is not closed. That is why we transform the problem into a more convenient form. Given a sufficiently small $\varepsilon > 0$.

(Problem ε)

$$\mathcal{E}_A(w) \rightarrow \min; \quad (24)$$

subject to

$$\sum_{r=1}^n w_r = 1, \quad w_r \geq \varepsilon \quad \forall r, \quad (25)$$

$$w_r - w_s \geq \varepsilon \quad \forall (r, s) \in I^{(2)}(A), \quad (26)$$

$$\frac{w_r}{w_s} - \frac{w_t}{w_u} > \varepsilon \quad \forall (r, s, t, u) \in I^{(4)}(A). \quad (27)$$

In (Problem ε), nonlinear constraint (21) (with the product normalization) is substituted by a linear constraint (25) (with the additive normalization). Such a transformation is possible as the multiplicative and additive normalization formulae of priority vectors are equivalent (see formula (6)).

Notice that here, strict inequalities have been changed to the non-strict ones by adding a sufficiently small constant $\varepsilon > 0$.

The following proposition says that both problems, i.e. (Problem 0) and (Problem ε), are in some sense equivalent. The proof of the next proposition is evident.

Proposition 4. *(Problem 0) has a feasible solution $w \in G^n$ if and only if there exists $\varepsilon > 0$ such that w is a feasible solution of (Problem ε).*

Moreover, if (Problem 0) has an optimal solution w^ then there exists $\varepsilon > 0$ such that w^* is an optimal solution of (Problem ε).*

Here, by (Problem ε) we denote the following three optimization problems depending on the particular formulation of the objective function (24) as well as constraints (25)–(27), i.e. nested sets of feasible solutions. Some examples are presented below. We shall consider the following optimization problem variants:

- (I) Minimize the objective function (24), subject to (25). The optimal solution is denoted by $w^{(I)}$. The ND, Co and In conditions are not necessarily satisfied.
- (II) Minimize the objective function (24) subject to constraints (25), (26). The optimal solution is denoted by $w^{(II)}$. The Co condition is satisfied; then by Proposition 4 the ND condition is also satisfied. The In condition is not necessarily satisfied.
- (III) Minimize the objective function (24) subject to constraints (25), (26), and (27). The optimal solution is denoted by $w^{(III)}$. Here, the ND, Co and In conditions should be satisfied.

4.3. Solving (Problem ε)

Notice that the set of feasible solutions of (Problem ε), (24)–(27), could be empty, e.g. for problems (II), and/or (III), see below. Even for a nonempty set of feasible solutions of (Problem 0), the optimal solution of the corresponding optimization problems (I), (II), or (III) need not exist, as the set of feasible solutions is not secured to be closed and/or bounded and the objective function need not be convex.

On the other hand, if the optimal solution $w^* = (w_1^*, \dots, w_n^*)$ of some problems of (I)–(III) of (Problem ε) exists, the ND, Co, and In conditions hold by the nested properties of the feasible solution sets. Then, $w^* = (w_1^*, \dots, w_n^*)$ is an appropriate priority vector associated with A satisfying the required properties.

Proposition 5. Let $A = \{a_{ij}\}$ be a consistent pairwise comparison matrix. Then there is a unique optimal solution $w^* = (w_1^*, \dots, w_n^*)$ of (Problem 0) satisfying:

$$a_{ij} = \frac{w_i^*}{w_j^*} \quad \text{for all } i, j \in \mathcal{N} \quad (28)$$

such that the ND, Co, and In conditions are met.

Proof. By Proposition 1 there exists a unique priority vector with positive components $w^* = (w_1^*, \dots, w_n^*)$, such that

$$a_{ij} = \frac{w_i^*}{w_j^*} \quad \forall i, j \in \mathcal{N}. \quad (29)$$

Then by property (ii) of the distance function δ , it follows that $\delta(A, w^*) = \mathbf{0}$, i.e. $\delta(A, w^*)$ is a zero $n \times n$ matrix. As the matrix aggregation function Φ is idempotent, it holds that $\Phi(\mathbf{0}) = \mathbf{0}$, which is the minimal value of (24). Hence, $w^* = (w_1^*, \dots, w_n^*)$ is an optimal solution of (Problem 0). By (28) we have that the ND, Co, and In conditions are met. ■

Now, we present some examples of simple distance functions $\delta(x, y)$ and the matrix aggregation function $\Phi(X)$.

Examples of distance functions $\delta(x, y)$: Let $x, y \in \mathbf{R}_+$.

- i. $\delta(x, y) = |x - y|$,
- ii. $\delta(x, y) = (x - y)^2$,
- iii. $\delta(x, y) = (\ln(x) - \ln(y))^2$,
- iv. $\delta(x, y) = \max\{\frac{x}{y}, \frac{y}{x}\}$.

Examples of aggregation functions $\Phi(X)$: Let $X = \{x_{ij}\}$ be a $n \times n$ matrix, $x_{ij} \in \mathbf{R}_+$.

- a. $\Phi(X) = \frac{1}{n^2} \sum_{i,j=1}^n x_{ij}$,
- b. $\Phi(X) = \max\{x_{ij} \mid i, j \in \mathcal{N}\}$.

Then the objective function in (Problem 0) and (Problem ε) is defined as:

$$\mathcal{E}_A(w) = \Phi\left(\left\{\delta\left(a_{ij}, \frac{w_i}{w_j}\right)\right\}\right). \quad (30)$$

In the sequel, we shall deal with the following particular items of the above examples: iv. and b. of distance function δ and aggregation function Φ , respectively, i.e.

$$\delta(x, y) = \max\left\{\frac{x}{y}, \frac{y}{x}\right\}, \quad \text{and} \quad \Phi(X) = \max\{x_{ij} \mid i, j \in \mathcal{N}\}. \quad (31)$$

Then we obtain the following objective function

$$\mathcal{E}_A(w) = \max\left\{\max\left\{\frac{a_{ij}w_j}{w_i}, \frac{w_i}{a_{ij}w_j}\right\} \mid i, j \in \mathcal{N}\right\}. \quad (32)$$

For other combinations of functions δ and Φ our approach presented below needs some modifications. When solving a particular optimization problem, (Problem ε), (24)–(27) with the objective function (32), we can encounter numerical difficulties, as this optimization problem is non-linear and also non-convex. Non-convexity is found in objective function (32) and also in constraints (27). Fortunately, these obstacles can be avoided by a proper approach – transformation of the non-convex problem to a convex one, which enables using standard numerical methods for solving NLP problems. Then, for variants (I)

and (II) of (Problem ε), we obtain an optimization problem solvable e.g. by efficient interior point methods (see e.g. Boyd and Vandenberghe (2004)). For solving variant (III) with non-convex constraints (27), we can apply e.g. an interior or exterior penalty method by penalizing this constraint and moving it into the objective function (see e.g. Boyd and Vandenberghe (2004)).

First, we analyze the objective function (32). Here, setting

$$f_{ij}(w) = \frac{a_{ij}w_i}{w_j}, \quad i, j \in \mathcal{N}, \quad (33)$$

where $w = (w_1, \dots, w_n)$, we obtain a simplified form of the linear fractional function on \mathbf{R}_+^n , which is a quotient of two linear functions. Function (33) is not convex, it is, however, quasiconvex. More precisely, it is strictly quasiconvex on \mathbf{R}_+^n , the positive orthant of \mathbf{R}^n .

Recall that a function $f_{ij}: \mathbf{R}_+^n \rightarrow \mathbf{R}$, is *strictly quasiconvex on \mathbf{R}_+^n* if

$$f_{ij}(\lambda x + (1 - \lambda)y) < \max\{f_{ij}(x), f_{ij}(y)\}$$

holds for all $\lambda \in]0; 1[$ and all $x, y \in \mathbf{R}_+^n$. Moreover, function $f_{ij}: \mathbf{R}_+^n \rightarrow \mathbf{R}$, is *strictly quasiconcave on \mathbf{R}_+^n* if $(-f_{ij})$ is strictly quasi-convex on \mathbf{R}_+^n . At the same time function (32) is strictly quasiconcave on \mathbf{R}_+^n . Hence, the reciprocal function

$$\frac{1}{f_{ij}(w)} = \frac{w_j}{a_{ij}w_i}$$

is strictly quasiconvex on \mathbf{R}_+^n . The pointwise maximum of two strictly quasiconvex functions on \mathbf{R}_+^n is again strictly quasiconvex on \mathbf{R}_+^n ,

$$g_{ij}(w) = \max\left\{\frac{a_{ij}w_i}{w_j}, \frac{w_j}{a_{ij}w_i}\right\}$$

is strictly quasiconvex on \mathbf{R}_+^n . Moreover, the pointwise maximum over all functions g_{ij} , $i, j \in \mathcal{N}$, is strictly quasiconvex on \mathbf{R}_+^n , and

$$\varepsilon_A(w) = \max\left\{\max\left\{\frac{a_{ij}w_j}{w_i}, \frac{w_i}{a_{ij}w_j}\right\} \mid i, j \in \mathcal{N}\right\}.$$

is strictly quasiconvex on \mathbf{R}_+^n .

It is a well-known fact saying that strictly quasiconvex functions are unimodal, i.e. each local minimum of a strictly quasiconvex function is a global minimum (see e.g. Boyd and Vandenberghe (2004)). Summarizing the above stated results, we obtain that the objective function (31) is unimodal. Taking into account the fact that constraints (24), (26) in (Problem ε), i.e. variant (II), define a convex set, we conclude that the set of all optimal solutions of (Problem ε), variant (II), is convex and each local optimal solution is global. Consequently, by solving (Problem ε), variant (II), e.g., by some interior point method (see Boyd and Vandenberghe (2004)), we arrive at the global optimal solution.

Alternatively, variant (II) of (Problem ε) can be solved by a sequence of linear problems as follows (so called the epigraph method):

Instead of minimizing objective (31) subject to constraints (25), (26), we set $t = \frac{a_{ij}w_i}{w_j}$ and solve the following system of linear constraints in each iteration

$$\begin{aligned} a_{ij}w_i - w_j t &\leq 0, & \text{for all } i, j \in \mathcal{N}, \\ w_j - a_{ij}w_i t &\leq 0, & \text{for all } i, j \in \mathcal{N}, \end{aligned} \quad (34)$$

$$\sum_{k=1}^n w_k = 1, \quad w_r \geq \varepsilon \quad \text{for all } r \in \mathcal{N},$$

$$w_r - w_s \geq \varepsilon \quad \text{for all } (r, s) \in I^{(2)}(A),$$

then adapting t in each step by the well known bi-section optimization method, Boyd and Vandenberghe (2004). The solutions of system (34) generate a sequence that converges to the optimal solution of variant (II) of (Problem ε).

Constraints (27) in (Problem ε), however, need a special treatment. The set of vectors $w = (w_1, \dots, w_n)$ fulfilling constraints (27) is neither convex nor starshaped (see Ramík and Vlach (2001)), and therefore, the usual interior point methods for solving the optimization problem (31), (25)–(27) could be inefficient, or, fail. That is why we propose for solving (Problem ε), variant (III), the popular penalty methods, see e.g. Boyd and Vandenberghe (2004). The main idea of penalty methods is to penalize difficult constraints of the problem and move them to the objective function. Then the remaining constraints of (Problem ε) are fairly tractable. They are linear, so the problem can be solved more easily by e.g. interior point methods, for example. The form of the constraints (27) is suitable for the application of the interior penalty methods (or, barrier methods), as it satisfies some appropriate assumptions: an interior point of the constraint set can be easily found, the values of the constraint functions are unlimited when approaching from inside to the border of \mathbf{R}_+^n , etc.

4.4. Illustrative Example

In this section we present an illustrative example of the 4×4 PC matrix from Example 1. All results have been obtained by Excel – Solver, see also Perzina and Ramík (2015).

Example 3. Consider the set of four alternatives $n = 4$, $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$, and the corresponding PC matrix A from Example 1 given as follows:

$$A = \begin{pmatrix} 1 & 1.5 & 2 & 2 \\ 0.67 & 1 & 4 & 4 \\ 0.5 & 0.25 & 1 & 1 \\ 0.5 & 0.25 & 1 & 1 \end{pmatrix},$$

From the first row of PC matrix A , the alternative c_1 clearly dominates the other three alternatives, hence, c_1 is non-dominated. Saaty's consistency index CI and consistency ratio CR are: CI = 0.052, RI = 0.089, CR = CI/RI = 0.058. Hence, by Saaty, inconsistency is acceptable and the priority vector generated by the EVM (additively normalized) is as follows: $w_{\text{EV}} = (0.350, 0.396, 0.127, 0.127)$. This priority vector corresponds to the ranking of the four alternatives $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$ as follows:

$$c_2 \succ c_1 \succ c_3 \simeq c_4.$$

The priority vector generated by the GMM is $w_{\text{GM}} = (0.343, 0.396, 0.130, 0.130)$. This priority vector corresponds to the same ranking of alternatives $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$ as follows:

$$c_2 \succ c_1 \succ c_3 \simeq c_4.$$

Set $\varepsilon = 0.0001$. We solve (Problem ε) as follows:

We consider the following items of the above examples: iv. and b. of metric function δ and aggregation function Φ , respectively,

$$\delta(x, y) = \max\left\{\frac{x}{y}, \frac{y}{x}\right\}, \quad \text{and} \quad \Phi(X) = \max\{x_{ij} \mid i, j \in \{1, 2, 3, 4\}\}.$$

We obtain

$$\mathcal{E}_A(w) = \max \left\{ \max \left\{ \frac{a_{ij}w_j}{w_i}, \frac{w_i}{a_{ij}w_j} \right\} \mid i, j \in \{1, 2, 3, 4\} \right\}.$$

In variant (I) of (Problem ε), we shall minimize objective function (24) subject to constraint (25). Then, solving (Problem ε), we obtain the optimal solution

$$w^{(Ib)} = (0.378, 0.361, 0.131, 0.131)$$

with the corresponding minimal error function: $\mathcal{E}_A(w^{(Ib)}) = 1.448$. This priority vector corresponds to the ranking of our alternatives $\mathcal{C} = \{c_1, c_2, c_3, c_4\}$ as follows:

$$c_1 \succ c_2 \succ c_3 \simeq c_4.$$

Here, the Co and ND conditions are satisfied, as can be immediately verified. We obtain $a_{12} = \frac{3}{2} > 1$, and, $\frac{w_1}{w_2} = \frac{0.378}{0.361} > 1.000$. Similarly, $a_{13} = a_{14} = 2 > 1$, and, $\frac{w_1}{w_3} = \frac{w_1}{w_4} = \frac{0.378}{0.131} > 1.000$, and, $a_{23} = a_{24} = 4 > 1$, and, $\frac{w_2}{w_3} = \frac{w_2}{w_4} = \frac{0.361}{0.131} > 1.000$. Therefore, the Co condition is met. Moreover, the In condition is not satisfied, e.g.

$$a_{23} = 4 > a_{13} = 2, \quad \text{and} \quad \frac{w_2}{w_3} = \frac{0.361}{0.131} < \frac{w_1}{w_3} = \frac{0.378}{0.131}.$$

In variant (II) the objective function (24) is minimized subject to constraints (25), (26). Evidently, here, we obtain the same optimal solution as in variant (I), i.e.

$$w^{(IIb)} = (0.378, 0.361, 0.131, 0.131).$$

By the same arguments as in variant (I), the Co and ND conditions are satisfied.

In variant (III) the objective function (24) is minimized subject to constraints (25), (26), (27). The Co and In conditions should be satisfied simultaneously, as well as the ND condition. By solving (Problem ε), we obtain that the set of feasible solutions (25)–(27) is empty. On the other hand, by omitting constraints (26), i.e. the Co condition, we obtain the following optimal solution:

$$w^{(IIIb)} = (0.378, 0.361, 0.131, 0.131) = w^{(Ib)}.$$

Here, the Co is not met.

5. Conclusion

In this paper we investigated some important and natural properties of PCMs called the desirable properties, particularly, the non-dominance, consistency, intensity and coherence, which influence the generated priority vectors for final ranking of the given alternatives. The purpose is to calculate the priority vector characterizing the ranking of elements for non-consistent pairwise comparisons matrices. There exist various methods for calculating the vector of weights, e.g. Saaty's Eigenvector Method, the Arithmetic Mean Method, Geometric Mean Method, Least Square Method and others. We proposed newly reformulated desirable properties – the non-dominance, consistency, intensity, and coherence – of the priority vector, investigated their properties and we also proposed a new method based on an optimization problem how to generate priority vectors with these desirable properties of the given pairwise comparison matrix.

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CREATIVITY AS A BLUEPRINT IN DECISION-MAKING PROCESS

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Abstract

Decision-making is defined as the process of generating and evaluating alternatives for decision problem solving in order to select the one with the highest utility. There are plenty of methods how manager can create and evaluate alternatives. However, the question remains which parameters can influence the phase of variant generation. It's the creativity of decision-maker that may be the answer. Creativity becomes popular among decision making studies these days. Creativity is connected with divergent thinking style, just like some decision-making styles. Therefore, the aim of our research study was to examine the specific relation between creativity and decision-making style among young people. The way, the decision-maker gain data, evaluate them and use it in decision making process was measure through MBTI (Myers-Briggs Typ Indicator). The aim of the research paper is to find out whether the creativity level is typical for a certain decision-making style of managers and to verify the assumption that higher creativity score is typical for sensing and thinking decision-making styles. Creativity of each respondent was measured by the Divergent Association Task, which is based on the premise that creative people are able to generate more divergent ideas. The research sample consisted of 163 native Slovak young people (N= 163; 85 females and 78 males), of which 90 were non-working students (mean age=22.00 years) and 73 working students (mean age=22.6 years).

Keywords: creativity, creativity in decision making, decision making styles

JEL codes: D91, M1, M10

1. Introduction - Decision Making Style and Creativity

Decision-making is the key competence of leaders, the outcome of which is primarily influenced by the personality of the leader defined through his or her decision-making style (West et al.,1992). Decision-making style is the result of the cognitive process, leading to the selection of solutions from several alternatives, based on the decision-maker's way of thinking (Wang and Ruhe, 2007; Shapiro and Bonham, 1973; Wang and Chiew, 2010). The style of decision-making is based on the theory of cognitive styles.

Decision styles can be identified by standardized tests. The most commonly used are "Decision making style inventory" (DMSI) (Loor, 2000), "Myaers - Bricks type indicator" (MBTI) (Myers, 1962) or "Cognitive style inventory" (CSI) (Martin, 1998). All three tests assess the style of decision-making from two point of view - the way of obtaining information and processing and the way of using the information in the decision-making process. DMSI testing provides four decision styles: systematic-internal, systematic-external, spontaneous-internal, spontaneous-external. Testing with MBTI provides four decision styles: sensing, thinking, feeling, intuiting. CSI testing provides two decision styles: systematic and intuitive.

Already in the 1990s, authors emphasised the key role of creativity in decision making process (Simon, 1987; Torrance, 1987; Dasgupta, 2003) because creativity focus on idea generation (Kijkuit and Van Den Ende, 2007). Likewise, the creation of alternatives is one of the decision maker's major activity (Pennington and Hastie, 1988) while performing the design process (Barfield et al., 1993), especially by framing the decision-making problem (Pham et al., 2023). The creativity in decision making leads to the identification of novel solutions to decision-making problems (Forgionne and Newman, 2007; Riordan and O'Reilly, 2011; Keeney, 1994).

Then arise the question what does creative decision-making look like? Many authors have defined creativity as a process (Torrance, 1993; Dasgupta, 2004; Hsiao and Chou, 2004) based on the concept of theory of creativity.

Already Herbert Simon outlined the idea of creativity in relation to analytical and intuitive decisions (Simon, 1987). The link between creativity and the manner in which managers gain information and make decisions is further developed by the authors. In their study, they looked at whether a particular decision-making style is characterized by a higher level of creativity (Lather et al., 2017).

According to Palmiero et al. (2020) creativity refers to the divergent thinking, which is associated with different cognitive processes, including intuitive and rational thinking styles. Basing on these findings, this study explored the extent to which divergent thinking is related to decision-making styles.

2. Data and Methodology

The aim of the research study is to find out whether the creativity level is typical for a certain decision-making style of managers and to verify the assumption that higher creativity score is typical for sensing and thinking decision-making styles.

In the present research, the decision-making style of managers was determined and related to the creativity level. The way the decision maker collects, evaluates, and uses data in the decision-making process was measured using the MBTI (Myers-Briggs Type Indicator). The creativity of each respondent was assessed using the Divergent Association Task (Olson et al., 2021), which assumes that creative people are able to generate more divergent ideas.

Data on decision-making styles were collected using the MB - type indicator, which considers two dichotomies: Sensing/Intuiting and Thinking/Feeling.

The research sample consisted of 163 Slovak adolescents (N= 163; 85 females and 78 males), of whom 90 were non-working students (mean age=22.00 years) and 73 were working students (mean age=22.6 years). The researchers ensured the objectivity of the measurement by using data collection instruments in electronic form to avoid influencing the research subject. Participants were given written instructions by a researcher.

The data obtained through the Divergent Association Task represent interval variables. The data obtained from MB – type indicator denote nominal variables, presented as decision-making styles. Two-dimensional inductive statistics methods were used to test the dependence of the variables. The parametric One-way ANOVA was used to identify and define the range in differences between decision-making style scores of managers within groups of nominal variables. Then the effect size r was calculated as a square root of the percent variance between groups (SSM) and total variance (SST). The assumption of homogeneity of variance and sphericity assumption was measured through Levene's test.

The assumption of homogeneity of variance and sphericity assumption was measured through Levene's test. The data were analysed in dataTab statistical software. Hypotheses were tested at a significance level of $p \leq 0.05$; while maintaining the primary rule of the Chi-Square Test of Independence, where the theoretical frequencies did not fall below a value of 5 in 80%, and for other values $X > 1$ applied. Null and alternative hypotheses were tested, which we present in individual results.

3. Results

Creativity becomes popular among decision-making studies these days. Therefore, it is interesting to ascertain what role plays the creativity of decision-maker in the process of creating alternatives of particular decision-making problem.

Table 1: Descriptive statistics for creativity level

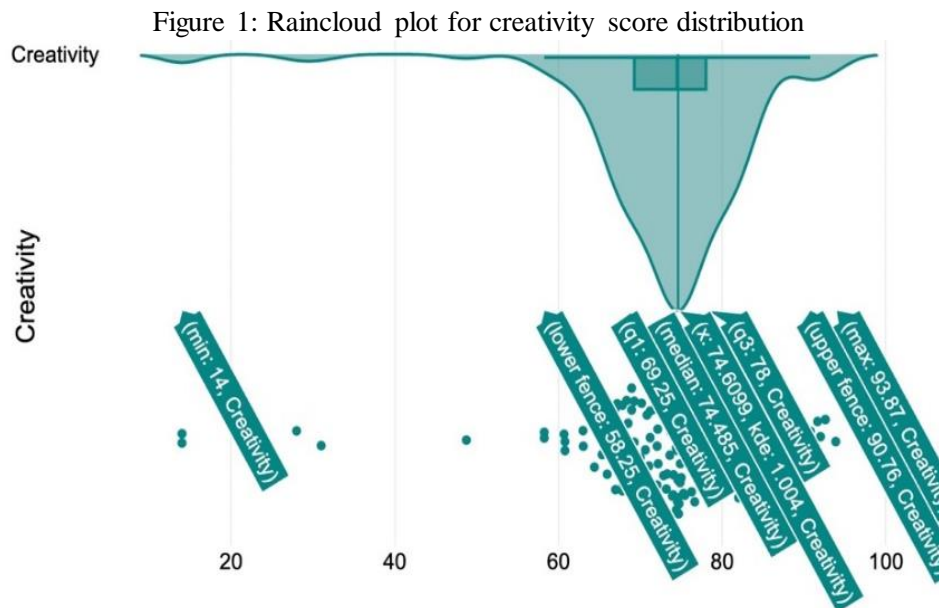
	N	Mean	Median	Std. Dev.	Skew	Kurtosis	Min	Max
Creativity	163	73.18	74.49	10.82	-2.74	12.7	14	93.87

Source: own processing

As shown in the Table 1 the mean value of the creativity of a young man is (M=73.18) what represent the lower value than the mean value of the population. Based on the results of descriptive

statistics on creativity, we can say that respondents are less creative than we expected (Median = 74.49; Mean of the population=78). The smallest score in creativity test was reached at the level of (Min = 14) and the highest score on the level of Max = 93.87 points.

In the raincloud plot are depicted basic statistical indicators, which are fencing the lower (LF = 58.25) and the upper fences (UF = 90.76) of the creativity score levels.



Source: own processing

Since the studies cited above (Lather et al., 2017; Palmiero et al., 2020; Simon, 1987; Wheatley et al., 1991) associate higher creativity level of a decision-maker and its influence on decision making process, we investigated whether a statistically significant difference arises in the creativity level of a decision-maker according to his/her decision-making style. To verify this, we applied the parametric one-way ANOVA, which told us how significant the difference between four decision making styles in the parameter Creativity is.

We have tested the following hypotheses: (1) H0: There is not statistically significant difference in creativity score among four decision- making styles. (2) H1: Higher creativity score is typical for sensing and thinking decision- making styles.

The data were analysed in dataTab statistical software. Hypotheses were tested at a significance level of $p \leq 0.05$. The null and alternative hypotheses were tested, which we present in individual results. The assumption of homogeneity of variance and sphericity assumption was measured through Levene's test. Based on the results of the Levene's test at a significance level of p-value > 0.05 presented in the table 2, we can interpret the results of the ANOVA.

Table 2: Levene's test of variance equality

F	df1	df2	p
0.13	3	158	.943

Source: own processing

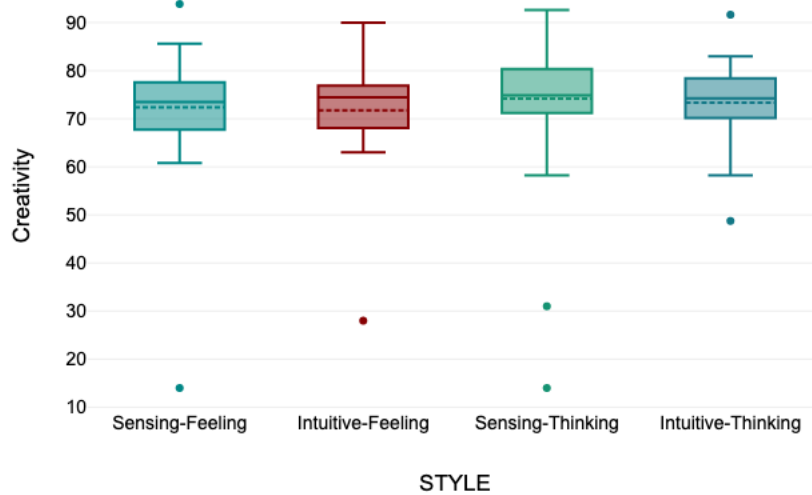
As we can see in the table 3, the highest score in creativity reached the sensing-thinking decision-making style (M = 74.15).

Table 3: Descriptive statistics for decision-making style

	N	Mean	Std. Deviation
Sensing-Feeling	54	72.36	10.42
Intuitive-Feeling	19	71.75	12.45
Sensing-Thinking	69	74.15	11.14
Intuitive-Thinking	20	73.38	9.5
Total	162	73.18	10.82

Source: own processing

Figure 2: Box plot for creativity score by decision-making styles



Source: own processing

In the table 4 are stated results of ANOVA. The one-factor analysis of variance has shown that there is no significant difference between the categorical variable decision-making style and the variable Creativity ($F = 0.4$, $p = 0.756$). Thus, with the available data, the null hypothesis is not rejected.

Table 4: ANOVA results

	Sum of Squares	df	Mean Squares	F	p	Critical F-Value
Between Groups	140.64	3	46.88	0.4	.756	2.66
Within Groups	18,697.46	158	118.34			
Total	18,838.1	161				

Source: own processing

According to authors' findings (Palmiero et al., 2020), rationality plays key role during the creative process. Our result shows that, young people with Sensing-Thinking decision-making style scoring high on creativity. However, this hypothesis was not statistically confirmed.

The research results provided by Lather et al. (2017) show that highly creative associates in all the sectors at all the managerial levels (except senior level managers in automobile sector) have scored higher on Impulsive decision-making style, this means that the managers act on physiological clues, instincts, and impulses. They don't take decisions with a lot of thinking and deliberations.

4. Conclusion

In our research sample, the mean value of the creativity of a young man is ($M=73.18$) what represent the lower value than the mean value of the population. Based on the results of descriptive statistics on creativity, we can say that respondents are less creative than we expected (Median = 74.49; Mean of the population=78). The smallest score in creativity test was reached at the level of (Min = 14) and the highest score on the level of Max = 93.87 points.

According to Palmiero et al. (2020) creativity refers to the divergent thinking, which is associated with different cognitive processes, including intuitive and rational thinking styles. Our result shows that, young people with Sensing-Thinking decision-making style scoring high on creativity. However, this hypothesis was not statistically confirmed.

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THE CHIEF DATA OFFICER: THE UNKNOWN BEING FOR SMALL AND MEDIUM SIZED ENTERPRISES?

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Abstract

The digital transformation has reached small and medium enterprises (SME). One of the main tasks in this process of transformation will definitely be the development of a data strategy concerning the data value creation. Making decisions faster and better, optimizing processes and developing customer-centric offerings or even innovative business plans can only be achieved by using data wisely and specifically. This is exactly what SME struggle with as they are missing out on these issues in top management due to their individual standards and this is also the study's starting point: In order to establish this data strategy, a Chief Data Officer (CDO), being responsible, is needed. The study's main goal is to analyze, if this aspiring C-Level function could play a main role by detecting the value of data and therefore using data as an asset with a Data Governance approach. A content analysis concerning science and practice focused on SME is used as a fundament. The results show reasons for the establishment of CDO, the identification of their tasks, responsibilities and skill, reporting lines within company structures and critical success factors as well as the added value of this position for a SMC's decision and management structure. At the moment, the research of this approach is absolutely unique and the emerging role of CDO in corporate environments serves as a clear sign of manifestation in the field of Data Governance.

Keywords: Chief Data Officer, Data Governance, SME, Content Analysis
JEL codes: M10, M15

1. Introduction

Small and medium enterprise (SME) have been acknowledged as a research object since 1980 (Lindner, 2019, p. 1). The development of this unique type of company with its special characteristic like a strong niche expertise, sustainable company strategy, lower budgets and less process landscape opposed to big companies is being in focus (Lindner, 2019, p.7). Decision making is influenced by a strong intertwining of formal and informal organization (Nicolescu, 2009). At the moment, SMC faces challenges (Hess et al., 2016; Verhoef et al., 2021) like *globalization* (a world without economic borders; Fernando, 2022; Robertson and White, 2007) as well as *digitalization* (the process of restructuring many parts of social life concerning digital communication and media infrastructure; Brennen and Kreiss, 2016; Gartner, 2022), leading to major changes. Even the COVID-19 pandemic forced SMC all over the world to digitalize business processes (Van Looy, 2021). Therefore, business activities leave “digital footprints on global digital paths” which are represented by data as a digital equivalent to nearly every (real) physic object (Gluchowski, 2020). Adding to business activities, entrepreneurial decision-making becomes more and more data-driven (Redman, 2008). In order to use data as a company asset and important strategic resource in digital competition, SME need to create prerequisites to manage data in terms of quality, money, time just like other assets. Organizational concepts to make data a company asset, e.g. Data Governance (DG), an approach that sets internal rules and standards for the collection, storage, processing and deletion of data (Newman and Logan, 2006; Khatri and Brown, 2010; Otto et al., 2007), as well as data-related (strategic, tactical and operative) roles and responsibilities (Weber and Klingenberg, 2021) become increasingly important (Jagels et al., 2021). This challenge has already reached the top management. Many companies appoint a data controller, the Chief Data Officer (CDO), next to already installed positions on the C-level like the Chief Executive Officer (CEO) or the Chief

Information Security Officer (CISO). Analysts from Gartner guess that 90% of all big companies will have a CDO by 2020, even though only 50% will be successful (Bennet, 2016). Possible reasons might be an insufficient understanding of the CDO's role in terms of tasks, organizational classification, reporting relations and unrealistic expectations of the company. Our research wants to find out if the CDO gets increasing awareness in publications related to SME and if this position might be an adequate organizational approach for SME in order to advance data value creation. On the other hand, we want to provide support for decision-makers in SME by creating and aligning the position of the CDO in their corporate environment.

This article is lined up as follows: section 1 introduces the topic, section 2 describes the material and methods used, section 3 presents and discusses the results in consideration of research questions and derives recommendations for action. The article ends with section 5, containing a conclusion and possible limits.

2. Materials and Methods

To get a better comprehension of the situation and in order to identify the implication and meaning of the CDO'S role, we first filtered the Scopus-platform for articles related to the research question (step 1). Afterwards we used the snowball method (also known as chain reference method) in order to include references of the filtered articles (step 2). Finally, we searched for publications from the last decade made by analysts and software providers using voice processing (step 3). Our procedure lead to 38 hits. We thereby used the keyword "chief" together with "data" and "officer". The abbreviation "CDO" was not taken into account as it is also known for other terms (e.g. "Chief Data Officer" or "Collateralized Debt Obligation" in the banking sector or "Contract Diagnostic Organization" in the health sector). With the identified works and studies, we were able to get an idea of the CDO's role in corporate environment and as well as growth drivers. We have determined (1) sector and size of companies, (2) reasons for the establishment of a CDO, (3) the tasks and responsibilities, (4) the resulting qualification for a CDO, as well as (5) the reporting lines and (6) critical success factors. The question arises of (7) the impact and the added value of this position for SME in their management and decision-making structure.

3. Statements

Based on the method used for the content analysis of the identified publications, we classify the individual results in seven levels. With reference to the year of publication, the 38 articles show a declining trend with a peak in 2017.

3.1 Sector and company size

In the sector of *banks and finances, services and commerce* and *IT*, it is most likely to find companies employing a CDO (e.g. Zhan et al., 2020; Nie et al., 2018; Earley, 2017a; Earley, 2017b; Insights, 2021; Jansz et al., 2017; strategy&, 2021, p. 6; Mathew and Zimmerman, 2012), showing a clear expression of an advanced digital transformation process in these industries. But also the *public sector* (Aitken, 2015; Lee et al., 2012), the *sector of higher education* (Crabtree and Wright, 2021) and the *building industry* (Ignatova, 2021), feature an increasing amount of CDOs.

The studies contain scattered references on company sizes by annual sales or headcount (Noh, 2016, p. 1663; Olbrich et. al., 2015, p. 22; strategy&, 2021, p. 5), which are often (way) above the target value for SMEs, meaning companies with less than 249 employees and a turnover of up to 50 Million Euro (Lindner, 2019, p. 5; EU2020, 2020).

In this respect, the articles found show a research gap for the SME type of company. However, the previous research states that the size of the company has a significant influence on the establishment of the role itself and the concrete appointment of the CDO. (Zhang et al., 2017, p. 4 f.).

3.2 Reasons for appointing a CDO

Technological innovations and the digital transformation have made data the basis of new digital business models and processes in recent years. One expression of this is the anchoring of the topic with responsibilities at the C-level of corporate management. Against this background, we have identified the following reasons for the introduction of the CDO role in companies in 33 of 38 selected contributions (Tab. 1):

Table 1: Reasons for appointing a CDO

Reasons for the appointing a CDO	Supported by...
New rules or the tightening of existing rules or regulatory obligations	Corea (2018); Earley (2017a); Earley (2019); Insights (2021); Jansz et al. (2017); Mathew and Zimmerman (2012); Savelloni et al. (2015); Schilling (2020); Teerlink et al. (2014)
Too large a number of projects or the failure of (business intelligence and analysis or information management) projects	Earley (2017a); Earley (2019); Harrison et al. (2018); Corea (2018)
Lack of business-wide data management	Earley (2017a); Earley (2019); Ebbage (2014); Harrison et al. (2018); Insights (2021); Mathew and Zimmerman (2012); Noh (2016); Savelloni et al. (2015); Schilling (2020); Strauss (2014); Teerlink et al. (2014); Whitman et al. (2019)
Disappointments about the existing data quality/data maintenance	Berkooz (2017); Celik and Tas (2019); Crabtree and Wright (2021); Earley (2017a); Earley (2019); Harrison et al. (2018); Mathew and Zimmerman (2012); Nie et al. (2018); Noh (2016); Olbrich et. al. (2015); Whitman et al. (2019); Zhang et al. (2017)
Existence of different and isolated legacy IT systems in a company-wide context	Earley (2017a); Earley (2017b); Earley (2017c); Earley (2019); Mathew and Zimmerman (2012); Olbrich et. al. (2015)
Lack of uniform business semantics across the company, such as missing data catalogues, models, processes, culture, guidelines and standards	Earley (2017a); Earley (2017b); Earley (2019); Harrison et al. (2018); Mathew and Zimmerman (2012); Schilling (2020)
Lack of leadership, responsibilities and accountability for resolving data issues, such as data ownership, data management	Earley (2017a); Earley (2017c); Earley (2019); Harrison et al. (2018); Noh (2016); Whitman et al. (2019)
Changing the way data is analysed	Dai and Wu (2017); Davenport et al. (2023); Ebbage (2014); Jansz et al. (2017); Kralina (2018); Mathew and Zimmerman (2012); Schilling (2020); Teerlink et al. (2014); Weber (2023)
Lack or absence of monitoring of data activities	Earley (2017a)
Inconsistent use of data elements in systems	Crabtree and Wright (2021); Earley (2017a); Harrison et al. (2018)
Missing Business-IT-Alignment	Crabtree and Wright (2021); Earley (2017b); Earley (2019); Mathew and Zimmerman (2012)
Dealing with the challenges and opportunities of Big Data	Aitken (2015); Dai and Wu (2017); Insights (2021); Kralina (2018); Lee et al. (2012); Nie et al. (2018); Ojimadu (2022); Strauss (2014); Tyler et al. (2016); Weber (2023); Whitman et al. (2019); Zhan et al. (2020); Zhang et al. (2017)
Governance issues between and across heterogeneous organisations	Teerlink et al. (2014); Whitman et al. (2019); Xu et al. (2016)
Increasing/avoidable data explosion in terms of volume, velocity, complexity, scale and variety	Aitken (2015); Jansz et al. (2017); Nie et al. (2018); Ojimadu (2022); Savelloni et al. (2015); Strauss (2014); Weber (2023); Xu et al. (2016); Zhang et al. (2017)

Reasons for the appointing a CDO	Supported by...
Company size characteristics, industry dynamics, diversification strategy	Zhang et al. (2017)
Characteristics of the top management team, such as functional heterogeneity within the top management team, tenure of the Chief Executive Officer	Zhang et al. (2017)
Deficiencies in risk management	Berkooz (2017); Earley (2017c); Jansz et al. (2017); Savelloni et al. (2015); Strauss (2014)
Ability to make data-driven decisions	Jansz et al. (2017); Mathew and Zimmerman (2012); Olbrich et. al. (2015); Tyler et al. (2016); Weber (2023); Wiseman (2017); Zhan et al. (2020)
Better allocation of resources to meet stakeholder needs	Aitken (2015); Wiseman (2017)
Data scattered across different business areas	Earley (2017c); Mathew and Zimmerman (2012); Olbrich et. al. (2015)
Disruptive new technologies, e.g. machine learning, real-time reporting, AI	Jansz et al. (2017); Ojimadu (2022); Weber (2023)

Source: author's contribution

The multitude of different reasons reflects the challenges that companies (including SMEs) face in today's (digital) world which they try to overcome through organizational changes (e.g. by appointing a CDO).

3.3 Duties and responsibilities of the CDO

The enterprise architecture defines an organization's need for standardized tasks, job roles, systems, infrastructure and data in core business processes (Ross et al., 2006). As a result, the CDO's role (and thus the roles and responsibilities) must align with and support the overall enterprise architecture. The CDO must address the following tasks and responsibilities (Tab. 2), the "four legs of the data schema" (supported by 32 of 38 papers):

Table 2: Duties and responsibilities of the CDO

Duties and responsibilities		Supported by...
Data leg	the improvement of data quality	Aitken (2015); Corea (2018); Crabtree and Wright (2021); Dai And Wu (2017); Davenport et al. (2023); Earley (2017c); Harrison et al. (2018); Ignatova (2021); Jansz et al. (2017); Mathew and Zimmerman (2012); Noh (2016); Olbrich et. al. (2015); Teerlink et al. (2014); Weber (2023)
	Managing the enterprise data ecosystem, in data architecture, data models, data management, end-to-end data workflow, frictionless data traffic, data storage, data integration, data consumption, metadata, master data	Aitken (2015); Celik and Tas (2019); Corea (2018); Crabtree and Wright (2021); Davenport et al. (2023); Earley (2017c); Ebbage (2014); Harrison et al. (2018); Ignatova (2021); Insights (2021); Jansz et al. (2017); Karpur et al. (2022); Lee et al. (2012); Lee et al. (2014); Mathew and Zimmerman (2012); Noh (2016); Ojimadu (2022); Olbrich et. al. (2015); Savelloni et al. (2015); Schilling (2020); Teerlink et al. (2014); Tyler et al. (2016); Weber (2023); Wiseman (2017)
	the implementation of data democratisation	Corea (2018); Harrison et al. (2018); Noh (2016); Schilling (2020)
	The implementation of data governance to improve data as an asset	Aitken (2015); Berkooz (2017); Dai and Wu (2017); Davenport et al. (2023); Earley (2017b); Earley (2017c); Harrison et al. (2018); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); Noh (2016); Ojimadu

Duties and responsibilities		Supported by...
		(2022); Schilling (2020); Teerlink et al. (2014); Tyler et al. (2016); Weber (2023)
	Improving internal business (process) performance through the use of Big Data	Earley (2017c); Harrison et al. (2018); Noh (2016); Schilling (2020)
	Building a data culture	Celik and Tas (2019); Earley (2017c); Teerlink et al. (2014); Weber (2023)
	Improving the interoperability of data	Aitken (2015); Davenport et al. (2023)
	Development and maintenance of data strategies	Aitken (2015); Celik and Tas (2019); Earley (2017b); Earley (2017c); Jansz et al. (2017); Lee et al. (2012); Mathew and Zimmerman (2012); Teerlink et al. (2014); Zhan et al. (2020)
	Monitoring data security	Aitken (2015); Earley (2017c); Insights (2021); Jansz et al. (2017); Lee et al. (2012); Lee et al. (2014); Noh (2016); Ojimadu (2022); Olbrich et al. (2015); Schilling (2020)
	Develop cross-organisational data policies for business strategy and external collaboration	Aitken (2015); Dai and Wu (2017); Earley (2017b); Lee et al. (2014); Mathew and Zimmerman (2012); Noh (2016)
Analytics leg	Development of a unified business analytics	Davenport et al. (2023); Karpur et al. (2022); Lee et al. (2012); Savelloni et al. (2015); Tyler et al. (2016); Weber (2023); Wiseman (2017)
	Fulfilment of internal and external reporting and compliance requirements	Ebbage (2014); Ignatova (2021); Jansz et al. (2017); Lee et al. (2014); Noh (2016); Ojimadu (2022); Olbrich et al. (2015); Savelloni et al. (2015); Schilling (2020)
Technology leg	Steering the development of IT systems for the collection and management of data	Berkooz (2017); Lee et al. (2012); Mathew and Zimmerman (2012); Tyler et al. (2016); Zhan et al. (2020)
Management leg	Being the "voice of data" within the C-suite and representing data as strategic assets of the company	Dai and Wu (2017); Earley (2017c); Ebbage (2014); Karpur et al. (2022); Weber (2023); Whitman et al. (2019); Xu et al. (2016); Zhan and Mu (2016)
	Training, coaching and employment on all data-related topics	Celik and Tas (2019); Noh (2016); Zhan and Mu (2016)
	Developing the strategy of a data-driven company	Earley (2017b); Ebbage (2014); Ignatova (2021); Noh (2016); Xu et al. (2016); Zhan and Mu (2016)
	Building relationships with external data partners and stakeholders to enhance externally provided data services.	Earley (2017c); Noh (2016); Schilling (2020); Zhan et al. (2020)
	Developing new ways for the organisation to use data	Earley (2017c); Jansz et al. (2017); Schilling (2020); Tyler et al. (2016); Xu et al. (2016); Zhan et al. (2020)
	Business Enablement: Exploration of new, as yet unidentified markets and products based on insights from data.	Earley (2017a); Earley (2017c); Jansz et al. (2017); Savelloni et al. (2015); Schilling (2020); Tyler et al. (2016); Zhan et al. (2020)

Source: author's contribution

The role of the CDO is complex and amorphous in terms of its tasks. Job overlaps with other C-levels are recognizable, e.g. the management tasks to the CEO or CIO or "monitoring data security" to the CISO, which harbour conflict potential. For these reasons, it does not seem unusual that the turnover rate among CDOs is high (Tyler et al., 2016).

3.4 Qualification profile of a CDO

At this point, comments are made on the qualification profile (skillset) of the CDO. In 18 of 38 studies, there is explicit information on the skills that the ideal candidate for a CDO position should have, grouped here according to the "three legs of the skill set" (Tab. 3):

Table 3: Qualification profile of a CDO

Qualification profile		Supported by...
Corporate governance skills	(Business, Project, Change, Risk, ...) Management	Corea (2018); Dai and Wu (2017); Jansz et al. (2017); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); Weber (2023)
	Business strategy and requirements, new business models	Corea (2018); Dai and Wu (2017); Earley (2017a); Earley (2017b); Lee et al. (2012); Mathew and Zimmerman (2012); Olbrich et al. (2015); Weber (2023)
	System, business, financial and strategic analytics	Corea (2018); Dai and Wu (2017); Jansz et al. (2017); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); Weber (2023)
	Legal knowledge, such as DS-GVO, compliance, contract law, etc.	Earley (2017a); Schilling (2020)
	Expertise about your industry	Ebbage (2014); Jansz et al. (2017); Mathew and Zimmerman (2012); Teerlink et al. (2014)
	Experience in process modelling	Mathew and Zimmerman (2012); Weber (2023)
Technology related skills	Knowledge of business intelligence and analytics/data science	Corea (2018); Dai and Wu (2017); Earley (2017a); Ebbage (2014); Jansz et al. (2017); Olbrich et al. (2015); Teerlink et al. (2014); Weber (2023); Zhan et al. (2020)
	Data Lifecycle Management/Data Architectures	Corea (2018); Dai and Wu (2017); Ebbage (2014); Karpur et al. (2022); Mathew and Zimmerman (2012); Olbrich et al. (2015); Teerlink et al. (2014); Weber (2023); Zhan et al. (2020)
	Knowledge in computer science or systems engineering	Ebbage (2014); Jansz et al. (2017); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); strategie& (2021); Teerlink et al. (2014); Zhan et al. (2020)
Soft Skills	Ability for social networking and interdisciplinary cooperation	Corea (2018); Ebbage (2014); Harrison et al. (2018); Jansz et al. (2017); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); Strauss, (2014); Teerlink et al. (2014); Weber (2023)
	Sufficient seniority, i.e. proven leadership qualities	Olbrich et al. (2015); strategie& (2021); Wiseman (2017)
	Strong educational background	Olbrich et al. (2015); Teerlink et al. (2014); Weber (2023)
	Ability to engage in continuous learning	Weber (2023)

Source: author's contribution

The studies suggest that the CDO must be multi-talented in his or her skills; a CDO appears to be a "jack of all trades". One study provides specific information on the educational level of appointed CDOs; ranging from a bachelor's degree to a master's degree to a PhD or MBA (Zhan et al., 2020). We also find information on gender: CDOs are predominantly men (Ebbage, 2014). Furthermore, it should be noted that little is known so far about how the hiring process for a CDO works (Zhang et al., 2017).

3.5 Reporting relationships

At this point, the reporting relationships (reporting line), i.e. the organizational structure in which the CDO is placed somewhere in an organizational chart, are discussed. In 13 of 38 studies, the following levels were found to which a CDO reports or to which he reports (Tab. 4):

Table 4: Reporting relationships

Report directly to...	Supported by...
Chief Execution Officer CEO	Earley (2017a); Karpur et al. (2022); Lee et al. (2012); Mathew and Zimmerman (2012); Ojimadu (2022); Olbrich et. al. (2015); Teerlink et al. (2014); Tyler et al. (2016); Weber (2023); Wiseman (2017)
Chief Information Officer, CIO	Teerlink et al. (2014); Tyler et al. (2016); Weber (2023); Wiseman (2017)
Chief X Officer, CxO, i.e. towards the business units	Aitken (2015); Lee et al. (2012); Mathew and Zimmerman (2012); Ojimadu (2022); Savelloni et al. (2015); Strauss (2014); Teerlink et al. (2014); Tyler et al. (2016); Weber (2023)

Source: author's contribution

The results show that reporting lines are unclear or volatile. The majority of studies argue that the CDO should report directly to the CEO. This would put the role on par with other C-level positions. However, it is also observed that CDOs' reporting lines shift towards business units or a function (e.g. risk or finance), as these can be implemented more quickly (Savelloni et al., 2015). In each case, the specifics of the company - size, complexity, maturity and other internal or external considerations - need to be taken into account.

3.6 Critical success factors

Critical success factors are factors whose observance and compliance are decisive for the success of a measure, here the introduction of the CDO role. They attempt to formulate approaches for the redesign of a possibly already inefficient procedure, but do not claim to fully explain the interrelationships (Leimeister et al., 2003). In 14 of 38 papers, factors for the successful establishment of the CDO in the company can be found in order to achieve the mission of "data value creation in the company" (Tab. 5):

Table 5: Critical success factors

Success factors	Supported by ...
Senior Executive Sponsorship	Jansz et al. (2017); Strauss (2014); Wiseman (2017)
Sharp eye and understanding of processes, especially in relevant business areas	Aitken (2015); Crabtree and Wright (2021); Earley (2017a)
Technological understanding	Aitken (2015)
Passion for the topic "what we do with data"	Aitken (2015); Strauss (2014)
Practical experience in the relevant business areas	Crabtree and Wright (2021); Earley (2017a); Karpur et al. (2022)
Building relationships between all stakeholders as equal partners, not as service units	Crabtree and Wright (2021); Davenport et al. (2023); Earley (2017a); Jansz et al. (2017); Karpur et al. (2022)
They have essential technical skills and an educational background	Dai and Wu (2017)
Clear job description and no overlap with other C-level functions	Davenport et al. (2023); Karpur et al. (2022); Tyler et al. (2016); Zhan und Mu (2016); Zhan et al. (2020)

Success factors	Supported by ...
Fair and realistic expectations in terms of value creation for the company	Davenport et al. (2023); Karpur et al. (2022); Tyler et al. (2016)
Focus on data as a product and how it can be measured	Davenport et al. (2023); Karpur et al. (2022); Strauss (2014); Teerlink et al. (2014)
Degree of freedom for dynamics and autonomy	Karpur et al. (2022); Tyler et al. (2016)
Granting executive status (a true part of the C-suite) and establishing clear reporting structures.	Karpur et al. (2022)
Secured funding, as the establishment of a CDO requires financial resources	Savelloni et al. (2015); Teerlink et al. (2014); Tyler et al. (2016)
Long-term orientation	Savelloni et al. (2015); Teerlink et al. (2014); Tyler et al. (2016)

Source: author's contribution

In the studies found, there are neither indications of the degree of importance of individual factors nor information on any relationships and effects between them. If CDOs succeed in anchoring data in strategy, culture, organization and leadership and ensure the necessary empowerment, then they become an important shaper of transformation.

3.7 Impact and added value for a company

We asked ourselves what effects and what added value a CDO has or could have for a company. In 9 of 38 contributions (Tab. 6), this question is addressed and it is explained that the introduction of the CDO function ...:

Table 6: Impact and added value

Impact and added value	Supported by...
... supports the creation of better data products	Lee et al. (2014); Olbrich et. al. (2015)
... helps to gain a strategic advantage in the market.	Lee et al. (2014); Olbrich et. al. (2015)
... supports the identification of innovative strategies for business growth.	Lee et al. (2014)
... is helpful in designing and experimenting with new information products to create strategic value.	Lee et al. (2014); Mathew and Zimmerman (2012)
... supports data initiatives to gain traction within an organisation.	Aitken (2015); Mathew and Zimmerman (2012)
... anchors the need for data-driven decision-making in the top management team	Aitken (2015)
... assists companies to achieve better financial performance and return on investment.	Xu et al. (2016)
... increases the competitiveness of the company and thus the value of the company.	Noh (2016)
... leads to better performance in terms of productivity and profitability due to greater reliance on data-driven decision-making	Celik and Tas (2019)
... leads to a significant increase in profit ratios, such as the sales growth rate	strategy& (2021); Nie et al. (2018)
... leads to a significantly higher return on sales (ROS) than companies without a CDO	Nie et al. (2018)
... leads to an improvement in the cost ratios, here operating costs (OPEXP/S) and cost of goods sold (COG/S), despite higher initial costs due to hiring, etc. Leads, because the organisational changes in the company compensate for the higher initial costs.	Nie et al. (2018)
... ensure increased compliance with data protection rules and adequate data protection	Olbrich et. al. (2015)
... causes positive reactions from the market if the company in question has high growth opportunities	Zhan et al. (2020)

Source: author's contribution

The listed effects clearly show the potential that can be raised with the introduction of the CDO role in the company. A CDO can become a catalyst in times of increasing digitalization.

4. Debate

This study sought to capture the economic reality of the CDO role in the corporate environment and place it in the context of SMEs in order to contribute to this knowledge base. With this in mind, we applied content analysis as a research method to a number of articles identified on the Scopus platform and expanded this to include other articles using snowballing and natural language online search. With a special focus on the type of company, we investigated the question of whether the CDO is (currently still) an unknown entity for SMEs.

Theoretical contribution: On the one hand, the study systematizes the reasons for establishing the CDO role in the company as well as the tasks and responsibilities of the CDO, and on the other hand, the skills required or desirable for this, reporting relationships (reporting lines) and critical factors for the success of the CDO role. The results show the importance of organizationally anchoring the topic of "using data as a strategic resource in digital competition" in the form of the desirable C-level CDO and support decision-makers in introducing and implementing it. Furthermore, the study is the first attempt to place the CDO role in the context of SMEs. The results reveal a research gap for SMEs, because the CDO is mainly found in large companies. Further research is now needed to investigate whether and, if so, how the recognized advantages of the CDO can be adapted to the specifics of SMEs in order to bring the CDO further "out of the shadows".

Implications for practice: If companies come to the conclusion to establish the CDO role, it is important from a practical management perspective to delineate the CDO's remit from other C-level positions to avoid friction. Clear guidelines to ensure the CDO's neutrality between business and IT are just as important as frequent and supportive communication from senior management to send the message from the top down that effective handling of data as a corporate resource is a strategic imperative to set the CDO's role for the entire company. Data needs a voice in digital enterprises.

5. Conclusion and future research

Research on the CDO is currently still very limited, as this C-level role is relatively new and there are therefore only a few papers that address this topic. The studies found focus primarily on the tasks and responsibilities of the CDO and their impact on business performance. Studies with special reference to the corporate environment are only sporadically available. However, the results of our research clearly show that the role of the CDO will lead to a greater diversity of functional backgrounds within the top management team, which will have a greater impact on the quality of decision-making, which in turn will have a positive impact on internal business processes, learning and business performance growth prospects. Data is ubiquitous; it underpins every transaction, process and interaction in today's businesses. In today's dynamic and global markets, companies should consider whether they can compete without CDOs.

Certain limitations exist in any research work. The most important limitation is that we have relied exclusively on data from previous publications (secondary research). However, the identified studies are useful starting points for further research around the organization of digital transformation in the SME environment. It is therefore recommended to further investigate the organizational activities around the CDO role in order to better understand the impact of its presence or absence on digital transformation in SMEs.

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THE MODEL FOR A PARTIALLY OUTSOURCED RPA IMPLEMENTATION

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Abstract

This paper is proposing a model of partially outsourced Robotic Process Automation (RPA) implementation in a company that doesn't have experience with this technology. The RPA implementation differs from the implementation of software automation or information systems such as Business Process Management Systems. Mostly because it builds on existing IT infrastructure without the need of changing it. Therefore, RPA is more business than IT oriented. Results are built on the knowledge of RPA experts and explore different RPA implementation approaches and for one of the more commonly used a detailed model is presented.

Keywords: implementation approach, operation model, robotic process automation, software automation

JEL codes: M15, O32, O33

1. Introduction

The Robotic Process Automation (RPA) is still relatively new approach for automating repetitive, structured tasks in business processes across industries (Aalst van der, 2018). Although the core RPA automation technology is not new the way of how it is incorporated into enterprise operating model is innovative (Asatiani et al., 2022). By its nature the RPA is perceived as a lightweight IT which is a big difference from the earlier automation solutions (Workflow Management Systems, Business Process Management Systems). The main enabler of RPA benefits is the fact that RPA builds upon existing systems (often legacy systems) without the need of sophisticated integration (Syed et al., 2020). Also, the configuration of software bots is tried to be technically undemanding which provide business-oriented persons outside IT department with more active role in implementation which is also crucial fact for scalability of RPA (Lacity and Willcocks, 2016). But also, it brings new challenges mostly in terms of implementation, growth and overall governance of RPA in a company. The contexts of application of RPA technology is mostly in these industries: Business Process Outsourcing, Financial and Health (Enríquez, et al., 2020).

With the growth of the market for RPA technologies also criticism comes. As it has been with BPR in the 1990s or BPM in the early part of this century, the new technology trends are very attractive to consulting firms or contractors that offer these solutions in the B2B market. However, they often fail to create real value in terms of process efficiency improvements. According to a report from Ernst & Young (Lamberton, 2016), 30-50% of initial RPA implementations fail. Also, Willcocks (2019) states that that only about a quarter of organizations reap the full benefits of the RPA projects. On the other hand, a research report by Hindle et al. (2017) provides data on various aspects of RPA implementations, and this research shows positive returns for 23 out of 24 implementation projects. The mentioned disagreement between the authors and the reported results only shows how this rapidly growing RPA sector is unstable and unclear. Such circumstances provide excellent opportunities for research to unveil the veil of ambiguity and bring new insights into domain. The RPA is also raising interest in the academic literature and journals but a number of authors agreed that this interest is lagging behind the real worlds company practice (Herm, et al., 2022; Ivancic et al., 2020).

Most of the RPA implementation cases described in scientific literature come from publications or projects whose primary research object was not the issue of RPA implementation, but it emerged as

a secondary outcome. Exceptions are publications by Taulli (2020), Sigurðardóttir (2018) and Santos et al. (2019). Also, the overall reliability and validity of the research conducted is questionable, as in some cases there are publications written by consultancies and other companies presented as white-papers, which are more like marketing publications that reflect industrial experience (Capgemini, 2016; Deloitte, 2017). But in recent years the number of studies of this phenomenon significantly raised. Publications describing implementation approaches (Sobczak, 2021; Santos et al., 2020) as well as the ones proposing implementation frameworks (Herm, et al., 2022; Asatiani et al., 2022) and also RPA literature reviews (Enriquez et al., 2020; Wewerka, Reichert, 2021; Ivančić et al. 2019). Unfortunately, academic research is still lagging behind the rapidly evolving RPA sector, thus the need for mapping practical experience is needed.

From literature there is a strong evidence that the implementation plays a key role in the overall success of RPA initiative in a company (Plattfaut et al., 2022). Also, RPA technology is often integrated into a company with the help of external consultants or RPA competency is even outsourced (Asatiani, et al., 2022). In much of a cases cooperation with external expert partner is crucial component in implementation projects and therefore this paper focuses on this approach for RPA implementation.

2. Methodology

The research question stated in this paper is as follows: What is the best possible way of implementing RPA into company which have any previous experience with this technology by using external company. The aim of this paper is to propose an RPA implementation model.

This paper uses qualitative research approach with Narrative inquiry as a research strategy. Each respondent presents narrative of one implementation project which met the scope of this study (external implementation project into the company without any previous experience with RPA). Narrative inquiry providing the opportunity to connect events, actions and their consequences over time into a 'meaningful whole' (Saunders, et al., 2016). The stories are viewed as data sets which provided thick description. Braun's and Clark's (2006) concept of narrative inquiry was used to carry out data collection (in-depth interviews) and data analysis (thematic analysis) and evaluation.

In addition to the narratives themselves, the author also acquired other know-how from the respondents or, by supplementary questions, verified the existence or non-existence of the respective phenomenon (existence of the phase, CSFs, etc.). The resulting list of topics that formed the conceptual framework which was distilled from literature review including: RPA definition, technology, implementation approach, initial motivation and expectations, the contextual definition of the narrative, phases and activities of the implementation project, CSF, success evaluation.

Respondents were found through online Google and LinkedIn search. Author was looking for RPA consulting or technology SME's and for bigger consulting or software houses and mostly for project managers or team leaders who lead RPA implementation projects in the central Europe area. From the list of 13 RPA experts who were contacted the final number of actual respondents was 9. After agreement with respondents, author send an email invitation with information about the purpose of the study, interview structure and ethical principles. When settling on date, actual interview was conducted through online call which was recorded. The list of the respondents is shown in table 3. During the data collection and continuous analysis of data the state of theoretical saturation was observed in all of the parts of the conceptual framework (Saunders et al., 2016).

In the phase of data collection, therefore, 9 interviews were conducted, which were recorded, and the total length of the footage is 569 minutes. Each of the in-depth interviews was transcribed for the purposes of thematic analysis, and the resulting transcript took 108 pages in the common formatting and 71,727 words.

After data collection, a thematic analysis according to Braun and Clark (2006) was performed on the transcripts. At first, the author reviewed the transcripts then generated first version of code structure and then continue to organize data into meaningful groups (topics and patterns) (Tuckett, 2005). Topics are clustered with codes that overlap or resemble. In the next phase – processing of topics – the relationships between topics and the ways in which the themes are intertwined are crystallised and form an integral story of the data, which provides data inputs for the proposition of the RPA implementation model.

Table 1: Introduction of respondents

Respondent No.	Company	Position	Practice in years	Role in the project
Respondent 1	Medium-size consulting co.	Director of the Automation Team	5	Project Manager
Respondent 2	Small IT company	Founder	2	Project Manager / Developer
Respondent 3	Large IT company	Automation Manager	4	Project Manager
Respondent 4	Small consulting co.	Owner	4	Developer
Respondent 5	Small automation company	Director	4	Project Manager
Respondent 6	Small consulting co.	Consulting Team Leader	7	Project Manager
Respondent 7	Global consulting co.	Team Manager	3	Business analysis / Developer
Respondent 8	Global consulting co.	Automation Team Leader	4	Project Manager
Respondent 9	Global consulting co.	Automation Team Leader	5	Project Manager

Source: author

3. Results

This part presents the results of conducted qualitative research. Figure 1 shows the proposed model, based on the outputs of narrative inquiry. However, before the author describes the proposed model of RPA implementation, the scope of the implementation needs to be more focused. In order to ensure the benefits of the design part, it is not possible to limit the complex issues and realities of the implementation of RPA in the company to a single model that will be applicable to all cases. Therefore, the author will focus on defining the model from the viewpoint of the implementation approaches (operating models). From narrative research a number of implementation approaches emerge, but by most of the interviewed only one was considered most suitable. So only one particular RPA implementation approach was chosen and the proposed model is built on it.

The proposed model addresses a deployment pattern that has occurred in all narratives examined, namely through a PoC/pilot, which took place in each project, and also the subsequent growth of RPA inside the company, which was addressed by respondents 1, 3, 5, 6, 7, 8, 9. The model forms the intersection of all investigated narratives and considers the most dominant way of implementation.

In addition to the model, special attention will be paid to the methods of implementation or cooperation between the consulting and the client company, where the author proposes 4 methods of implementation. The variable “development/maintenance” and the use of “internal/external” resources are combined here. Although not the main subject of research, the growth phase has a special position in the model and research has shown that this is a key phase ensuring the successful implementation of RPA in the company and its long-term and sustainable development. Therefore, this will not be a comprehensive view of the growth phase, but rather the fundamental overview.

The interviews revealed 3 types of cooperation between the client and an external consulting company.

External development, external maintenance – specifically, Respondent 1's company is pursuing this business model and offers RPA as a complete outsourced solution. Accordingly, they also choose a clientele, which is mainly medium-sized companies, which do not have the ambition and resources to create their own RPA centers. The size of the client company therefore also affects which method of implementation will be chosen.

External development, internal maintenance – this method occurred most often and the respondents also mentioned it (with an exception of Respondent 1). The advantage of this method is that in order for the internal team to be in charge of maintenance, it must be thoroughly trained. As a result, RPA gets into the structure of management or support processes of the client company and thus ensures viability and long-term operation. On the other hand, the risks are associated with insufficient training

or transfer to the internal team, as well as further growth of RPA to the company, which may no longer be progressive if a clear plan is not set. The research shows that the departure of an external company after PoC/Pilot without the creation of a competence center (or at least assistance to it) will have a negative impact on the growth phase and will jeopardize the success of the entire RPA initiative.

Internal development, external maintenance – again, this is a less common method of implementation. According to the respondents, some companies will encounter RPA and initially intend to address the development through internal IT or another department. However, over time, they find that the method of implementation and the whole logic of RPA is so different that they invite an external entity to the project. On the other hand, it happens that the maintenance phase is planned to be carried out by internal forces, but after a short time a consulting firm is invited again, because the client company is not able to take advantage of all opportunities and its capacity is undersized. Thus, in practice, maintenance is often combined with the use of internal and external resources.

Internal development, internal maintenance – in the discussed narratives this method did not logically occur, because the subject of the research was the method of implementation with the help of a consulting firm and the respondents were also representatives of the consulting firm.

3.1 Proposed Implementation Approach

There were large differences between the respondents in the implementation approaches, which are determined in both directions – i.e. from the position of a consulting company (the essence of the services offered, focus, strategy, etc.) and the client company (internal capacity, size, field, etc.). The proposed model should also reflect these variables. A 2x2 matrix is proposed, from which 4 different implementation approaches are based that can be encountered. Figure 1 shows these approaches and they will be discussed further.

Each of the 4 implementation approaches is a combination of top-down vs. bottom-up implementation strategy and two types of cooperation used in research – external development and internal maintenance and external development and maintenance, which are the only ways that have occurred in narrative research.

Figure 1: Matrix of implementation approaches

Top-down	Bottom-up	
Natural Growth	Fade Away	External development and internal maintenance
Untapped potential	Small Victories	External development and maintenance

Source: author

The top-down vs. the bottom-up implementation strategy is determined by the phase and time when the strategic governance will enter the project, i.e. if after the PoC phase the implementation is still not covered by the plan, strategy, competence center, but iterations on other processes still take place at the level of the department management without the necessary support, it is the bottom-up implementation. The latest phase, when the company's management (represented by top management) must enter the automation project, in order to implement it from top to bottom, is immediately after the end of PoC/Pilot, i.e. in the production phase, in order to be acquainted with the results and to be able to decide on the basis of objective benefits.

The four proposed implementation approaches are as follows:

FADE AWAY

The risk of this approach has been described relatively clearly in respondents' narratives. According to Respondents 3, 4 and 5, it often happens in practice that the automation project does not

gain the support of the company's management, either from the start (the impulse for implementation arises at the middle management level) or after PoC and the project as such gradually disappears. This may be because PoC does not produce the desired results, but is usually due to misunderstandings, lack of communication or internal politics. According to Respondents 5, 6 and 9, there is no unsuccessful PoC, or they have not encountered it during their practice. Thus, if after PoC, the project does not gain strategic auspices from the top management and continues, it is only a matter of time before its sponsors (often middle management) stop having the energy to push it further without support, or this project may be halted directly.

SMALL VICTORIES

The situation is more stable than in the previous approach, but again without the timely involvement of top management, the RPA project will remain only at the level of partial departments of the company and therefore only automation of some processes is implemented, and small victories are achieved. The RPA projects managed in this way are in the jurisdiction of the department, where the middle management decided to choose the path of fulfilling the KPIs through the RPA and pulled it into the company with the help of its own budget. This approach is typical for smaller consulting or development companies offering complete outsourcing, but at the same time do not have the capacity or business opportunities to reach the upper levels of corporate management. However, over time, the RPA initiative may be registered and may be given strategic protection and relocation to another quadrant in the matrix.

UNTAPPED POTENTIAL

Similarly, to the previous approach, the involvement of an internal team is not envisaged here, but it only relies on the delivery of RPA solutions from an external entity. In this case, the patronage of the top management has already taken place, which has affected the scope of the project and its growth into the company. However, as Respondents 3, 6 and 7 describe, without the involvement of the internal team, the potential that automation could fulfil is not fully exploited and thus the individual life cycles of RPA are extended. Respondents also encountered a situation where they supplied (as representatives of a consulting firm) their own employees to work full-time for the client on RPA projects, which is similar to agency work, and in this case, it can be debated whether administration and maintenance is still in external or internal competence. The author considers this to be an internal solution, because even though they are external employees, they belong to the internal organizational structure and therefore behave as an internal team.

NATURAL GROWTH

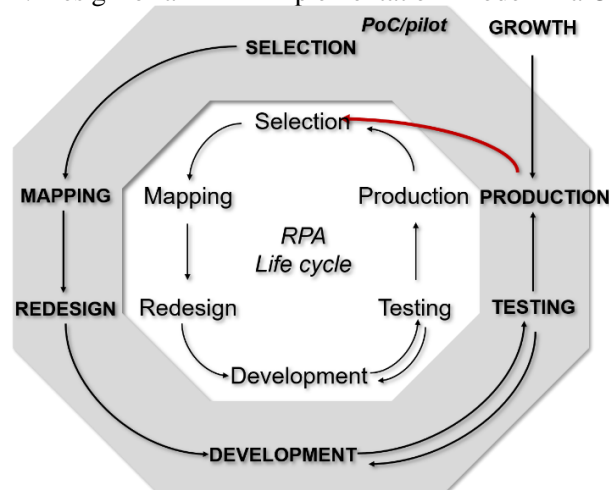
The last implementation approach shows the optimal variant ensuring the development of RPA and overall successful implementation. The RPA initiative is covered immediately from the start or immediately after the PoC, and at the same time the internal team is involved in the maintenance and growth. During or after PoC, a competence center or CoE is created, which takes on the role of RPA development and all other agenda around – administration, maintenance, communication, active collection of suitable candidates for RPA, prioritization, etc. The interviews showed that although this may not be the most common method of implementation in the conditions of the Czech Republic / Slovakia, the respondents more or less agreed that it is the most suitable. It certainly depends here also on the size of the company, but if it is not explicitly a global company (as in the case of Respondent 9), then it is most appropriate when the growth phase enters the implementation only after PoC. This avoids over-planning and lengthy preparatory strategic work that, according to some respondents (1, 5, 6) is not appreciated by clients and if implemented before the PoC is completed, it tends to be premature. In the next part, the author will focus on this implementation approach and propose a model describing the implementation method respecting the essence of “Natural Growth” implementation approach.

3.2 Design of an RPA Implementation Model in a Company

Figure 2 below shows the model. It is align with the implementation approach – "Natural Growth". The basic division is into two layers. One of them deals with PoC/Pilot and the other with the RPA life cycle, which is closed and already shows the situation of further development of RPA in the company, where other processes take place through this life cycle and are gradually automated. The individual phases are selected from narrative research, where they were discovered on the basis of interviews with 9 respondents (RPA experts). In its last phase, PoC/Pilot moves smoothly to the level of the life cycle, but in order for this to take place, there must be a growth phase, within which RPA must get into the organizational structure of the client company. Except for the development and production phase, this is a linear scheme, where one phase follows another. The development and testing phase is specific in this regard, as it needs to be agile.

This model envisages the involvement of an external consulting firm, but also counts on the ongoing training of internal staff, which is an activity taking place across the model, but falls within the critical success factors (CSFs), which will also be part of the description of the proposed model. The following will be a description of the individual phases in terms of key activities and CSFs.

Figure 2: Design of an RPA Implementation Model in a Company



Source: author

3.3 Description of the Model and Phases

It is important for implementations to be systematic and to keep pace over time, otherwise this may mean a decline in the RPA initiative and an increase in the inefficiency of deploying additional robots and other automations. Therefore, the phases in the PoC/Pilot (grey zone) and RPA Life Cycle (internal cycle) levels do not differ in content (key activities, CSFs). The description of the phases will therefore be summarized for both levels together. The red arrow shows the transition between the PoC/Pilot level to the RPA life cycle using the "Growth" phase. For each of the phases, the author will describe its goal, key activities, output and CSFs. The CSFs will also be supplemented by a self-evaluation scale, serving as a guide and (subjective, objective) evaluation tool for users of this model when used in their own RPA implementation projects. The scale is shown from Point 1 to Point 5, where both of these extreme values provide a verbal description of the evaluation of a given factor and the user evaluates according to them after the completion of the respective phase or project. A value of 1 indicates the best possible result in the CSF and a value of 5 indicates the worst.

SELECTION PHASE

The aim of this phase is to select suitable candidates (processes or parts thereof) based on the analysis, which will be automated through RPA and will be the content of the respective iteration.

Key activities:

- Introductory workshop – the purpose of the workshop is to acquaint stakeholder groups within the company with RPA and to ensure a thorough understanding of the basic principles. It depends on the readiness of the company, but there can also be a discussion about the selection of suitable processes. However, it depends on whether the company already has a list of candidates ready, before the arrival of the consulting company. This activity is specific to the PoC/Pilot level and no longer takes place in the RPA life cycle.
- Technology selection – takes place only if the consulting company has a wider portfolio of implemented technologies. Based on the experience of the consulting company and the specifics of individual platforms, the one that meets the conditions and fits well into the existing IT environment of the company is selected. As there are almost no differences in the method of implementation between the platforms, the choice of the platform will not affect the next phases and activities.
- Creating a longlist of candidates – A high-level analysis of the department and the environment in which the technology should enter takes place. With the help of interviews or guided workshops, there is a debate about the nature of processes, their complexity and other aspects that affect the suitability of the process for RPA automation. A longlist is being created containing a number of potential candidates who need further analysis and prioritization. An RPA calculator, a PM or a simple prioritization graph, are suitable tools for selection and prioritization. Savings and benefits are meant as qualitative and quantitative variables, most often they include (FTE savings, increased employee satisfaction, increased process quality, accelerated process flow, etc.), while cost-effectiveness and complexity mean the complexity of the process predetermining the costs of automation of a respective process (represented by financial costs for external companies, time invested by internal employees, etc.). Suitable process candidates are then processes that bring significant savings (y-axis) and at the same time without high costs (x-axis).
- Creating a shortlist of candidates – from the previous step suitable candidates will emerge that must undergo a deeper analysis. It consists in getting acquainted with the processes at the level of process participants, where the process analyst (or the person responsible for this phase) maps a specific workflow.

The output of this phase is a narrower list of candidates for automation, which respects the scope of the project (in smaller projects it may be one specific process). Another output is a longlist, which is used for the RPA life cycle, because after the end of PoC/Pilot, the team returns to the longlist and selects other candidates (or enters other departments and creates new lists).

CSFs:

- The right choice of communication messages. Self-evaluation scale:
 - 1: Acceptance of RPA technology by stakeholders.
 - 5: Boycott of the RPA initiative
- Manage the time of the client's employees effectively. Self-evaluation scale:
 - 1: High number of invested hours of the client's employees in relation to the scope of the project or project plan.
 - 5: Low number of invested hours of the client's employees in relation to the scope of the project or project plan.
- Selection of a process bringing quick wins. Self-evaluation scale:
 - 1: Positive benefits from automation within PoC/Pilot against predetermined (qualitative, quantitative) indicators.
 - 5: Negative or insufficient benefits from automation within the PoC/Pilot against predetermined (qualitative, quantitative) indicators.

MAPPING PHASE

The aim of this phase is to create reference documents – a thorough description of the process, which will be used as a basis for all other phases.

Key activities:

- Creation of Process Definition Document (PDD) – this is a detailed description of the process, mapping each screen, every click in the process. Creating a document is challenging and is performed throughout this phase. A video recording technique is used here, where process participants perform and comment on the process.
- Exception mapping – it is a part of PDD, when it is necessary to map all possible process scenarios within the analysis. It is very difficult to capture all scenarios at this stage, but it is necessary to detect as many of them as possible. Of course, not all exceptions will be automated, but it is important to decide at this stage how the exceptions will be handled.
- Test data analysis – this activity is typical for the testing phase, but some respondents encountered the analysis of test data also during the mapping phase. There is no solution yet that works with test data, but the analysis reveals other possible exceptions or confirms the correctness of the previous analysis.
- Identification of key metrics – to capture performance metrics and the state of the process before and after implementation, it is necessary to choose the right metrics that will be monitored and evaluated (FTE savings, process lead time, etc.). In addition to identifying them, it is also necessary to find out how the data will be collected. Some respondents mentioned that it is only at this stage that the so-called "business case" can be quantified and an offer made to a client company.

The output of this phase is a prepared documentation in the form of PDD containing a very granular description of the process, including dealing with exceptions and setting key indicators. Acceptance from the client company must also be a part of it.

CSFs:

- Detailed analysis and description of the process. Self-evaluation scale:
 - 1: Low percentage of changes discovered in the development/testing phase relative to overall complexity.
 - 5: High percentage of changes discovered in the development/testing phase to overall complexity.
- The developer must learn and understand the process. Self-evaluation scale:
 - 1: Low percentage of changes discovered in the development/testing phase relative to overall complexity
 - 5: High percentage of changes discovered in the development/testing phase to overall complexity.

REDESIGN PHASE

The goal of this phase is to redesign the process and optimize it so that the development phase runs efficiently. It also includes the creation of a Solution Definition Document (SDD) document describing how the solution will look like.

Key activities:

- Process redesign – although it is not always necessary for the process redesign to take place, it is really necessary to think about the process from the point of view of the basic principles of BPM. Thus, the redesign can take place with the help of traditional BPM tools, or it is possible to use industry standards that some consulting companies have and use in projects. The purpose is to optimise the process in terms of customer value or business value and get rid of obstacles and inefficiencies.

- Technical redesign – this redesign is already specific to RPA, as it takes into account the differences in the ways in which the robot works. Most often, it is necessary to map the issue of connectivity and connection to the API of involved programmes which offer a more stable environment for development. This redesign can save the developer a lot of time, but also speed up the execution of the process by the robot, so it should always take place.
- Infrastructure preparation – infrastructure needs to be secured before development, especially when it comes to PoC/Pilot. Within the RPA life cycle, this phase may no longer exist, or its content may be embedded in the competence centre. Content can include issues related to gaining access rights, creating development and testing environments, and other software and hardware development requirements.
- SDD creation – the resulting document is an extension of the PDD document, which describes the process. SDD, on the other hand, describes the proposed solution, which also includes an optimised process and other technical and IT issues that are important for developers. Acceptance of the document from the client is a natural end to this phase.

As mentioned, the output of this phase is an SDD document that is accepted by the customer.

CSFs:

- Quality environment preparation. Self-evaluation scale:
 - 1: The ratio of differences in individual environments and therefore also the time invested in covering these changes are low.
 - 5: The ratio of differences in individual environments and therefore also the time invested in covering these changes are high.
- IT department support. Self-evaluation scale:
 - 1: The support of the IT department is excellent.
 - 5: IT department support is non-existent.
- Avoid exhaustive redesign. Self-evaluation scale:
 - 1: The number of iterations of the redesign of the given process is low.
 - 5: The number of iterations of the redesign of a given process is high and the phase takes a long time.

DEVELOPMENT AND TESTING PHASE

The goal of this phase is to develop and prepare the automation for a state that will be ready for production and live start. The development and testing phases are linked because as respondents stated these phases run in parallel and it's iterative process – an agile development that prevailed among all respondents.

Key activities:

- Development of the first version of the robot – Based on PDD and SDD, the development of the first version of RPA automation can be started immediately. According to the chosen technology and the development approach either a specific part of the automation or a complete automation is developed, but only the main scenario. In the first variant, exceptions are incorporated immediately and therefore must be tested immediately using a test data set to verify the correctness of the automation. In the second variant, the so-called "happy day" scenario is automated, which also serves as a demo for representatives of the client company.
- The introduction of the first version – also CSFs show that the involvement of internal parties is crucial, and this is primarily true of PoC/Pilot, where it is common that workers have not yet seen any RPA robot in action. The performance also includes, of course, feedback on the operation and collection of comments for incorporation.
- Testing with a test data set – the same data set can be used as in the case of the process mapping phase, but here the data is already driven by the developed automation, which runs on a test or development environment. Using this data set, errors are captured

directly in the simulated operation and continuously incorporated into the so-called "exception handling model".

- Acceptance tests – used for final testing by users who take over the responsibility for the developed robot and its commissioning at the moment of takeover and acceptance. Here, users and potential administrators are also tested and trained how the robot will engage in day-to-day operations and be part of the execution process. Again, this activity needs to be highlighted in the first automated processes within PoC/Pilot.

The output of this phase is a robot operating according to the specification (SDD) on a test environment and prepared for conversion to a production environment. It is also a condition that the robot has passed acceptance tests.

CSFs:

- Ensure zero robot error rate in PoC. Self-evaluation scale:
 - 1: The robot developed in PoC works without error.
 - 5: The robot developed in PoC has a large number of errors.
- Connectiveness of the RPA to the application backend. Self-evaluation scale:
 - 1: High proportion of applications connected to the backend.
 - 5: Low ratio of applications connected to the backend.
- Develop for reusability. Self-evaluation scale:
 - 1: The ratio of reusable automation parts is high compared to the total number of individual elements of automation,
 - 5: The ratio of reusable automation parts is low compared to the total number of individual automation elements.
- Client involvement in testing. Self-evaluation scale:
 - 1: The client was involved at the ideal time and with ideal number of hours.
 - 5: The client was not involved at all.

PRODUCTION PHASE

The goal of this phase is to transfer the robot to the production environment and ensure full functionality according to the assignment (SDD). It can also be understood that after the completion of this phase, the robot should be involved in the operation and execution of the process and should also have resolved the issues of responsibility, administration and maintenance.

Key activities:

- Transferring the robot to the production environment – connecting the robot to the production environment means another round of adjustments and optimisations, because as the interviews showed, the environment is (although it should not be) different. Production data is already used for testing and the robot is connected to normal operation, although the classic (as-is) execution of the process often runs in parallel.
- Training of employees of the client company – training in various cases will take place across the whole project, but in most cases, it will be carried out at this stage. It is necessary to train the employee in administration and maintenance (if s/he is to move under the internal team) or in standard operational matters (in which situations to contact the administration, how to control the robot, how to start it, etc.).
- Close monitoring – From the transfer to the production environment through the connection to live operation to the final handover, close monitoring takes place from the consulting company, which is associated with regular and intensive control of the automation process and a very short response time in case of error or failure.
- Final handover – The entire PoC/Pilot or basically the finalisation of any process automation (within the RPA life cycle) ends with the final handover of documents – robot architecture, technical description, operation manual. This may be accompanied

by a workshop where the project will be evaluated retrospectively and new, more effective ways to improve cooperation throughout the life cycle will be sought.

The output is fully functional RPA automation connected to normal operation and also trained personnel ensuring smooth operation and management.

CSFs:

- Solve the responsibility for the robot. Self-evaluation scale:
 - 1: The robot's responsibility is formally addressed and clear parameters are set.
 - 5: The responsibility of the robot is not solved in any way.
- Count on the error rate of new internal RPA developers. Self-evaluation scale:
 - 1: We are ready for the error rate of new internal RPA developers and we count on it in the implementation process
 - 5: We do not take this criterion into account.
- Smooth transition into operation. Self-evaluation scale:
 - 1: The transition to live operation took place without unexpected complications.
 - 5: The transition to live operation was problematic and had to be postponed.

GROWTH PHASE

The aim of this phase is to ensure the emergence of the breeding ground and structure that will be used as a stable basis for further development of the RPA initiative and the expansion of robotisation processes across the company. The purpose is to further develop RPA, but also to accelerate this development and make it as efficient as possible. This phase is specific, however, based on data from narratives, it is most common to address this issue immediately after completing PoC/Pilot and gaining the support of top management, which is usually the trigger for this phase. It is the successful PoC/Pilot that serves to demonstrate whether RPA can achieve savings and other goals in the respective environment and thus convince the company's top management for support and strategic auspices. The role of the consulting company has changed considerably since this phase, and from the position of outsourcing, external development and delivery of automation, it is rather directed to the role of coaching, correction and guidance. The growth phase is pulled out of the closed RPA life cycle and enters the proposed model once. Nevertheless, of course, the outputs of this phase (competence centre, operating model, etc.) need to be constantly improved and shifted.

Key activities:

- Creation of an operating model – all tasks can be placed under two activities, which are, however, very challenging and represent separate blocks with the potential to bring long-term benefits. The operating model was presented by Respondent 9 and forms a strategic document, through which the RPA initiative is formalised. It answers questions – responsibilities/roles, goals/metrics, approaches to HW/SW equipment, involvement in the organisational structure, communication flows and platforms used for communication, crisis management scenarios, control and auditing of robots. The operating model is the determining tool and starting point, by which the competence centre or CoE is created.
- Establishment of a competence centre, CoE – without an internal team sponsoring the RPA initiative, there is little hope that RPA will continue to develop. It is also possible to outsource this part (according to Respondent 3), but it usually passes under internal management, which is accountable to one of the company's top management (board of directors). There are several models, but Respondent 9 recommended a hybrid model, where there is a centre accumulating know-how and decision-making power regarding RPA procedures and development, but on the other hand in each department involved there is a person who deals with RPA and serves as a contact and competent person for contact with CoE.

The output of this phase is an established and clearly defined competence centre or CoE operating according to the established operating model and achieving positive results meeting the set metrics.

CSFs:

- License utilization. Self-evaluation scale:
 - 1: We have utilised a 90 % of the robot license.
 - 5: We have only utilised a 10 % of the robot license.
- Overcome resistance to change. Self-evaluation scale:
 - 1: People are prepared for change and take it as a challenge, which is reflected in the process of adopting RPA.
 - 5: People make it very difficult for us to adopt and grow RPA in the company and they learn and adapt very slowly.
- Obtaining an ambassador from the executive management. Self-evaluation scale:
 - 1: A larger number of ambassadors was obtained from the ranks of process participants and process owners.
 - 5: Not a single ambassador has been acquired to raise awareness and facilitate adoption.
- Obtaining top management support. Self-evaluation scale:
 - 1: Unanimous support from top management obtained.
 - 5: No support is obtained from any of the members of the board of directors or other supreme body of the company.
- Follow the procedures and practices strictly within the PoC/Pilot and in the growth phase. Self-evaluation scale:
 - 1: A predetermined implementation procedure was planned and followed.
 - 5: The implementation procedure was not known in advance and was random.
- Representatives of IT and "Business" are part of the competence centres. Self-evaluation scale:
 - 1: In the competence centre, we have actively involved representatives of the IT and "Business" departments.
 - 5: We do not have a representative of any of these departments in the competence centre.
- Invest RPA savings in people. Self-evaluation scale:
 - 1: We regularly invest at least 70% of the savings back in employees.
 - 5: We do not invest any part of the savings back in employees.

3.4 Model Limits

The exploratory nature of the research results in a number of limitations, which have been transferred to the model. The research mapped the little-explored area of RPA implementation in a company, so the final model is only a draft model. Although it is based on narrative research, it is not substantiated by practical application or otherwise validated, e.g. through further follow-up research. It is therefore necessary for this initial design of the model to be subject to further review and evolve gradually in order to increase its reliability.

The author sees another limit in the self-evaluation criteria of the CSFs in the design part which are not directly related to the results found in narrative research but are proposed by the author on the basis of acquired knowledge across research processes. These scales need to be calibrated by further research.

The growth phase, often mentioned in the paper, including the issue of competence centres or CoE, was addressed in the work, but only marginally; as a matter of fact, it was given the same amount of space as the other stages, but the interviews show that it is absolutely crucial and often problematic in practice. The execution of a successful PoC/Pilot is not usually a problem, but the growth and establishing of RPA technology in the company already is, and this phase is often the cause of the failure of RPA initiatives. This is a complex topic, which should be the subject of separate research, and it certainly cannot be asserted that the model covers it sufficiently.

Case study research or action research that would apply the proposed model to a real case of RPA implementation in a company or contrast it with established practices of industry experts and thus gaining the necessary feedback might be another follow-up step contributing to the validity of the model.

4. Discussion

The research question: “What is the best possible way of implementing RPA into company which have any previous experience with this technology by using external company” has been addressed and model of implementing RPA into company with nonexistent RPA initiative was proposed based on 9 in-depth interviews with RPA experts from various fields. The implementation approach of using external competence was described and used as well. The implementation approach was also tackled in Asatiani (2022) who discussed about using hybrid model (combination of insourced and outsourced RPA competency) which most of the studied companies used initially but then gradually shifted towards entirely or mostly insourcing-based model. Model proposed in this paper recommend similar hybrid model of cooperation.

Conclusions from Enríquez et al. (2020) shows that the analysis phase where the business case for RPA is built and right processes for automation are picked are the most underestimated by most (85 %) of the RPA platforms providers. This correlates with the statement from respondent 4, 8 and 9 who tell that clients and decision makers don't see the value within analysis phase nor are willing to pay the cost of analysis which according to respondent 8 could be up to the half of the cost of the overall project.

Herm et al. (2022) expanding on the view of PoC which is because the lightweight nature of RPA development more a pilot where automations are implemented and launched. So the question of feasibility don't have to be addressed. Also the results emphasize the need to set up a competence center and the use of external consultants with providing guidance till the time when company can perform independently.

Many RPA implementation processes shows a similar pattern of phases. Some of them are focused more on the pre-implementation phases (Asatiani and Penttinen, 2016; Lowes et al. 2017). Others focus on the end to end perspective of RPA implementation (Santos et al., 2019; Syed et al., 2020; Enríquez et al., 2020). Hallikainen et al. (2018) and Syed et al., (2020) are considering growth/expansion/scaling up phase and Sigurðardóttir (2018) and Balasundaram and Venkatagiri (2020) present RPA life cycle as an end phase to their proposed RPA implementation.

5. Conclusion

The issue of business process management has been an important topic in the field of business management. The diversity of this discipline only underlines its complexity and high demands on the interconnection of two often inconsistent worlds – IT and management. The exponential growth of technology brings new perspectives and huge opportunities for businesses, but their speed of response to change may not be sufficiently dynamic. RPA technology has the potential to shorten this gap, thanks to two facts in particular: (1) the speed of implementation without the need to change the company's IS, (2) the replacement of human labour by a robot labour.

This paper presents results from narrative research which extract qualitative data from respondent narratives. Each narrative present particular project of RPA implementation in companies that have not yet had any experience with RPA. Also, the research is focused on the model when external party (consulting/software company) is involved by bringing RPA competency and delivering RPA as a service. The research was done in the context of central Europe (CZ/SK) environment.

The results show that best implementation approach (operation model) is when the RPA project gets strategic support immediately at the start or after the PoC and that external partner is involved in RPA development (mostly in the phase of PoC). Additionally the role of external partner shifted to training of internal staff and after successful PoC the maintenance and growth initiative is take over by internal staff. This approach author calls “Natural growth” and implementation model presented a process that is consistent with this implementation approach.

The RPA implementation model is divided into 2 dimensions, first is considering the PoC/Pilot implementation which is always present within the projects where the company don't have any previous experience with RPA. During the PoC/Pilot the suitability and potential benefits of RPA technology are

evaluated and based on that findings a further course of action is set. After successful PoC the company must determine if they will scale the RPA further into company and what model they will pursue (CoE, Competence centre, etc.). After this so called growth phase, the RPA life cycle is take place which is the tool of how to proceed with RPA implementation further.

The growth phase emerged for the research as a one of the crucial part in overall RPA success within the organization and also the more complicated challenge. The PoC in most cases providing good financial and other results within suitable processes (early candidates) but as RPA progress in a company more complex and robust processes needs to be automated and the difficulty of additional implementation is growing. That's why creating suitable operating model and incorporate RPA into company strategy and governance is so important. Author sees a blank spot and potential for future research in examine the the ways of how to manage the growth of RPA and properly scale the technology across the company to reaps the full benefits.

Academic insight is very important for such a dynamically growing technology as RPA, because as history shows a lots of hyped technology ends in the abyss of history or are replace by something new and more "fresh". So academic research should aspire to find a true view on this domain and provide all interest groups with a grounded knowledge.

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MANAGEMENT METHODS IN HEALTHCARE ORGANIZATIONS: A PRELIMINARY COMPARATIVE ANALYSIS

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Abstract

Today, healthcare facilities are mainly focused on reducing the costs of their operation, especially in public health facilities. In this context, the correct setting of the management method of medical facilities and the search for innovative uses of SMART technologies will lead to the implementation of processes and organizational innovations that will not only reduce the cost of operation, but will be reflected in the context of sustainability and acceptance of prerequisites for the quality of management approaches or corporate social responsibility. The purpose of this paper is to define and classify the management methods used in healthcare organisations. The emphasis is placed on secondary research using content analysis. The analysis assumes that effective management methods involving the CSR approach can help improve management decision making. This article uses comparative analysis of selected healthcare organisations to compare the management methods used within three hospitals, established as a contributing organization, based on secondary data analysis. In conclusion, a checklist evaluation proposal is presented and evaluated.

Keywords: contributory organisations, CSR, hospitals, SMART technologies

JEL codes: I15, L26, M14

1. Introduction

The strategic dynamics of an organisation represents the synchronisation of activities in order to achieve formal goals (Grohar-Murray and DiCroce, 2003; Remund and McKeever, 2018). Bucci (1999) emphasises that through the development of strategic management, innovation and the development of managerial skills and methods in the chosen field can also become more developed. However, they should realise that it is always a service business, like any other, (1) knowledge intensive, (2) working with and for people, (3) but using the same principles of service business, so coordination is needed (Kivisaari and Väyrynen, 2004). One can also agree with the components of skills that should be developed and that a health care entrepreneur should understand, at least in a basic description - financial plan, marketing, cost analysis, basic communication, basic business, and health care law. All of this is also related to their success in the marketplace, growth, and development. Sometimes surprise when one hears about the success of the health service chain and the way it operates a portfolio of high-tech and professional hospitals, clinics, and outpatient clinics. Health care management is linked to the fulfilment of sustainable SDG goals (UN, 2015), specifically SDG 3 Good health and well-being, where it aims to ensure greater capacity, sustainable financing, and development of human resources in the health sector by 2030. This cannot be done without innovation, adaptation technologies, and also the use of SMART solutions for selected activities (automatization, digitalisation, patient localisation, use of telemedicine, e-prescription, e-health applications. Trentin and Tontini (2021) compared more than 41 studies, focused on management methods within hospital and health care management, when 13 of them specialised on information management, 5 studies on quality management, just two on team work development, 6 on supply chain optimisation, 5 on service development, 5 on hospital governance, and four on maturity models. This study showed that methods use is related to the technology management dimension, while the other dimensions like strategy, structure management, people management and decision making were second. In this context, a research gap can be seen in the area of the

implementation of the SDG and the development of CSR reporting and hospital management activities, especially in the form of contributing organizations (publicly funded).

The purpose of this article is to define and classify the management methods used in healthcare organisations, especially within hospitals, as contributory organisations as a preliminary study for future primary research. The emphasis is on secondary data research using content analysis. A checklist is developed to assess the organisation according to secondary sources using a qualitative approach. Therefore, three short case studies will be presented to demonstrate the use of the tool.

2. Theoretical Framework: Use of Managerial Tools within Hospital Management

The provision of health care services must have a clearly stated objective. Who should run the business, the physician personally, or a delegated manager? The service provider also knows the basic principles of management? This affects the process of managing and leading people (management and leadership). Using theoretical knowledge of management and current methods of managing service enterprises in general, it can be deduced that an enterprise can grow into an open system that is able to adapt more quickly to external favourable and unfavourable influences. A possible reason for the difficulties in implementing strategic management principles can also be found in work of Padilla et al. (2011) when discussed a position of general manager within health care organisations as being specialists in biochemistry, anatomy, cardiology, gynaecology, but they're completely unaware of how to creatively address changes in workflow, how to work as a team, or how to communicate effectively. They have learnt how to be as an expert, but they know absolutely nothing about how to be part of a business, how to be a leader, how to conduct meetings, or how to behave towards their patients. This motivates us to use managerial methods, primarily invented for traditional companies. This is why the emphasis has recently been placed on corporate social responsibility (CSR), in all areas and in the non-profit sector, including the management of public hospitals. A CSR is characterised by voluntary actions that an organisation implements as it pursues and fulfils its perceived obligations to stakeholders, including employees, communities, the environment, and society as a whole, including hospitals (Farmer and Hogue, 1985; Coombs and Holladay, 2012; Remund and McKeever, 2018). Therefore, several areas can be defined in the management that can be considered key areas, namely (Trentin and Tontini, 2021): (i) Strategy; (ii) Technology Management; (iii) Structure Management; (iv) Decision Making and (v) People Management.

What concrete management tools are used in hospital management? Various studies are seeking performance models or quality management. As was previously defined, the successful use is closely connected with organisational culture and, in line with that, hospital could be defined as complex, dynamic and specialized ecosystem, and the establishment of thoughts through processes and its effective management requires the right tools and the support of a mature organizational culture, which is the result of Kirchmer et al. (2013) study. On the other hand, Burmester et al. (2007) and Carvalho et al. (2019) argued that the practical use of managerial methods must support hospital decision-making skills and improve processes and systems. It is the reason why some recent studies tend to improve supply chain management (Mettler and Rohner, 2009; Mettler, 2011; Freixo and Rocha, 2015; Blondiau et al., 2013). As other special methods can be mentioned, Management Process Excellence Model (MEG) and Process Enterprise Maturity Model (PEMM) mentioned by Oliveira (2015).

Another group are methods focused on lean management (Usman, 2020; Graban and Prachand, 2010; Hines and Rich, 1997), widely promoted by Naidoo and Fields (2019), namely Healthcare Lean Assessment (HLA) as a part of the model Lean Sprint and finally information infrastructure in the digital transformation of hospital organisations presented by Williams et al. (2019) as the Capability Maturity Model (CMM), developed the Infrastructure Maturity Model (IMM).

When the question about the use of management tools is very important, another question arises: Is the patient as the customer or is the type of diagnosis an object of the service? The possible way of simplification of the system is the application of the time-driven activity-based costing system (TDABC), presented by Popesko and Novák (2011). An alternative approach to performance improvement, transferred from business practise, is presented by the study of Niknam et al. (2020) as outsourcing as one of the tools for organisational development and productivity promotion in the form of downsizing costs and efficacy growth. This process should be supported by the hospital management

system project to simplify all management processes, including patient registration and doctor appointments, to also be able to use activity-based pricing (Nishanthan et al., 2022).

Areeda et al. (2015) speculates about complexity in hospital management, when mentioned areas for managerial methods use as Operations (actions), Finance (money and resources), Personnel (human relations), Information (needed information for wise decisions) and Time (own and that of others). Therefore, in managing, they described the internal process links that contribute to the performance and efficiency of the health service enterprise using the Ishikawa diagram. This simple tool helps to find the elements and their connections in the internal structure of the enterprise and their influence on overall efficiency. Each process can then be decomposed into a main process that creates value and secondary processes, otherwise known as supporting processes, which may include the process of learning, improvement and innovation (Zdogavová and Džupka, 2004). The disadvantage of using the Ishikawa diagram is the decomposition of processes into success factors in business. Then there may be an incorrect evaluation of the contribution of processes to the creation of value for the hospital, as well as the expertise of the diagram maker and focussing on only part of the ongoing processes.

2.1 CSR Connection within Previous Methods

As we expand that previous summary, Reeves et al. (2011) demonstrate the importance of teaching management skills, marketing, and fundamentals of business economics to learn how a business of this type even works. The comparison of these studies reveals four important areas where the use of management methods in hospital management must be monitored. In parallel, the four main areas are management skills, logistics, innovation, and atmosphere. The human factor has a large impact on hospital management, and the implementation of strategy and the creation of a company culture will most influence the repertoire of skills that will be brought to bear as input to hospital effectiveness. The important thing is to find a balance between all essential indicators (Dobni et al., 2001). It is clear that hospital organisations must integrate social, economic, and environmental aspects into health care, but often only information is available on accreditation, quality labels, standards, and certifications. This approach to nonfinancial reporting can also affect managerial decision-making and its impact on the management of the organisation. If a repertoire of CSR activities and the impact is defined, linked to the environment of the organisation, the uniqueness of the approach to the customer (patient) would be expected, and this is then another reason for seeking services (Creixans-Tenas et al., 2019). In the national environment, only subtopics of hospital management are addressed, focused on reporting and efficiency or quality management. The Kraftová et al. (2011) study focused only on the functioning of the spa. For this reason, there are not many available studies for comparison. Secanell et al. (2014) and Dubas-Jakóbczyk et al. (2020) studies just made comparison between participating countries. The linkage of factors from management techniques and CSR can be considered an original idea, when CSR reporting can belong to the nonfinancial evaluation of hospitals.

3. Research Methods and Background of Case Studies

In the pre-research phase, it was necessary to be aware of several facts regarding the future primary sample of the research subjects and the service sector under study: (i) health care is provided in health care facilities or, if necessary with regard to the health condition of the insured person, in another place where care must be provided, by health care professionals or other health care professionals, within the scope of their professional competence; (ii) health care in hospitals is mostly provided to the insured in the form of outpatient or inpatient care. Healthcare providers can provide a combination of these types of healthcare. The scope of care provided and reimbursed is determined by contracts with health insurance companies. The method of reimbursement is defined by price supplements, which are always updated for the relevant reimbursement period, usually one year (Šebestová, 2011). The preliminary study was designated in several phases.

PHASE ONE

This phase consists in the construction of a self-evaluation checklist, based on four areas mentioned in the section 2 (Trentin and Tontini, 2021; Reeves et al., 2011; Dobni et al., 2001), which

was made with examples to help organisations evaluate their methods and connection to CSR reporting, but four out of five items were used as (i) Strategy; (ii) Technology Management; (iii) Structure Management; and (iv) People Management. All areas were divided according to the triple impact assessment. The authors were inspired for this type of evaluation by the methodology for non-profit organisations presented by Brunclíková et al. (2020). A weighting criterion will be needed to be able to calculate their strategic position in each area. Mixed methods have been used for the case studies, when a fully mixed sequential dominant status research design was used. It means that in the first phase a qualitative approach was used, then a form of quantitative evaluation was applied, but qualitative evaluation is predominant (Leech and Onwuegbuzie, 2009).

PHASE TWO

A panel of five experts from practise (three managers in contributory organisations in social and health care, two managers of social care) evaluated the economic, social and environmental contribution of each suggested area separately. In the second step, by the compromise, the evaluation was made according to the following key: When the goal meets the most criteria in one area (primary goal) was evaluated with the sign $\sqrt{\sqrt{\sqrt{\cdot}}}$. If the panellists saw also a second area of impact, a secondary contribution was added ($\sqrt{\sqrt{-}}$) or third (when all impacts were met, $\sqrt{-}$). If the members were not sure of the contribution, the sign “×” was used (Table 1). According to those signs, the weights were calculated as follows: (i) meets criteria in 100% () - weight of 1, meets criteria in 50% (-) – weight of 0.5, meets criteria in 30% (-) - weight of 0.3, meets criteria in 10% (×) – weight of 0.1. The presented version has four areas and six items, a maximum of 30 points.

Table 1: A checklist with weights checked by a panel of experts

Area	Examples	Evaluation (1-5)	CSR area weights setting		
			Social impact (SIw)	Economic impact (EIw)	Environmental impact (EnIw)
Strategy					
Planning techniques used	Use of modern techniques, research support		0.5	1	0.3
Structure Management					
Internal logistics	Type of distribution, logistics process		0.3	1	0.5
Technology Management					
Investment in equipment	Type of investments		1	0.5	0.5
SMART Activities	Type of activities		0.5	1	0.3
Financial resources for innovations	Type of resources		0.1	1	0.1
People Management					
Corporate culture	Unified communication standards		1	0.1	0.3

Source: author calculations

PHASE THREE

Data set: Information was collected from secondary sources such as Web sites, financial statements, and annual reports for the last 10 years.

To compare examined organizations, a table was used. To obtain information on the goals included in their strategy, a Likert scale was used, when 1 means ‘we do not care’, 5 means ‘we are fully involved in that area’. Each criterion has to finally be recalculated as a weight \times scale. When areas are evaluated, score in each area to obtain the final strategic position and orientation of hospitals A to C.

4. Case studies and discussion of the results

First, three mini-case studies of contributing organisations that have a common e-health application for sharing patient treatment data are presented, however, this option is not highlighted for any of the organisations. They are similar in size, age, and focus; therefore, their positions are comparable. Finally, a discussion is made on whether methods other than the theoretical framework are used.

4.1 Case one: Hospital A

This hospital is a contributory organisation established and financed by the local government. It provides a wide range of health care services for more than 40 years. The hospital is especially accredited for paediatric care (baby-friendly hospital) and for urinal diseases. It has 413 beds; in 2021, the hospital employed 1,049 individuals, 854 of whom were women. The composition of the personnel in 2021 consisted of 15.4% medical doctors, 69.78% non-medical health workers, and 14.82% technical and economic staff and workers. It is the only hospital with a strategy document presented online. The vision of the hospital is "*The best hospital in the region and provider of comprehensive health care from birth to old age*", connected with the motto: "*Partner with families for life*". The hospital meets the requirements of ISO 9001 standards. They widely present CSR activities, as innovation or SMART solution introduced an online interpretation service in a sign language for the hearing impaired, the so-called Silent Line or a pilot telemedicine project involving 20 obese patients.

Table 2: CSR position evaluation: Hospital A

Area	Examples	Evaluation (1-5)	CSR area – weighted impact		
			Social impact weighted	Economic impact weighted	Environmental impact weighted
Strategy					
Planning Techniques used	Quality management. Security management	3	1.5	3	0.9
Structure Management					
Internal logistics	Traditional logistic methods, not mentioned others	3	0.9	3	1.5
Technology Management					
Investment in equipment	Replacement, new services	3	3	1.5	1.5
SMART Activities	Telemedicine, digitalisation within the hospital, network with hospital B and C. within e-health app	4	2	4	1.2
Financial resources for innovation	Mixed resources, support of EU projects	4	0.4	4	0.4
People Management					
Corporate culture	Unified communication standards, strategy to build strong culture	4	4	0.4	1.2
		21	11.8	15.9	6.7

Source: author calculations

Social impact is present with kindergarten for employees' children or hospital involvement in volunteer programmes and events. The hospital's decontamination unit to eliminate the hazardous properties of hospital waste and cleaning the hospital with the ozone. The bicycle shelter and a station outside the hospital with a bike sharing and charging station for electric vehicles. Catering has made it

a point to reduce waste food; unissued lunches are sold at the hospital bistro or eaten for dinner by patients (summarised in Table 2).

Evaluation: The hospital identified and evaluated by the hospital. A SMART approach was found. Hospital A is taking a proactive approach to CSR activities and has developed a strategy. It is most focused on the economic impact of its activities, a relationship with the founder, and least focused on environmental activities. Scored 21 points out of 30, which is 70%.

4.2 Case Two: Hospital B

Hospital B provides health care for the region's area, a total of 180 000 inhabitants. Provides care at two workplaces (B1 and B2). As of December 31, 2021, the Hospital employed a total of 1,070 people, including 136 doctors, 752 nonmedical health personnel (NMPs), and 182 workers and operational staff with capacity of 415 beds. Department B1 provides acute care in its departments, including the internal ward, surgical ward, children and new-born ward, gynaecological and obstetric ward, emergency department, and long-term care clinic. Among the top workplaces of the B1 Eye Centre and the Orthopaedic Department, which is extended in its robustness through the Day Surgery Centre to the second workplace in the B2 department. The B1 site provides outpatient specialist clinics, complementary services, transfusion service facilities, two pharmacies, as well as a medical emergency service for adults, children, and adolescents and a dental emergency service. In part B2, health care is oriented towards the provision of aftercare, in the following departments: rehabilitation department and long-term care clinic. The hospital has not published a strategy on-line.

Hospital B is increasing the security of information systems, computer centres, and network communication. The motto is 'The reward for our work is your health', connected to the mission: to provide comprehensive, quality and safe care. The vision is based on values such as (i) favourable working conditions and fair staff relations, (ii) professional care - quality in a safe environment, and (iii) An economically stable and prosperous hospital. It has Quality and Safety Certificates, based on ISO 9001 and ISO 15189. Very important for atmosphere was a change of the hospital's communication concept, which included the creation of a new name and logo for the hospital, implemented by 2022 (summary in Table 3).

Table 3: CSR position evaluation: Hospital B

Area	Examples	Evaluation (1-5)	CSR area – weighted impact		
			Social impact weighted	Economic impact weighted	Environmental impact weighted
Strategy					
Planning Techniques used	Quality management	2	1	2	0.6
Technology Management					
Investment in equipment	Replacement	3	3	1.5	1.5
Financial resources for innovation	Mostly public resources	5	0.5	5	0.5
People Management					
Corporate culture	Unified communication from 2022	3	3	0.3	0.9
		13	7.5	8.8	3.5

Source: author calculations

Evaluation: The evaluated hospital had 4 of the 6 areas assessed, with SMART and CSR activities missing. The involvement in electronic health was not mentioned at all in the secondary documents. In general, the hospital scored 13 out of 30 possible points and is therefore 43%. Again, it has the least impact on the environment.

4.3 Case three: Hospital C

This hospital is a contributory organisation established and financed by the local government. It provides a wide range of health care services for more than 50 years. The hospital is especially accredited by the Czech Society for Sleep Research and Sleep Medicine. It has 385 beds and, in 2021, the hospital employed 957 people. The composition of the personnel in 2021 consisted of 14.6% medical doctors, 70.63% non-medical health workers, and 14.77% technical and economic personnel and workers. The hospital passed an external quality and safety assessment. Motto: ‘A hospital without borders. Objectives: improving the quality and safety of services provided with the participation of persons, bodies, and teams responsible for quality and safety management, personal commitment of top and middle management, interconnection of quality and safety management with other hospital management procedures, awareness, and participation of all staff (summary in Table 4).

Table 4: CSR position evaluation: Hospital C

Area	Examples	Evaluation (1-5)	CSR area – weighted impact		
			Social impact weighted	Economic impact weighted	Environmental impact weighted
Strategy					
Planning Techniques used	Quality management, other certificates	3	1.5	3	1.5
Technology Management					
Investment in equipment	Replacement	2	2	1	1
Financial resources for innovation	Public resources 90%	2	0.2	2	0.2
People Management					
Corporate culture	Not communicated to public	2	2	0.2	0.6
		9	5.7	6.2	3.3

Source: author calculations

Evaluation: The evaluated hospital had 4 of the 6 areas assessed, with SMART and CSR activities missing. Again, involvement in the e-health network was not mentioned in the secondary documents. In general, the hospital scored the lowest, 9 out of 30 possible points, which is 30%. Again, the least impact of CSR is on the environment. The exception is the balanced balance between social and economic impact. Sub-assessments in Tables 2 to 4 provide the basis for the comparison of hospitals A to C in Table 5. Only hospital A could be evaluated on all six indicators. Hospital C achieved the lowest score.

Table 5: Comparison of hospital's position

	Hospital A	Hospital B	Hospital C
Number of items	6/6	4/6	4/6
Average score per item	3.5	3.25	2.25
Score total	21/30	13/30	9/30
Social - Weighted score	11.8	7.5	5.7
Economic - Weighted score	15.9	8.8	6.2
Environmental - Weighted score	6.7	3.5	3.3
Main gap within area	9.2	5.3	2.9

Source: author calculations

Through this pre-research phase, the limitations of the research were revealed, namely, that each evaluation must be supplemented with primary data in order to complete information, which is not published externally. Furthermore, the number of indicators will have to be expanded and this will require the use of experts from practise and focus groups, where it is necessary to find out whether hospitals use other management methods besides quality management elements, whether cost

management (Popesko and Novák, 2011) or lean management elements (Usman, 2020), or how they report CSR activities (Remund and McKeever, 2018; Coombs and Holladay (2012), when out of three randomly selected hospitals only one did so, as well as in the identification of the strategy document, which does not correspond to the studies of Williams et al. (2019) or Trentin and Tontini (2022). Although the study was not very extensive, it pointed out the possible pitfalls of primary research, namely the setting of a checklist, the necessary link to CSR reporting the need to ascertain the sub-element of management as shown a case of Hospital B and C (the reports were not found).

Therefore, the next phase of research should be to continue to scan the type of organizations and familiarise them with the content of management methods and CSR and how they are connected. It is necessary to test the current set of the checklist to be able to develop the evaluation model and be able to add other indicators to that dashboard. As secondary data analysis showed the resources cannot answer clearly all areas which they are meeting within a CSR reporting approach, which could be closer to them (Palová and Šebestová, 2020; Brunclíková et al., 2020). However, using that matrix (Table 1), the imbalance of all three CSR pillars was quantified and which part needed support or better promotion or participation of clients. Other organisations could gradually use the tool created to self-evaluate individual processes to adjust their mission or strategic goals, especially within health care.

5. Conclusion

The comparative analysis carried out showed that hospitals of the contributory organization type primarily pay attention to the social aspect of their care in accordance with financial indicators. The environmental impact is then subversive. all this can be a starting point for the upcoming primary research, which area to focus on, so that even SMART technologies contribute to the development of the CSR concept not only in terms of cost savings, but also in terms of environmental impact. A *limitation of this study* could be seen in several case studies tested on those indicators and the second limitation of quantitative measurement prepared by the expert panel based on the Trentin and Tontini (2022) study.

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DETERMINANTS INFLUENCING CUSTOMER BEHAVIOUR IN RETAIL

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Abstract

The aim of the paper is to examine the situation of customer buying behaviour in retail, including the reference groups that influence this behaviour and how these areas intersect. The starting point is a bibliometric analysis, which makes it possible to analyse the frequency of occurrence of the research subject and the authors who deal with this issue. The theoretical research will focus on the purchasing behaviour of customers, retailers, SMEs, or the reference groups themselves. The results of the secondary research will be used for further scientific research in the mentioned areas for the purpose of the planned primary research.

Keywords: MSP, buying behaviour, reference group, retail, customer

JEL codes: M 31

1. Introduction

For a long time, retail has been a small and medium business. However, its form is constantly evolving. The retail business is subject to certain developments. The typical phenomenon is that there is an increase in sales capacity while the number of retail units (outlets) is decreasing. Purchasing conditions are changing and retail concentration is occurring. Large capacity retail units, such as supermarkets, hypermarkets, and discounters, are becoming the core of the retail network. The networks of these units are often operated by large retail chains with all logistics facilities. These chains usually have a dominant position in the market, which is also the case in the Czech Republic, which after 1989 has seen a transformation of the trade and retail market within the European market, where internationalisation has increased dramatically (Starzyczna, 2010). Therefore, large foreign companies have a significant influence on the Czech market and are increasing their influence and impact on the business environment. Among the European Top 50, most companies today have widespread foreign activities, and many of them are also active in the Czech Republic. There is a new generation of consumers who know how to work with the Internet, which may bring about a possible radical change in shopping and purchasing behaviour.

The aim of this paper is to examine the situation in the field of customer buying behaviour in retail including reference groups based on the frequency of occurrence of selected key terms or phrases in the scientific literature. The authors start with a brief theoretical discussion that deals with the subject under investigation. The research method chosen was the VOSviewer method, which is used to determine the level of attention to selected key terms and connections in scholarly publications devoted to the subject. At the same time, attention is paid to the authors dealing with the subject of the research.

1.1 Theoretical background

Let us now take a closer look at the theoretical background of the issue under study. Let us examine the main concepts related to retailing, internationally perceived retailing, as well as the nature of firms and buying behaviour, including reference groups.

1.1.1 Retail, Retailing, and SMEs

The goods travel from the producer to the customer in the logistics chain. The purchase and sale of goods are carried out by intermediaries. At the end of the logistics chain, the retailer who sells the goods to the final consumer. The retailer can buy goods directly from the producer or from a wholesaler.

In the broadest sense, retailing can be said to have begun when one valuable item was first exchanged for another. In a narrower sense, it is a full-time specialised business. The first retailing can be dated back several thousand years, when peddlers first began selling their goods and when the first marketplaces were established (Britannica, 2023).

As with most business activities, there is extreme competition and "mortality" of retail establishments. This mortality rate is quite high. It depends on the business mix sold. The basic competition is primarily based on price, but in the case of bricks-and-mortar retailers, it is somewhat mitigated by nonprice forms of competition. These include the location and display of goods on the sales floor, the attractiveness of the retail outlet itself, and intangible factors that can attract customers (e.g., competitions, loyalty programmes) (Britannica, 2023).

As mentioned in the introduction, retail has been a small and medium-sized business. It was only after the Second World War, when living standards were rising in most market economies, that the qualitative aspect of retailing changed. New types of stores appeared on the market and their size increased. Retail organisations operated networks of these large-scale outlets. However, small and medium-sized retailers still have a place in retail, not only in brick-and-mortar stores but also in e-commerce.

Retail marketers are concerned with the identification of their customers and consumers, their segmentation, in-store marketing, creating a shopping atmosphere, and marketing tools that are fulfilled in the store (Jaderná & Volfová, 2021). Small retailers can be closer to their customers. They can establish closer contact and longer-term relationships with them. They can better understand them and understand their needs. Today, every SME, not only in the retail sector, tries to respect the needs of its customers. However, they do not always manage to adapt their marketing activities accordingly. In addition to a quality product and an adequate price, customers value additional services and after-sales care (Stoklasa et al., 2013).

In the international environment, people talk about retailing. According to Kotler and Keller (2013), it is an internationally perceived retail business fully equipped with all logistics facilities (own wholesale, transport, foreign representation, possibly some manufacturing activities, and a highly qualified information system with professional management". The concept of retailing is also already understood as a venture of retail managers, while retailing can be associated with purely marketing issues, which can distance some managerial activities (Jaderná and Volfová, 2021).

Two factors were and are still a prerequisite for the development of retailing. There is a long-term effect of the continuous growth of the income of the population and their standard of living, and there is also a more frequent determination of the buying and selling process by the buyer and the end customer (Starzyczna and Bauerová, 2020). Some authors discuss so-called retail innovations in the context of a globalizing international environment (Reinartz et al, 2011), which could positively influence the customer relationship.

1.1.2 Purchasing Behaviour and Reference Groups

Parallel with qualitative changes in retail and retailing, customer demand is increasing and customer orientation is continuing. This increasing demand is reflected in higher requirements for quality, service and service, comfort, and experience. Customer behaviour is changing. Their desire is not just for goods, but for a comprehensive service and relationship. The retail industry strives to create a range of goods that suits customers in terms of location, time, types, quantity, quality and price level (Mulačová et al, 2013). For these reasons, it is necessary to identify customer desires and monitor their buying behaviour and the influences on them.

Each consumer takes different factors into account when choosing products. Age, income, gender or place of residence have an impact on their purchasing behaviour (Novotný and Duspiva, 2014). Research on purchasing behaviour cannot do without market segmentation, which examines segmentation criteria (cultural, social, economic, personal and situational) (Solomon et al., 2006; Turčínková, 2011). Social and cultural factors and the retail environment have an impact on customer decision making and includes cognitive as well as emotional and behavioural responses (Grewal and Roggeveen, 2020). Positive affective or social experiences of customers (whether self-reported or mediated by referrals) are also important and can lead to customer loyalty (Thompkins, 2022).

Reference groups can also decide what a customer buys, what brand, or what product. Reference groups belong to social factors. It is primarily the family that is the decision-making unit and has a direct influence on customer decision-making. It is a membership group and includes, in addition to family, e.g. friends or neighbours. In addition, customers belong to secondary groups (religious, professional, trade union) which are more formal in nature. However, they can influence the lifestyle and behaviour of the individual (Kotler and Keller, 2013).

Often, customers are influenced by variously large groups of which they are not even members (Novotný and Duspiva, 2014). However, identification with a group can arise. If it is an open group, anticipatory socialisation should take place and the individual becomes a member of the group (Boháček, 2020, p. 24).

The very concept of reference groups was introduced by Merton in collaboration with Rossin as early as 1950. They defined a reference group as *"a group which serves as a standard for an individual to evaluate his own behaviour, attitudes, aspirations, lifestyle, ambitions, appearance, etc., with which the individual compares himself as a member, to which he aspires if he is not a member"* (Merton, 1968).

2. Methodology

As mentioned in the introduction, the objective of this article is to determine whether customer behaviour in retail is in any way pervasive in the research literature and to evaluate the occurrence rate of selected keywords based on the information found. To achieve this goal, the VOSviewer method was used, specifically its software, with the help of which the corresponding bibliographic maps were created.

VOSviewer is software that is used to construct technical maps; these maps are used to better visualise the relevant information (Van Eck et al., 2007). It is also able to display the created maps, using any mapping technique. Thus, the software can be used not only to display maps but also as a multidimensional scaling tool. VOSviewer itself runs on a large number of hardware and operating systems. Another advantage of this software is that it can be run directly from the Internet, and no installation is directly required (Van Eck and Waltman, 2007).

For the VOSviewer analysis in the field of customer behaviour in retail, 1,000 articles from the Web of Science database were used, which were found by keywords: customer behaviour, customer behaviour in retailing, purchasing behaviour in retail SMEs, reference group in purchasing behaviour. For the last link, the maximum number of articles found in the Web of Science database was used. That is, 89 publications. We also wanted to keep a time resolution of 5 years.

The applied method will enable the initiation of a theoretical discussion of the study with regard to the thematic focus of the dissertation, which also applies to the selection of keywords. The historical method can be applied to further research in the theoretical area.

3. Results and discussion

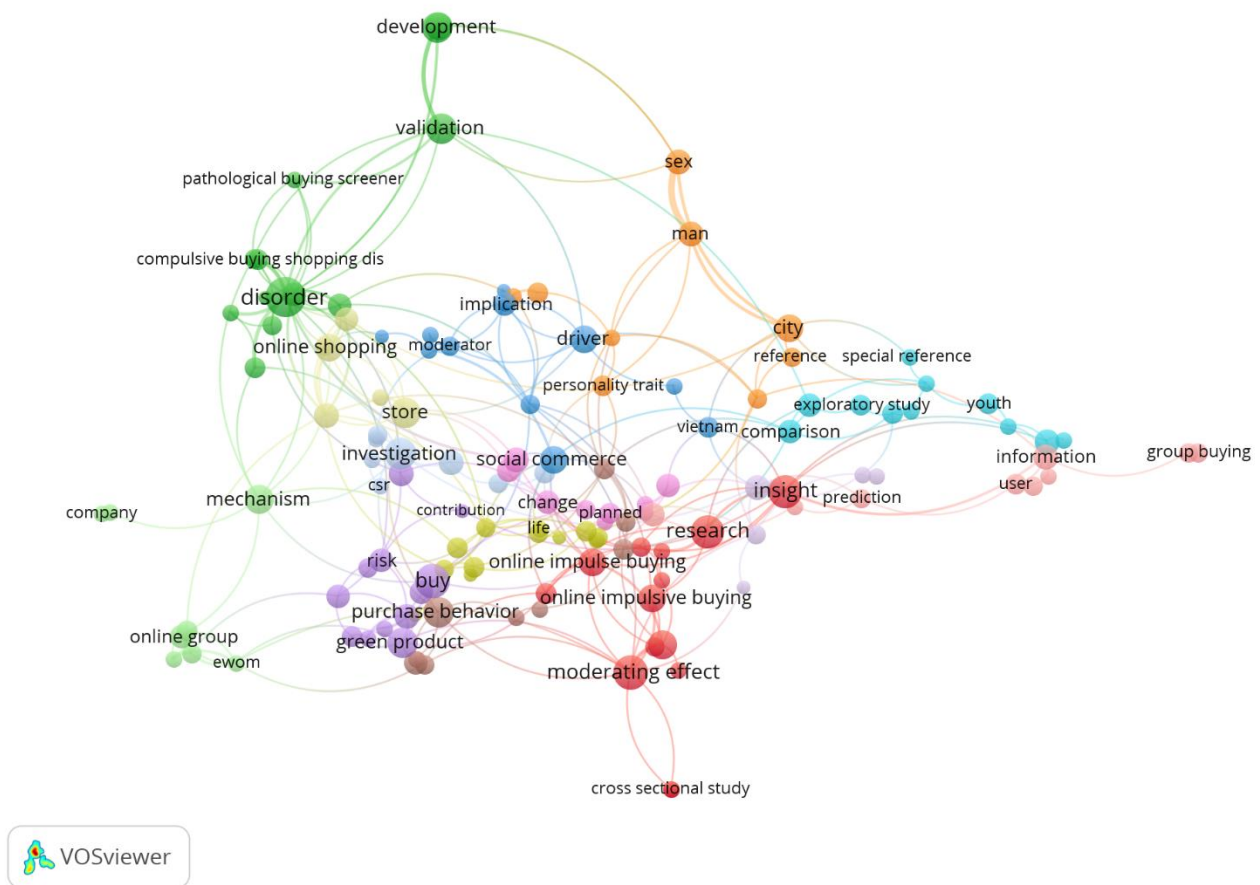
At the beginning of the research, we will start by examining maps of key concepts and key connections, followed by maps of authors who are working on the issue. Among the key concepts and connections, we have included shopping behaviour, retail shopping behaviour, purchasing behaviour in retail in SMEs and reference group in shopping behaviour.

3.1 Bibliometric map of the key concept of purchasing behaviour

The map is based on 2639 phrases, where the keyword must appear at least 3 times in the text. The map is divided into several parts. The term consumer-dependent buying behaviour appears seven times on the map, and compulsive buying behaviour occurs nine times on the map. It can be seen from the figure that the most important keyword for purchasing behaviour is the word disorder. This word occurs 17 times, and other words (addictive behaviour, mechanism, risk, self-esteem, review, compulsive buying dis, pathological buying screener, validity, or development) are related to it. This linkage highlights that researchers are more interested in atypical behaviour, risks associated with pathological buying, and the mechanism of buying. This information can also be useful in marketing research, but is not very concerned with homogeneous groups with buying patterns.

The thematic focus of the articles is also related to the problems accompanying retail sales, such as the Covid pandemic, which has transferred some of the shopping activities to the online environment. Attention was also paid to impulse buying in the online environment. This link can be seen in Figure 1.

Figure 1: Bibliographic map of buying behaviour keywords



Source: custom processing via VOSviewer software

Among other significant phrases, the moderating effect occurs 13 times in the text and is associated with other terms such as ewom (Electronic word of mouth), green product, purchase behaviour, online impulse buying, cross-sectional study, meta-analysis, or research). According to the map, the least used words are (group, buying, company, online group or pricing). These words occur a maximum of 4 times in the texts. Thus, less attention was paid to group buying, which could indicate a lack of interest in customer segmentation?

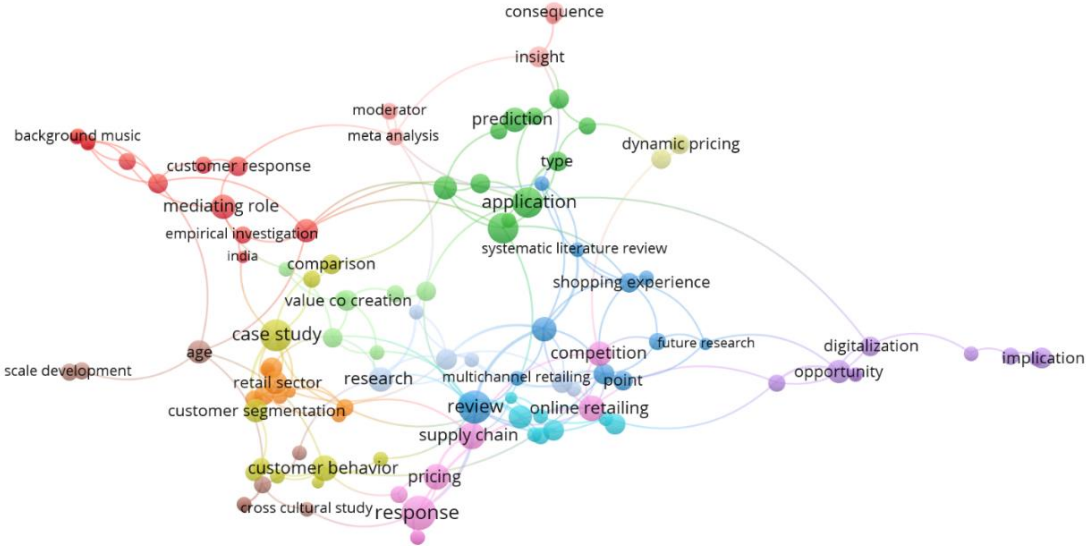
3.2 Map of the key link shopping behaviour in retail

Next, we focus on the word connectedness for the key phrase retail shopping behaviour, which is shown in Figure 2.

This concept map is based on 2852 phrases that must appear in the text in at least three publications. The main keywords related to retail purchasing behaviour are divided into five groups. These are red where the main keyword is mediating role, followed by yellow-orange where the main keyword is case study, then there is a blue-purple section where the main keyword phrases are response and review, then there is a green section where there is a midpoint at the word application and the last section is brown and there the most important keyword phrase scale development emerges. The most important concept can be considered to be the word response. Its occurrence is the highest. It occurs up to 15 times. Customer response and feedback is very important for a retailer. It indicates customer satisfaction or suggestions for the creation of an offer.

Other words such as pricing, customer attitude, online retailing, or review are related to the term response. The word review is used 14 times and is linked to other words such as research agenda, evaluation, multichannel retailing, online retailing, marketing strategy, and response.

Figure 2: Bibliographic map of keyword shopping behaviour in retail



Source: custom processing via VOSviewer software

Another significant word is the phrase retail environment, which has been used to link 12 keywords such as shopper, segmentation, application, type, shopping experience, and internet. The keyword Internet is paradoxically the least frequent compared to the others. The retail environment is constantly evolving, the exterior and interior quality of traditional stores and websites in the online environment is changing.

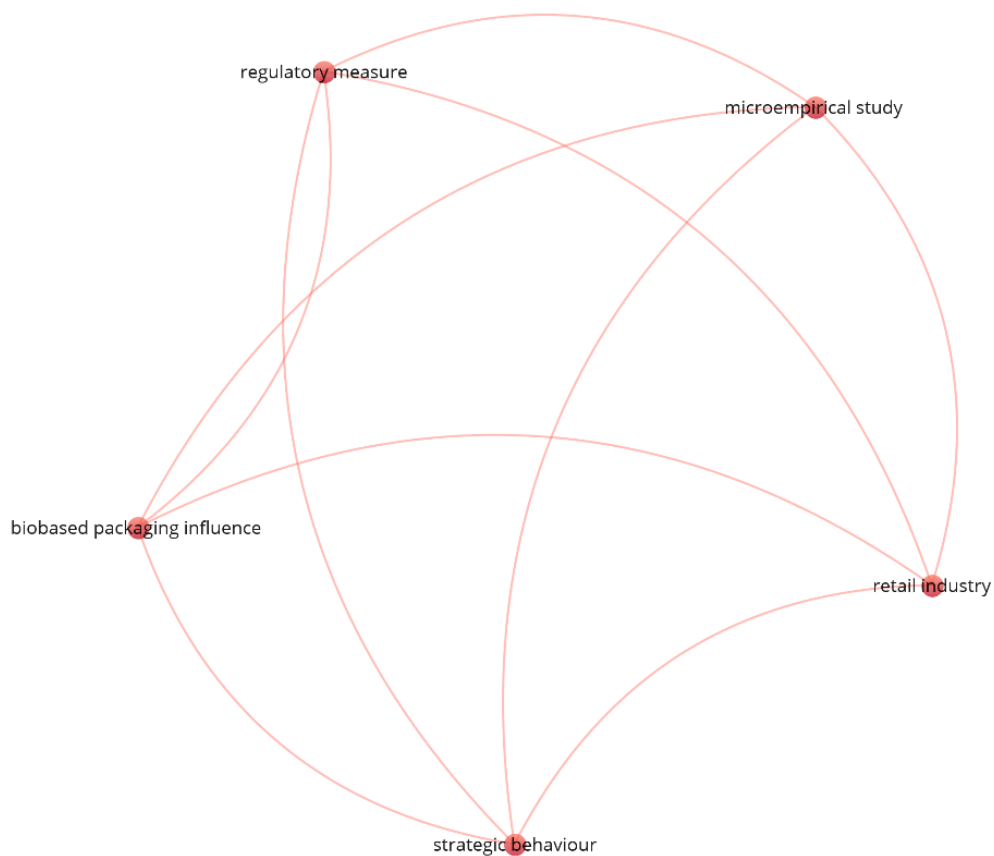
The map clearly shows that implication, dynamic pricing, consequence or scale development are the least connected to the field of shopping behaviour in retail. All the words mentioned have an occurrence of up to 6.

The next map is based on the key link of retail shopping behaviour in SMEs.

3.3 Map of the key link of purchasing behaviour in retail in SMEs

A graphical representation of the key concepts can be seen in Figure 3. The map is based on 16 phrases that must appear in at least 10 publications. All words can be considered as key words because the frequency of occurrence is the same everywhere. The phrase with the highest connectivity is the influence of biobased packaging, which is related to regulation measure, strategic behaviour, retail industry, and microempirical study.

Figure 3: Bibliographic map of keywords of purchasing behaviour in retail SMEs



Source: custom processing via VOSviewer software

If you look at other word connections, it is clear that another connection is found in the phrase regularity measure, which is related to the packaging influence, strategic behaviour, retail industry, and the microempirical study mentioned above. From the figure it is clear that all the word phrases are linked together. The focus was on the strategic behaviour of the retail industry I with regard to microempirical

studies and the influence of packaging on consumer decision making, which is also indirectly related to purchasing behaviour. The strengths of SMEs were not observed in relation to customers and their behaviour.

3.4 Map of the key link of reference groups on purchasing behaviour

The next map is linked to the key association of reference groups with buying behaviour. Its graphical representation can be seen in Figure 4.

Figure 4: Bibliographic keyword map reference groups in purchasing behaviour



Source: custom processing via VOSviewer software

This map is based on 381 phrases that must also appear in the text in at least three publications. It can be seen from the figure that only five key phrases met this condition. These are green product, reference group, influence, purchase, and effect. From the examination, it is clear that the keyword effect has the highest representation, which appears 9 times in the text and has a direct line, to the word purchase. The next most frequent keyword is purchase, and this is found 8 times in the text and links to the words, reference group, influence, or effect. The other three words are found only 3 times in the text. The green product is in focus in terms of the trend of development in the global environment and the ecological requirements of the goods, in retail sales. This is related to the modification of marketing as such in the form of social marketing and the newly opened green stores, which are part of the trend of humanising sales (Ciobanu and Tuclea, 2022).

3.5 Map of authors dealing with purchasing behaviour

For the first analysis in this sector, the key phrase of buying behaviour was chosen. From the Web of Science database, 1,000 publications were selected from authors who use this key phrase the most. We still keep the same time interval, i.e. the last 5 years. There were 2,900 authors, and 293 of them met the conditions. What is clearly visible in Figure 5 is that more researchers are interested in this issue, which is colour-coded according to the year the article was published.

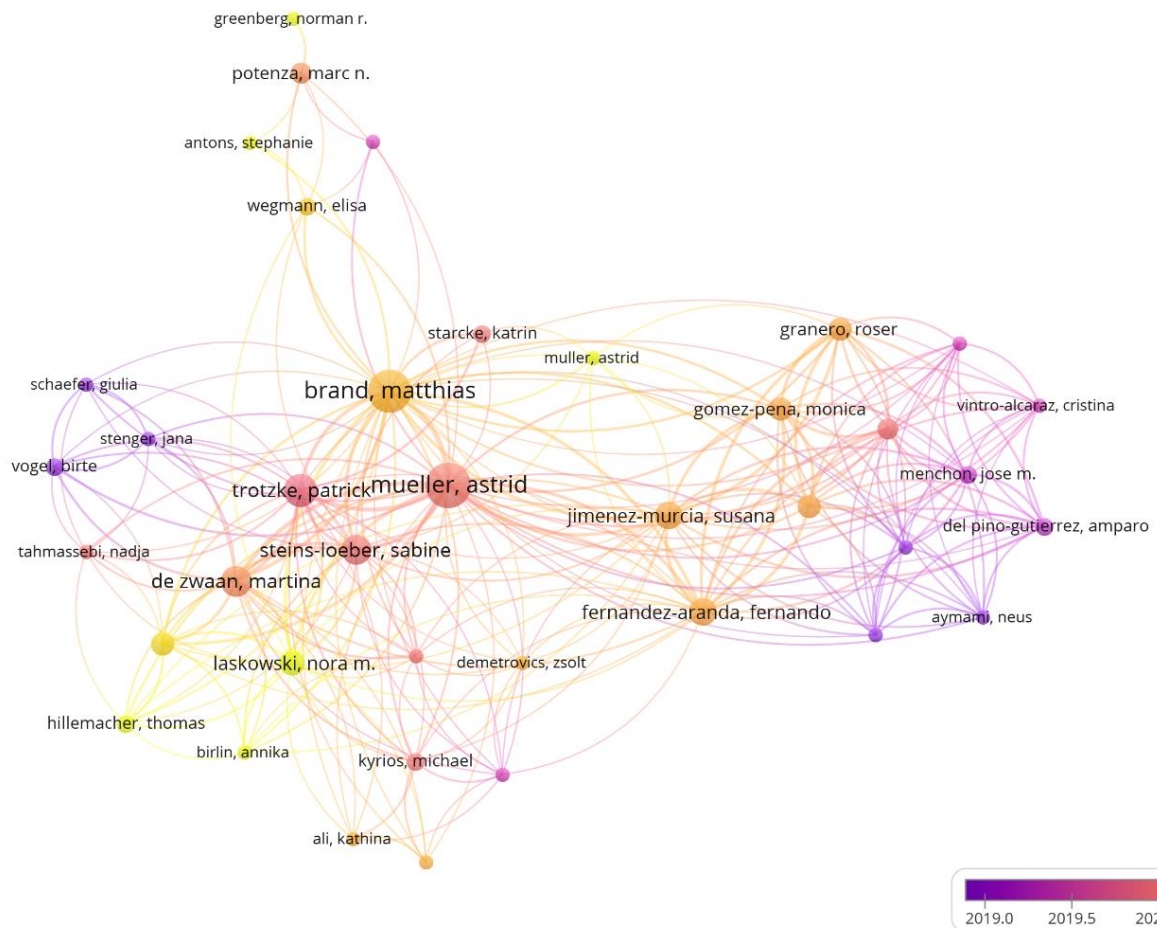
The largest group on this map is shown in red-orange. This is the group that contains the most frequently occurring author, Mueller, who is also one of the most cited authors with links to all the other authors. Mueller is mainly concerned with psychological aspects of buying behaviour (Mueller, 2020). Psychological factors include customer attitudes and are thus related to attitudinal loyalty, which has been the focus of research by other authors (Oliver, 1999; Esmaeilpour, 2015). Creating an emotional attachment to a company or brand in today's competitive market is highly desirable (Buttle and Maklan, 2015).

Psychological factors include customer attitudes and are thus related to attitudinal loyalty, which has been the focus of research by other authors (Oliver, 1999; Esmaeilpour, 2015). Creating an emotional attachment to a company or brand in today's competitive market is highly desirable (Buttle and Maklan, 2015). There is a significant collaboration between Mueller and Trotzke, who write about pathological buying behaviour or buying behaviour itself (Mueller and Trotzke, 2019; Mueller and Trotzke, 2020).

Other prominent authors according to the map include Brand, who is also one of the most cited authors, who has his branch marked in orange. This author also examines buying behaviour from a

psychological perspective (Brand et al., 2022), as does Mueller. They have worked on some articles together (Mueller and Brand, 2019).

Figure 5: Bibliographic map authors with key buying behaviour



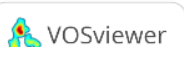
Source: custom processing via VOSviewer software

Another prominent part on the map is visible on the right side, where the authors are coloured, take orange. In this part of the map, we can notice Jimenez-murica and Fernandez-aranda (Fernandez-Aranda et al., 2020). These authors investigated suicidal tendencies in people with a shopping behaviour disorder (Fernandez-Aranda et al., 2021).

3.7 Map of authors dealing with purchasing behaviour in retail SMEs

The next analysis looked at the key link between purchasing behaviour in retail SMEs. Here, the maximum number of articles written over a period of 5 years was selected from the Web of Science database, i.e., 3 publications. In figure 6 it can be seen that not many authors deal with this issue. Only 12 authors have met this condition.

Figure 6: Bibliographic map authors with key purchasing behaviour in retail SMEs



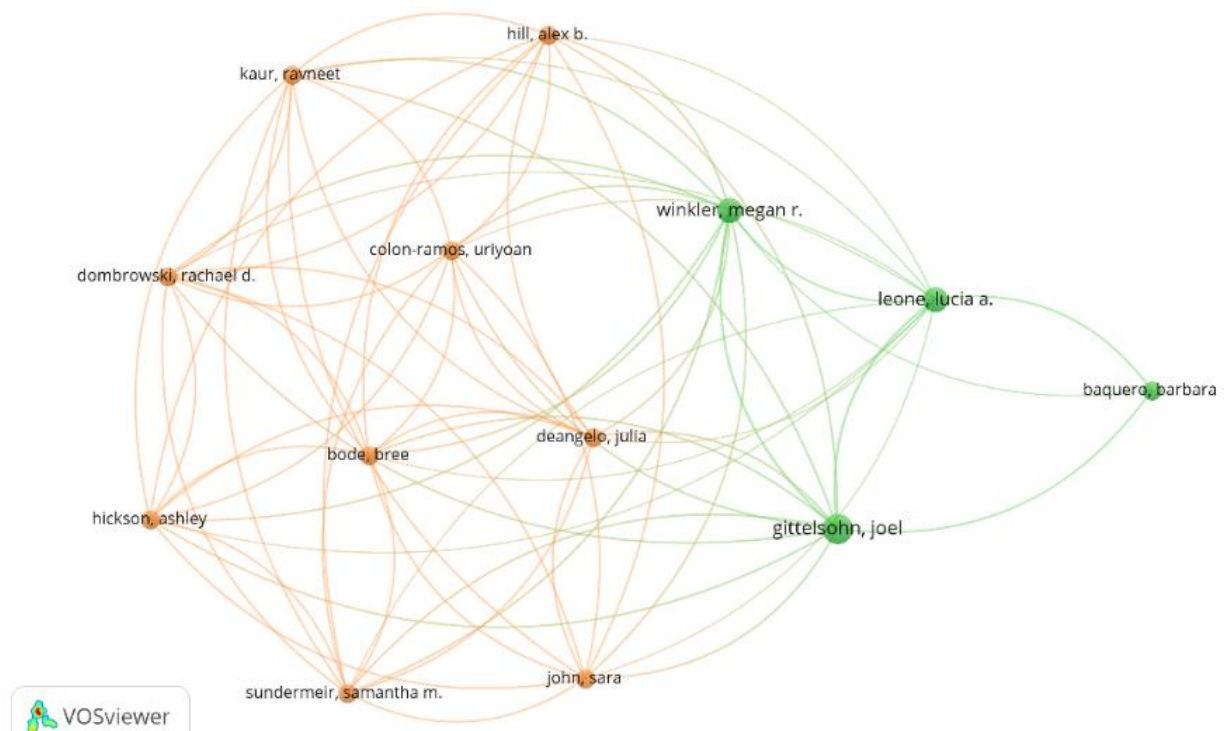
Source: custom processing via VOSviewer software

The main publishing authors include Ghouri, who is linked to the other authors and is thus at the centre of the map. This author has written a publication on real-time customer orientation where he examined differences in the service industry (Ghouri, 2021). A number of authors outside our sample deal with customer orientation in the Czech market conditions in different retail sectors (Simová 2009; Kozák 2013). Several authors outside our sample deal with customer orientation in the Czech market conditions in different retail sectors (Simová 2009; Kozák 2013). These authors are connected by five lines that are linked to other authors, Mirza, Gayane, Meyer, Venkatesh, or Pervaiz. All the mentioned authors have also collaborated on this publication.

3.8 Map of authors dealing with shopping behaviour in retail

For the third analysis of the authors, the keyword customer behaviour in retailing was used, for which 1,000 publications were found in the Web of Science database for the last 5 years, i.e. from 2019 to 2023. When creating the analysis, a minimum of two authors could be involved in one article. Thus, of the maximum number of 2 841 authors, 243 of them met this condition. Figure 6 shows two coloured scales in which it can be seen which authors collaborated the most and with whom.

Figure 7: Bibliographic map of authors with the key term customer behaviour in retail



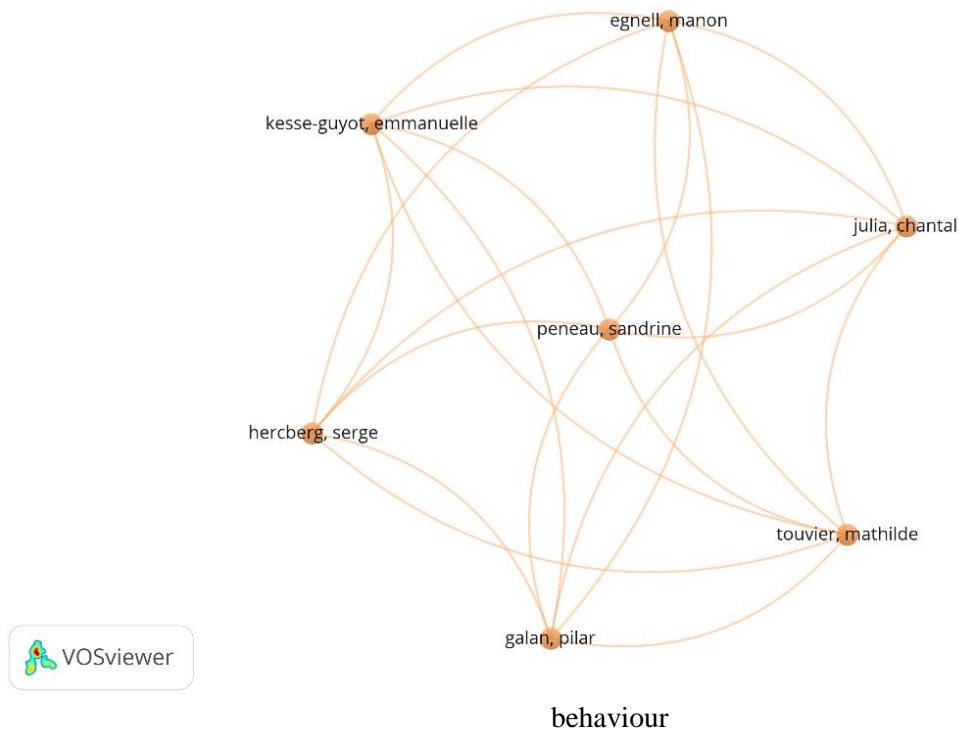
Source: custom processing via VOSviewer software

If we look at the first colour resolution, orange, we can see that Ravneet collaborates with all the authors in the red part and 6 in the green part, namely Winkler, Leone, and Baquero (Leone et al., 2020). They focus their publications on the retail environment itself, both in the Covid era and beyond. They also examine the interaction with customers themselves (Leone et al., 2020). In the green section, the most prominent authors are Kaur and Gittelsohn (Kaur et al., 2022). This author collaborates with all the authors seen in the figure and has focused on the same kind of problem in his publications as the authors before him. He has also focused his attention on healthy community stores and the implications of Covid 19 for retailers and retail policy itself. From the map here, it is clear that the most prominent author using the keyword customer behaviour in retailing is Gittelshon.

3.9 Map of authors dealing with the influence of reference groups on purchasing behaviour

The authors' final analysis concerns reference groups. For this link, there were 89 articles in the database that are less than 5 years old. The conditions of the analysis are the same as for the previous maps. Here, all conditions were met by 13 authors out of 327.

Figure 8: Bibliographic Authors' map with the key concept of reference group in purchasing



Source: custom processing via VOSviewer software

Only one colour interface can be seen here, and that is orange. Here there are authors who are linked to each other. There is no dominant bubble that is superior to the other authors. In fact, all authors are cited equally. All of them in the figure are interested in similar or the same issue, namely consumer behaviour, brand loyalty, or brand targeting (Ding et al., 2020). Fostering customer loyalty contributes to customer loyalty, which is challenging to maintain in today's highly competitive market.

4. Conclusion

From the analysis of the maps that were created using the VOSviewer software method, it was found that the frequency of occurrence of the key terms or key phrases under study is very diverse. Researchers show a differential interest in certain areas. Some areas are given more attention, others less attention.

The maps are intertwined, but overall the issue of purchasing behaviour in reference groups is not given comprehensive attention. Although there are authors who define reference groups, in the literature search, as an essential link of purchase behaviour (Novotny and Duspiva 2014). The authors in the research section of Ding, Lin and Zhang (2020) share this view and talk about the fact that reference groups are a very important factor that influences buying behavior are the ones that can have informative influence and normative influence.

The maps are intertwined, but overall the issue of purchasing behaviour in reference groups is not given comprehensive attention. Although there are authors who define reference groups, in the literature search, as an essential link of purchase behaviour (Novotny and Duspiva 2014). The authors in the research section of Ding, Lin and Zhang (2020) share this view and talk about the fact that reference groups are a very important factor that influences buying behaviour are the ones that can have informative influence and normative influence.

It can be said that scholars who deal with buying behaviour focus their work mainly on terms associated with the concept, such as disorder, store, buy, impulse buying (see Table 1). However, if we look at researchers who study retail purchasing behaviour, they focus mainly on terms such as prediction, review, response, or application.

Table 1: Summary of research results related to concepts and key phrases

Key term	Number of phrases	Frequency of occurrence min. 3	Related terms
Buying behaviour	2 639	247	Addictive, behaviour, mechanism, risk, self-esteem, review, compulsive buying shopping dis, pathological buying screener, validity, or development.
Buying behaviour in retail	2 852	209	Response, review research agenda, evaluation, multichannel retailing, online retailing or marketing strategy
Behaviour in retail SMEs	16	(here the frequency of occurrence was only 1) 16	Regulation measure, strategic behaviour, retail industry, and microempirical study.
Reference groups on purchasing behaviour	381	14	Green product, reference group, influence, purchase, and effect.

Source: own processing

However, if we look at the map of reference groups and influence on buying behaviour, we can see that the most important keyword here is purchase, which is a logical connection.

The most frequently cited author who has worked on purchasing behaviour is Mueller, who has 18 publications on this topic, with a total link strength of 109. The second most prominent author who has worked on the issue of buying behaviour is Brand, he has 17 publications and a connection strength of 98. In the map of authors who deal with buying behaviour in retail, the most frequent author is Winkler, he has 3 publication outputs and a connection strength of 24. In the case of retail purchasing behaviour in SMEs, the author of the, which would have the largest number of outputs, All authors interested in this issue publish equally. For the reference groups in purchasing behaviour, the same result is found as for the previous group.

In conclusion, the selected key connections have some occurring on multiple maps and some not at all. Further theoretical discussion should see this analysis as a starting point for exploration and proceed now to the historical method of how these key terms have been treated over time and what each scholar's approach to them has been.

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COMPARISON OF THE SCORING METHOD AND THE CONJOINT ANALYSIS IN PREFERENCE EVALUATION

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Abstract

This article deals with the preferences of young customers for restaurant choice. Its purpose is to support the decision-making process of managers in restaurants in Karvina near the Silesian University in Opava, School of Business Administration in Karvina. The opinion of the young generation can be a significant hint for the future development of customer behaviour. Research was carried out in the winter semester of 2022. First-year semester students were asked. Their preferences for the choice of restaurant for lunch were investigated. The evaluation was performed by two methods. Particular criteria were evaluated using the method of scoring. This method seems to be direct, simple, and conscious. Furthermore, the students evaluated 27 defined combinations composed of 4 factors (restaurant, dish, price, experience). This was solved by conjoint analysis, which is more intuitive and unconscious. The aim of this paper is to compare the ranking of criteria using two of the above-mentioned methods.

Keywords: Conjoint analysis, evaluation, preference, restaurant choice

JEL codes: C15, C44, M31, L83

1. Introduction

The central theme of the article is to point out the differences between the method of scoring and the conjoint analysis. Although the method of scoring is easy for the respondent, the conjoint analysis demands more of his/her attention. With the method of scoring, the respondent quickly evaluates his/her preferences. He/she decides directly on the factors. In the conjoint analysis, combinations of factors are evaluated. It is actually a simulation of the real market. The respondent has the opportunity to put himself/herself in a real situation. Its assessment is more intuitive and unconscious. This article compares these methods and the results of these two methods, too.

Research was carried out in the winter of 2022. First-year students from the Silesian University in Opava, School of Business Administration in Karvina, were approached. In addition to the comparison of methods, research can also serve as a means and a topic of thinking for restaurants in Karvina, located near the university. It may seem a smaller group of respondents – 83 (obtained by cleaning from inconsistent and incomplete answers), but this is an experimental sample typical and sufficient for the needs of conjoint analysis. Research results indicate significant changes in consumer behaviour. It is very important to follow the trend in customer behaviour of the younger generation. Customer behaviour between generations is often very different. While tracking the young generation helps to indicate the future direction of the market. Knowing the preference characteristics of the target group in advance and determining those factors that can enhance the preference and purchase intention of customers is essential for the successful management of catering industries (Zuo et al. 2022).

This topic might seem well-researched, but there are not many studies in the world dealing with conjoint analysis in the area of customer preferences regarding the choice of a restaurant for lunch. This is certainly due to the fact that it is always a local problem and, in essence, very individual (for each of the customers). The authors believe that small businesses, local businesses, such as restaurants, would benefit from focussing on the analysis of potential customers. This is especially important in the wake of the COVID-19 pandemic, which has significantly affected this segment.

2. Literature review

In this part of the paper, the authors focus on literature review, similar articles, and research with a similar theme. First, they generally address the issue of consumer behaviour and the general characteristics of shoppers on the Czech market. They pay attention to the segmentation of customer groups according to generational differences, where they focus on generation Y and especially on generation Z. Finally, they pay attention to customer preferences during decision-making about restaurant choice. Compared to extensive studies on hotel selection, a conjoint analysis has done little to predict overall consumer preferences in restaurant selection, although there is a similar pattern of selection between them (Rhee et al. 2016).

2.1 Characteristics of Czech respondents

Kotler and Keller (2016) state that consumers behaviour is influenced by three factors: *cultural* factors including culture, subculture and social class, *social* factors, where reference groups, family, and social roles and statuses are counted among, and *personal* factors such as age and stage in the life cycle, occupation and economic circumstances, personality and self-concept, and lifestyle and values.

Vysekalová (2011) characterises the Czech respondents in the following way (Table 1). *Influenceable individuals* make emotional purchasing decisions based on advertising and the attractive design of the product. They buy impulsively and try new brands. They belong to a younger population with higher education. *Demanding consumers* have high demands on the quality, modernity and facilities of the place of buying. They emphasise accompanying services. These are younger people with university degrees and higher incomes. *Mobile pragmatists* optimize the relationship between price and value of the goods. They buy rarely and in large volumes. As a rule, these are people between 30 and 49 years of age with higher incomes.

Table 1: Representation of Types of Czech Shoppers

Type of shoppers	Represented in the population	Shopping orientation
Influenceable	15 %	Modern (47%)
Demanding	16 %	
Mobile pragmatist	16 %	
Cautious conservative	12 %	Traditional (53 %)
Thrifty	13 %	
Loyal housewife	12 %	
Undemanding phlegmatic	16 %	

Source: VYSEKALOVÁ, J. (2011), p. 244.

Cautious conservatives are characterised by rational conservative decision-making. Their buying behaviour is usually not impulsive. They don't trust advertising and don't want to be influenced by the design of the product. They let themselves be influenced more by previous experience than by price. This is an older population, people with lower education and lower incomes. *Thrifty people* minimise their expenses. They buy only the necessary goods. The price, discounts, and sales are the most important to them. Older people with low education and low income are included here. *Loyal housewives* are strongly orientated towards the social side of shopping. They appreciate the friendly manner of the staff. They buy in smaller quantities. *Undemanding phlegmatics* don't have more demands on the place or the price.

Respondents on whom this research is focused belong mainly to the following groups: Influenceable and Demanding.

2.2 Identification of generational differences in preferences

The next way to segment consumers is based on the age of the consumer. There are well-known generational types that characterise their different lifestyles. The most used division is into generation X, Y, Z, baby boomer, and silent generation (Schiffman and Kanuk, 2004). In recent years, due to the COVID-19 pandemic, there has been talk of a new group, the youngest respondents, or a new lost generation, namely COVID-ials. Sources differ in their definition of age. Some authors say that this is the generation that experienced e-learning due to COVID-19, and most authors claim that the generation that is/will be born during the COVID-19 pandemic. Visković et al. (2021) investigated how the COVID-19 pandemic affected buyers' preferences in Croatia. On the contrary, Horáková and Maršíková (2021) focused on knowledge sharing in small and medium-sized enterprises, its success and barriers in conditions of the pandemic.

The authors present different time intervals of generations, partly overlapping. *Silent generation*, which Carpenter et al. in 2012 claim that these are people who were born between 1925 and 1942, whereas other authors push the upper limit up to 1945. This generation partially overlaps in definition with the *baby boom generation*. This is the fastest growing demographic group; they concentrate wealth, savings, and purchasing power. These people are individual and self-confident in their decision-making. They believe in rational arguments and the usefulness of products. They like to collect information about the purchase. Baby boomers (born 1946 – 1964) buy for themselves and the household, are consumer orientated and loyal to brands. *Generation X*, is the so-called lost generation born 1965 – 1979 (Wahyuningsih et al., 2022). Other authors such as Carpenter claimed that Gen X are people born 1961 – 1981, as well as Twenge in 2015. They consider these people important to enjoy life and embrace a lifestyle that provides freedom and flexibility. The price and the materialism are important to them.

Generation Y (born 1977 – 1994) is impressionable by media; they are marketing-active individuals. They spend a lot of time on the Internet. When shopping, they consider the price/quality ratio and prefer branded goods. They are characterised by pragmatism. A subgroup, or another name for Gen Y, is Millennials who were born between 1983 and 1994.

Gen Z respondents were born between 1995 and 2003. Twenge in 2015 defined this group as people born between 1992 – 2000, Koksal in 2019 and Shams et al. in 2020 determined it like a group of people who were born between 1995 and 2000. Lo et al. (2022) investigate young consumers' attitudes and behaviour toward restaurant. They suggest the information on the menu that customers value the most, namely nutrition and sustainability. According to the results of the Deloitte agency (2022), the biggest priority for Generation Z and Millennials is environmental protection. Therefore, this factor will certainly have an influence when making the decision about a restaurant. The survey also showed that 46 % of Generation Z are always or almost always stressed. 64 % of respondents of this generation think that the possibility of working at home would relieve them of stress in the future. This fact shows the significant influence of e-learning on thinking. It influenced not only habits, but also the perception of the world (Deloitte Global, 2022). These generations use home delivery more than others. It was shown that younger generational cohorts are more likely to select high prices with good quality and value (Parment, 2013). Yarimoglu in 2017 identified that Gen Z has a different perception of service quality and value among other generations. Although people of the same generation have experienced the same events, they may interpret them in different ways so that generations are not homogeneous. However, the results of the authors are based on the general tendencies of the group, which can be read from the data obtained.

2.3 Important factors in making the decision about the restaurant of choice

Rhee H. T. et al. (2016) examine 3 different restaurant types: low-priced food stand, low-priced indoor, and high-priced indoor restaurant. They investigated that the most important factor, regardless of restaurant type, is the food. They use 4 attributes: value, service, atmosphere, and food. The other studies by Baek et al. (2006) investigate differences between Korean and Philippine college students' perceptions on the fast food restaurant selection criteria with respect to the attributes they feel are important. They viewed the price of the menu as the most important attribute. It should be noted that this study examined the preferences of Generation Y. The aforementioned is also

confirmed by Tse's study (2001), revealed that price has a greater relative importance compared to service quality. Studies Huertas-Garcia (2014) researched conjoint analysis of tourist choice of hotel attributes, its results suggest advertisement size, a hotel's starred rating and price influence perceived value at this stage. The presence of a positive combined effect of price and advertising was found. Saxena and Taneja (2020) stated that the demand for restaurants has increased, especially among young people, due to changes in their lifestyle and dietary habits. The price of food was found to be the most important factor with the highest utility, while it is least influenced by the attributes of the food. Other studies by Liu et al. (2022) showed that visual information is the most important attribute in decision-making. In research of this type, the current moment during sorting also matters, i.e. the taste for a certain dish, perceptions, fatigue, etc. Beekman's and Seo's study (2022) proves that analytic-holistic cognitive differences between consumers can impact how their food perception is altered by their eating environment. Yoo and Ha also investigated (2022) the interrelationships among online reviews, trust, attitude towards a restaurant and purchase intention. The diet of the past has led to an increasing availability of industrially processed foods that are high in salt, fat, and sugar. The expectation of modern food drives Gen Z to actively search for reliable and transparent food sources actively and to consume brands and products that meet their standards. (Zuo et al., 2022)

Although the arrangement of the order of the 27 variants of the offer may seem more complicated to the respondent, in real life we are faced with a much wider range of variants every day. We often do not admit the complexity of our choice. With the help of this simple tool, Conjoint analysis, we will get as close to decision-making in real life. Customers tend to select a restaurant by considering the whole range of restaurant attributes in total rather than each attribute separately (Baek et al., 2006).

3. Methodology

Two used methods of the research are presented in this section – the method of scoring as the simple and direct one and the conjoint analysis representing more sophisticated way of deriving preferences.

3.1 Method of scoring

The method of scoring belongs to multicriteria decision making (MCDM) methods. It enables to derive not only the ranking of compared objects (factors, criteria, ...) but also their weights as relative importance (Ramik and Perzina, 2008). The method of scoring represents one of the simpler MCDM methods. Respondent knows exactly what (which objects) he/she is evaluating. The principle of this method is based on assignment of values of specific scale – whether interval one or point one. If n objects are evaluated, weight of each object can be derived as follows:

$$w_i = \frac{v_i}{\sum_{i=1}^n v_i}, \quad (1)$$

where w_i is weight of the i -th object and v_i is value of the scale assigned to the i -th object.

3.2 Conjoint analysis

Conjoint analysis is a universal tool that could be used in market research to determine a marketing strategy. It belongs to the group of multivariate statistical methods designed for the most exact market survey. It was derived from the field of mathematical psychology and psychometry (Grünwald, 2011). The basis is the analysis of variance, which is applied to ordinal variables expressing the respondent's preferences. Conjoint analyses the rating, preference, or selected data using least squares. It works with a file created using plan cards or a file entered by the user using the data list function. It displays individual and aggregated results. It also identifies inverse scales based on whether it is a discrete (nominal) or linearly categorized factor – scores or ranks are linearly related to the factor, ideal or anti-ideal, where a quadratic relationship is expected between the scores or ranks and the factors.

The method works with the data of individuals, with the indicative values of the selection, with the ranks, or with the data of the rating scales of the answers. The choice-based model emerges

from McFadden's economic theory. A controlled set of potential products or services is shown to survey respondents, and by analysing how they make choices among these products, the implicit valuation of the individual elements making up the product or service can be determined. These implicit valuations (utilities or part-worths) can be used to create market models that estimate market share, revenue, and even profitability of new designs.

The authors decided to use conjoint analysis created only from necessary combinations – orthogonal array. The first thing that had to be done was the orthogonal design generate. Orthogonal plans represent the “most economical” partial factorial plans (typically 16, 18, 20, 24, 27, 28 concepts) from the overall factorial arrangement. The number of concepts I in the complete set can be high even with a relatively small number of factors J with the number of levels K , where $I = K^J$.

An example of a simple plan composition where each pair (s, t) of the Cartesian product $S * T$ appears exactly once, as it can be seen in Table 2.

Table 2 Orthogonal Graeco-Latin square designs

		Factor S		
		1	2	3
Factor T	1	A α	B γ	C β
	2	B β	C α	A γ
	3	C γ	A β	B α

Source: BOX, G.E.P., et al. (1978), p. 167.

The Graeco-Latin square represents a square of order n over sets S and T . If both sets contain n characters, it is $n * n$ ordered pairs (s, t) , where $s \in S$ and $t \in T$. Each row contains S and T exactly once and all pairs are also contained exactly once in the square. Orthogonal plans reflecting the essence of the levels of each of the factors can be divided into plans where the factors have the same number of levels (symmetrical) and those with different numbers of levels (asymmetrical) (Addelman, 1962). If the levels of each factor are arranged so that they occur with the level of any other factor with proportional frequencies, it is possible to derive several classes of orthogonal main-effect plans for asymmetrical factor experiments. One such class permits the estimation of all main effects, without correlation, for an experiment that entails t_1 factors at s_1 levels, t_2 factors at s_2 levels, up to t_k factors at s_k levels, with s_i^n tests, where s_i is a prime of the power of a prime,

$$s_1 > s_2 > \dots > s_k, \text{ and } \sum_{i=1}^k t_i \leq \frac{s_1^n - 1}{s_1 - 1}. \quad (2)$$

In the next stage, the plan is randomised. It is the process of sorting rows into random order. In this investigation, the method to evaluate the profiles of the respondents was chosen so that the preferences of the respondents are expressed in rank. The relative importance of the attribute is calculated in such a way that the range of estimates of the utility coefficients of the monitored attribute is divided by the sum of the ranges found for all attributes and multiplied by 100. When determining the importance of attributes, the range between the highest and lowest utility values is used. The attribute that has the largest margin of utility between the least and most desired level of the given attribute is more important. Using these utility scores, the market preference for any combination of attribute levels can be predicted. Reversals are also important in the interpretation of conjoint analysis. These are answers from the respondents contradict the assumed utility function (for example price have decreasing utility function. Reversals are not a test error; it may be a different perception of utility of the given respondent: higher quality = higher price.

To evaluate the quality of the model, the Pearson correlation coefficient for the real and test data is used here. Also, Kendall's tau for real and test data. The non-parametric correlation coefficient known as Kendall's tau was first discussed by G.T. Fechner and others about 1900, and was rediscovered by M.G. Kendall in 1938. It is normalisation of the Friedman test and it assesses the agreement of the evaluations of individual evaluators. In modern use, the term “correlation” refers to a measure of a linear relationship between variates (such as the Pearson correlation coefficient), while “measure of association” refers to a measure of a monotone relationship between variates (such as Kendall's tau or Spearman's rho metric). The Kendall test makes no assumption about the nature

of the probability distribution and can handle any number of individual outcomes (Kendall and Babington Smith, 1939).

Definition Kendall's tau: Let $(x_1, y_1), \dots, (x_n, y_n)$ be a set of observations of the joint random variables X and Y , such that all the values of (x_i) and (y_i) are unique (ties are neglected for simplicity). Any pair of observations (x_i, y_i) and (x_j, y_j) , where $i < j$, are said to be concordant if the sort order of (x_i, x_j) and (y_i, y_j) agrees: that is, if either both $x_i > x_j$ and $y_i > y_j$ holds or both $x_i < x_j$ and $y_i < y_j$, then they are said to be discordant. The Kendall's tau formula:

$$\tau = \frac{(n_c) - (n_d)}{\binom{n}{2}} = 1 - \frac{2(n_d)}{\binom{n}{2}}, \quad (3)$$

where n is number of pairs (so the coefficient must be in the range $-1 \leq \tau \leq 1$), n_c is the number of concordant pairs, n_d is the number of discordant pairs and $\binom{n}{2} = \frac{n(n-1)}{2}$ is the binomial coefficient for the number of ways to choose two items from n items.

If the agreement between the two rankings is perfect, the coefficient has the value 1. If the disagreement between the two rankings is perfect, the coefficient has value -1. If X and Y are independent and not constant, then the expectation of the coefficient is zero.

4. Research

The pre-research was realized in the first phase. The purpose was to discover if students go for lunch in restaurants and what are their basic preferences – which restaurants are visited and what kind of food is preferred. Gained answers helped to define questions for the research and for factors/attributes determination.

The main result of the pre-research was the fact that many students don't go for lunch in restaurants. These who eat lunch in restaurants usually don't visit classic restaurants, but chain fast-food restaurants, pizzerias, Asian or kebab bistros. Modification of the lunch menu offer in classic restaurants is to recommend to attract young generation.

Basic factors influencing young potential customers' decisions were chosen according to the primary findings. Restaurant, dish, price, and experience were evaluated by the method of scoring and selected as main attributes for conjoint analysis.

Respondents determined importance of attributes for restaurant choice by assigning points from scale 1 to 10, where 1 means the least importance. Weights of factors were calculated according to (1) and mean weight of every attribute was derived to rank them (see Table 3).

Table 3: The method of scoring results

Attribute	Restaurant	Dish	Price	Experience
Mean weight	0.240	0.238	0.293	0.229
Ranking	2	3	1	4

Source: Own research

It is obvious that the most important attribute is price with mean weight 0.293. Factor restaurant with mean weight 0.240 follows and the third one is dish with mean weight 0.238. The least important factor in this research is experience (mean weight 0.229).

Respondents evaluated the same factors indirectly by conjoint analysis. They expressed their preferences assessing ranking to simulated variants made of particular attribute values.

Table 4: Attribute values

Restaurant	Dish	Price	Experience
Classic restaurant	Roast Sirloin in Sour Cream Sauce w/ Dumplings	99 CZK	Good experience
Another	Fried Cauliflower	150 CZK	No experience
	Hamburger		Bad experience
	Pizza		
	Kebab		
	Kung-Pao		
	Another		

Source: Own research – Conjoint analysis

In the case of attribute restaurant, it was specified what “another” means. It was about themed restaurants such as fast food, pizzeria, Asian restaurant, kebab bistro, etc. The selection of dishes was inspired by the pre-research. Respondents chose these specialities of fast-food sort often. The question is if this preference is about price, speed of cooking, availability or just taste. Only two levels of price were chosen to reduce the necessary among of variants. These values were registered during October and November 2022 by market monitoring of local daily offer. Authors selected three values of the experience attribute – good, bad and no experience. The total number of feasible attribute combinations is 84. The 27 necessary combinations were chosen by SPSS software (see Table 5). These are essential to assess the utility levels of attributes.

Table 5: Plan Cards

Restaurant	Dish	Price	Experience
Another	Fried Cauliflower	99 CZK	Bad experience
Another	Fried Cauliflower	150 CZK	Good experience
Another	Kebab	99 CZK	Bad experience
Another	Roast Sirloin in Sour Cream Sauce w/ Dumplings	150 CZK	Bad experience
Another	Another	150 CZK	No experience
Classic restaurant	Kebab	99 CZK	Good experience
Another	Roast Sirloin in Sour Cream Sauce w/ Dumplings	99 CZK	No experience
Classic restaurant	Another	99 CZK	Bad experience
Classic restaurant	Fried Cauliflower	99 CZK	No experience
Classic restaurant	Fried Cauliflower	150 CZK	Good experience
Classic restaurant	Kung-Pao	150 CZK	Bad experience
Classic restaurant	Hamburger	99 CZK	Bad experience
Another	Hamburger	99 CZK	Good experience
Classic restaurant	Pizza	150 CZK	Good experience
Another	Kung-Pao	99 CZK	Good experience
Classic restaurant	Roast Sirloin in Sour Cream Sauce w/ Dumplings	99 CZK	Good experience
Classic restaurant	Kung-Pao	99 CZK	No experience
Classic restaurant	Fried Cauliflower	99 CZK	No experience
Classic restaurant	Pizza	99 CZK	Bad experience
Another	Pizza	99 CZK	No experience
Classic restaurant	Kebab	150 CZK	No experience
Classic restaurant	Roast Sirloin in Sour Cream Sauce w/ Dumplings	150 CZK	Bad experience
Classic restaurant	Fried Cauliflower	99 CZK	Bad experience
Classic restaurant	Another	99 CZK	Good experience
Classic restaurant	Hamburger	150 CZK	No experience
Classic restaurant	Roast Sirloin in Sour Cream Sauce w/ Dumplings	99 CZK	No experience
Classic restaurant	Roast Sirloin in Sour Cream Sauce w/ Dumplings	99 CZK	Good experience

Source: SPSS software – Generate orthogonal design

Utility levels and importance values of attributes were discovered according to respondents' evaluations (see Table 6). The data in Table 6 show that pizza has the strongest preference and the attribute dish is the most important one for the respondents according to the conjoint analysis. The second one is experience. Restaurant and price have significantly lower importance according to conjoint analysis. Summary utility of attribute dish indicates that the strongest utility belongs to above mentioned pizza, kebab and kung-pao follow and last four positions are occupied by another dish, hamburger, roast sirloin in sour cream sauce and fried cauliflower (in this order). The ranking for the second most important attribute (experience) is in accordance with expected linear less trend: good experience, no experience and the last one is bad experience. The classic restaurant won the attribute restaurant decidedly. This result is interesting – the pre-research showed that when respondents go for lunch to restaurants, they usually prefer fast-food type. Most of the respondents chose the lower price. Price was in the last position in the decision-making process according to the conjoint analysis. It is caused by number of attribute restaurant values partly. It is proved that increasing number of values cause false rise of given attribute importance, but not in such extent.

Table 6: Utility and Importance Values

		Utility Estimate	Std. Error	Importance Values (Averaged Importance Score)	
Restaurant	Classic restaurant	0.277	0.244	Restaurant	9.683
	Another	-0.277	0.244	Dish	47.409
Dish	Roast Sirloin in Sour Cream Sauce	-0.293	0.478	Price	9.613
	Fried Cauliflower	-1.638	0.478	Experience	33.296
	Hamburger	-0.138	0.631		
	Pizza	2.135	0.631		
	Kebab	0.091	0.631		
	Kung-Pao	-0.038	0.631		
	Another	-0.118	0.631		
Price	99	-1.253	0.488		
	150	-2.506	0.976		
Experience	Good experience	-3.288	0.282		
	No experience	-6.577	0.564		
	Bad experience	-9.865	0.845		
(Constant)		22.370	0.898		

Source: Own research (SPSS)

The model validity is demonstrated by Pearson's R a Kendall's tau (Table 7). These two statistics provide measures of the correlation between observed and estimated preferences. The conjoint procedure computed the correlations between the observed and predicted rank orders for these profiles as a check on the validity of the utilities. In this case, there are high significant correlations between observed and estimated preferences.

Table 7: Correlations between observed and estimated preferences

	Value	Sig.
Pearson's R	0.952	<0.001
Kendall's tau	0.774	<0.001

Source: Own research (SPSS)

Reversals were found for two attributes, price and experience. Reversals are searched when linear decreasing or linear increasing relationship is expected. The price levels chosen for this research are not very different, and they correspond to the upper and lower price limits at the time of research realisation and local restaurants. The small price margin could cause the placing of price. When the respondent goes to the restaurant and is ready to spend money, he/she chooses what is delicious for him/her. Regarding experience, the restaurant with no or bad experience may be preferred because the respondent's favourite dish is in its daily offer. Balancing all factors and making a compromise between them is always necessary when deciding on a restaurant for lunch.

Weights and rankings of attributes according to both used methods are summarized in Table 8. Lesser differences in weights derived by method of scoring (comparing to conjoint analysis) are visible.

Table 8: Attribute weights and rankings according to both methods

Attribute	Method of scoring		Conjoint analysis	
	Weight	Ranking	Weight	Ranking
Restaurant	0.240	2	0.097	3
Dish	0.238	3	0.474	1
Price	0.293	1	0.096	4
Experience	0.229	4	0.333	2

Source: Own research

Very surprising is the contrast in ranking of the attribute price. Most researches of the other authors (including the above mentioned) find out that price is the most important factor. Especially for the young generation – current students, i.e. respondents of the research. This fact is in accordance

with the result of method of scoring (position 1), but it is in contradiction with outcomes of conjoint analysis (position 4). In contrast to this the most important attribute is the dish according to conjoint analysis, but it is the third based on method of scoring. Attributes restaurant and experience differ in their rankings too. As we can see, conscious evaluation brings very different results than unconscious one.

5. Conclusions

Two methods for finding consumer preferences were applied in the research. The method of scoring is the simpler one. The respondents know exactly what entities are evaluated by assigning values of a given scale. We can say that this evaluation is intentional and occurs on a conscious level and it is rational. The conjoint analysis is more complicated. It seems that this method can uncover subconscious preferences – factors are not evaluated directly but by ranking specific variants consisting of different levels of factors. The respondents think that they are judging these variants. But in fact, preferences of factors are investigated and derived too.

83 respondents evaluated four factors (restaurant, dish, price, experience) important for restaurant choice in this research. They applied the method of scoring by assigning values from 1 to 10 scale to the factors. These respondents had to rank 27 variants necessary for the calculations of the conjoint analysis. The results of these methods showed a surprising fact about the price: while its (first) position according to the method of scoring complies with frequent common opinion and results of other researches, on the basis of conjoint analysis, it is the least important factor. On the contrary, the most preferred factor found by the conjoint analysis is dish. It seems that the respondents want to enjoy their dish regardless of expenses subconsciously. The dish according to the method of scoring occupies the third place.

Also, the distribution of weights (from interval [0;1]) is significantly different for both methods. While they are quite near each other according to method of scoring (weights from 0.229 to 0.293), the conjoint analysis brought noticeable contrast (weights from 0.096 to 0.474).

Both used methods brought significantly different results of preferences obviously. It is the responsibility of each restaurant management to determine, which approach of consumer decision-making (rational or unconscious) is the right one and which factor should be focused.

Acknowledgement

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HOW STABLE ARE STUDENTS' INTENTIONS TO BE SELF-EMPLOYED? A QUALITATIVE STUDY OF STUDENTS' ENTREPRENEURIAL INTENTION CHANGE

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Abstract

Behavioral scholars propose that entrepreneurial intention (EI) is the best way to predict an entrepreneurial action. However, it has been observed that students at the beginning of their studies show increased entrepreneurial intention, especially when attending an entrepreneurship course, while after its completion and before completing their studies, their intention is changed. The present research attempts to extend the knowledge of how Entrepreneurial Intention is changing over time. A qualitative research was conducted with the use of structured interviews with 140 university students who had attended the entrepreneurship and innovation course two years before, to evaluate the changes and the reasons for changing their entrepreneurial intention during the last two years. Data were analyzed with the use of NVivo coding software. The findings suggest that factors such as the attractiveness of the entrepreneurial idea, the cohesion of the teams, the teaching methods used, and the support that students receive from their university as well as some personality characteristics were significant factors that caused changes in students' entrepreneurial intention within the last two years of their studies. The main contribution of the study is the examination of the changes in students' entrepreneurial intention and the highlighting of the challenges that appear at different times of their studies.

Keywords: entrepreneurial intention, entrepreneurship education, longitudinal study, university students

JEL codes: I2, I23, J24, L26

1. Introduction

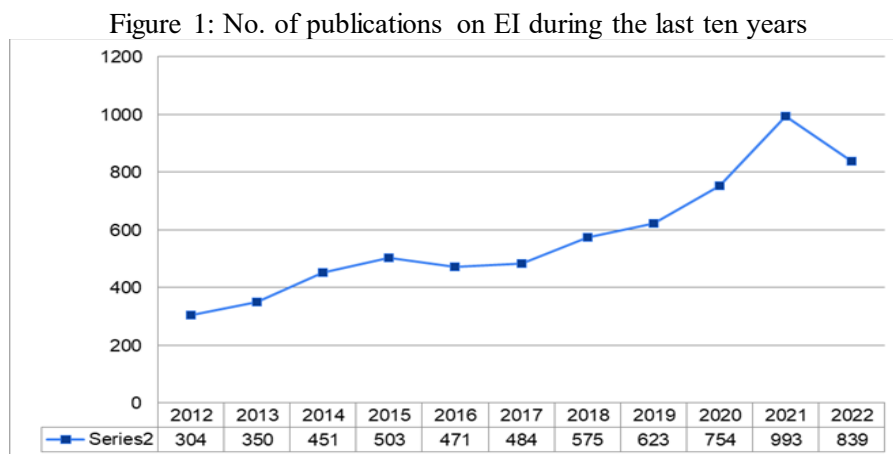
Entrepreneurship is commonly viewed as a key economic tool that brings social and economic welfare. However, although many people show entrepreneurial intentions, they fail to turn them into action. This fact is called the “entrepreneurial intention-action gap” and this is a result of changes in individuals' intentions due to a variety of reasons. Scholars often use dominant models of intentions to predict entrepreneurial behaviors, however, entrepreneurial intention alone is an insufficient predictor of subsequent entrepreneurial behaviors (Shirokova et al., 2016; Sahinidis et al., 2020). Therefore, there is a need to determine the reasons of these changes in students' entrepreneurial intention after the completion of an entrepreneurship education program. Despite its importance, students' entrepreneurial intention and its development over time have received little attention. Current research calls for exploratory studies to understand why some students do not take entrepreneurial actions despite their high entrepreneurial intentions, particularly while taking an entrepreneurship course (usually during the first semesters of their studies). In this context, the purpose of this study is to investigate the changes in students' entrepreneurial intention during the last two years of their studies, after completing an entrepreneurship course. A qualitative research has been implemented to study the intention of 140 students who now attend the last semester of their studies. The research questions are the following:

1. What changes occurred in the entrepreneurial intention of students over time?
2. Why is the entrepreneurial intention of students changing?

The study will contribute to the emerging literature on students' entrepreneurial mindset and intention by identifying the factors that influence their intention to start an entrepreneurial venture. In addition, the findings will contribute to the better understanding of the students' intention-behavior gap by highlighting the challenges that appear at different times of their studies.

2. Literature Review: Entrepreneurial Intention and its Determinants

Entrepreneurial intention (EI) is described by Thompson (2009) as a person's self-acknowledged conviction to launch a new business in the future. EI is also considered as the search and investigation of information that may be utilized to achieve the objective of a venture creation (Neneh, 2014). Furthermore, the term of "entrepreneurial intention" (EI) refers to the people's propensity for engaging in entrepreneurial activities, such as starting a new firm or working for themselves (Anwar et al., 2022). Entrepreneurial intention is seen as a major component in explaining and forecasting entrepreneurial behaviors since it explains why some people choose to launch a firm. As shown in Figure 1, entrepreneurial intention is one of the most rapidly evolving sub-fields within the broader field of entrepreneurship research (Linan and Fayolle, 2015). The literature on EI has been increased exponentially, which reflects the interest that EI has generated in the research community worldwide (Soria-Barreto et al., 2017).



Source: Science Direct

A variety of determinants or motivators are mentioned in the literature including attitudes, values and psychological factors (Do and Dadvari, 2017; Mahfud et al., 2020; Barba-Sánchez et al., 2022; Wiklund et al., 2019), demographic factors such as gender, education and family background (Kefis and Xanthopoulou, 2015; Sahinidis et al., 2019; Nowiński and Haddoud, 2019; Maresch et al., 2016; Gielnik et al., 2018), while a significant number of researchers (such as Lee and Park, 2014; Xanthopoulou and Sahinidis, 2022; Puni et al., 2018), refer to education as one of the most important factors that may foster the entrepreneurial intention. Personality traits often act as a catalyst for changing how entrepreneurs perceive risk in their decisions (Mahfud et al., 2020). Some personality traits such as "self-confidence", "need for achievement", "risk-taking tolerance", "internal locus of control", "innovativeness", and "autonomy" (Do and Dadvari, 2017; Ozaralli and Rivenburgh, 2016; Barba-Sánchez, et al., 2022; Barba-Sánchez and Atienza-Sahuquillo, 2017) are commonly accepted as determinants of people's entrepreneurial intention. Individuals with high levels of entrepreneurial intention show significantly higher scores in risk-taking than those with lower ones. Another key factor that impacts on individuals' intention towards self-employment is their need for achievement. People with a high need to achieve will show greater entrepreneurial behavior (Verheul et al., 2012). It is also found that some people would like not to depend on others for their living and this way of thinking drives them to become independent by finding their own resources. Maslow (1943) in his theory of needs states that individuals will shift to a higher-level need only when their low-level ones are met. From that point of view Self-actualization or Self-fulfillment can be considered as entrepreneur's greatest satisfaction when trying to achieve goals (Dong et al., 2019). People with a

need to be independent show an increased entrepreneurial intention (Omar et al., 2019). Additionally, a variety of studies found that age, gender, family entrepreneurial experience, and level of education significantly impact on individuals' entrepreneurial intention (Xanthopoulou and Sahinidis, 2022; Sahinidis et al., 2021; Tsaknis et al., 2022). Although the determinants of age and gender are under question from many researchers regarding their impact on starting-up a business, however there are many scholars such as Gielnik, Zacher and Wang (2018) who revealed that successful entrepreneurs are relatively young as the older people are discouraged in selecting forms of employment that involve uncertainty. It is traditionally considered that men have higher inclination to self-employment than women. Liñán and Fayolle (2015) write that there are findings which show that women are more risk averse than men are, especially when it comes to financial risks. Significantly, education and entrepreneurial training have a more crucial role in improving entrepreneurial activities of people. In general, entrepreneurship education is positively associated with entrepreneurial intention (Debarliev et al., 2022; Sherkat and Chenari, 2022). Finally, another determinant is the social environment of students such as peers and close friends, which also has a positive effect in EI as those who have friends with an experience in self-employment directly consider starting a new business or not (Saptono et al., 2021).

3. Methodology

To collect the primary data, qualitative research was followed, studying the changes in students' entrepreneurial intention during the last two years of their studies. According to Bryman (2017) quantitative methods examine the theory of the researcher, while qualitative methods focus on the meanings of the participants thus, in the current research required the second ones. The aim of the study is to examine the changes in entrepreneurial intention of university students who have attended an "entrepreneurship and innovation" course and then to understand the reasons for this change. The research tool was the "structured interview". This specific type of interview was preferred, as the predetermined questions ensure more objectivity, validity, and reliability (Corrington, 2022). The interview questions were sent via an online link with the use of Google Forms. The answers were submitted in written format, and this was a good way to get familiar with the data. Written answers are shown to be a time-efficient means of gathering good-quality, descriptively rich data. Google Docs is under-utilized as a tool to facilitate qualitative interviews within research, however it is argued that synchronous web based written interviews via Google Docs offer unprecedented opportunities for qualitative research. Since transcribing verbal interviews into written texts and then abstracting key themes from these texts is a large amount of qualitative research, written answers produce data which can more easily understood and analyzed (Zdrowski and Letherby, 1995). The primary data was analyzed using the QSR NVivo program. Researchers tend to use NVivo (Nabi et al., 2018; Li and Zhang, 2022) as it covers three major aspects of the research process, specifically the data analysis, the theoretical development, and the presentation of findings (Dalkin et al., 2021). The initial sample amounted to 140 people. Due to specific criteria (e.g. there were students who had not prepared a mid-term assessment during the "entrepreneurship and innovation" course or they did not give sufficient answers to make the subsequent coding by answering one-word answers or by skipping questions) the final sample used in the thematic analysis was 85 students. Overall, ages ranged from 18 to 54 years, with 53,6% male and 46,4% female students. The segmentation of this sample led to a 1 × 3 matrix (see Tables 1A, B) according to students' attendance in entrepreneurship education and the increase/decrease/steady entrepreneurial intentions.

Table 1A: Scenarios and entrepreneurial intentions change (entrepreneurship course)

	Entrepreneurship course
Increased intention	Scenario 1 → 20 students
Decreased intention	Scenario 2 → 4 students
No change in intention	Scenario 3 → 9 students

Source: authors' own work

Another segmentation of our sample led to a 2 × 3 matrix according to the initial entrepreneurial idea and the increase/decrease/steady entrepreneurial intentions.

Table 1B: Scenarios and entrepreneurial intentions change (entrepreneurship course)

	Attractive entrepreneurial idea
Increased intention	Scenario 1→27 students
Decreased intention	Scenario 3→ 5 students
No change in intention	Scenario 5→ 13 students

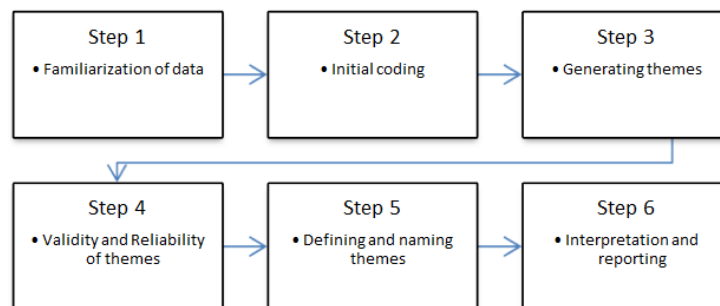
Source: authors' own work

This study used an explanatory research design because it is appropriate for a deep and sufficient understanding about the change in entrepreneurial intention over time and the antecedents of entrepreneurial intentions (EIs) among graduates (Creswell, 2014). This type of study gives answers to “*what*” and “*why*” questions, mostly when the current knowledge about the question is relatively insufficient. The present research fully complied with the ethical and moral principles of scientific research. All participants were informed about the topic of the research, its purpose, and the reason for conducting the research, as well as about the fact that the results of the research could be sent to them after its completion, if they wanted it. They were also informed that there would be complete anonymity and that their questionnaires and interviews would be used exclusively for the needs of the research, as well as that they could withdraw at any time they wished.

4. Results

Thematic analysis was based on the six stages suggested from Braun and Clarke (2006) (See figure 2).

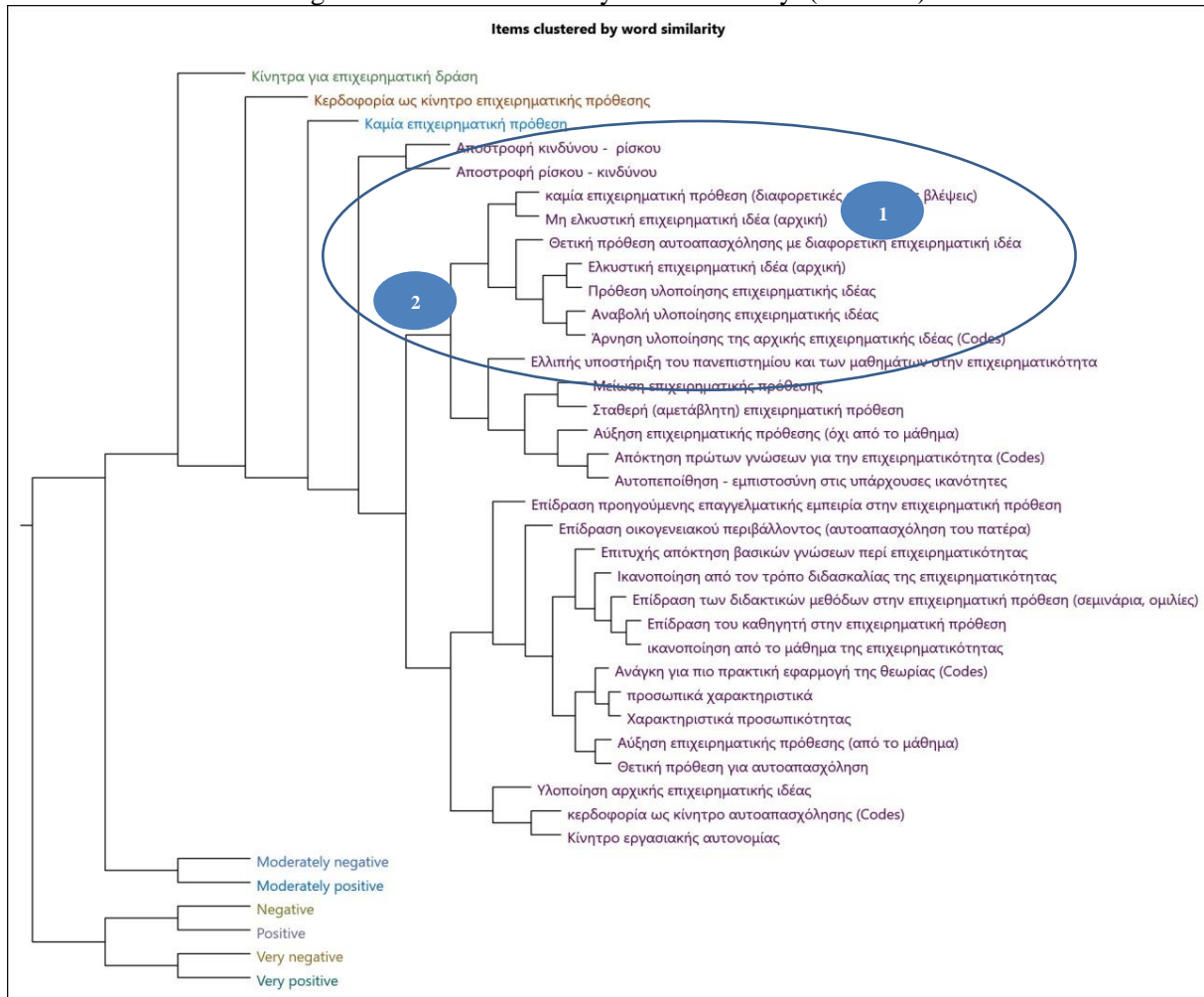
Figure 2: Thematic analysis stages



Source: Braun and Clarke, 2006

During the first stage, the familiarization with the data took place. Then, while reading the responses, patterns were formed and the first thoughts about coding them into themes were made. The second stage concerned the coding of the data through the QSR NVivo program. Then, the researchers made a first identification of meaningful units connected to each other and they grouped the data. Figure 3 illustrates the first thematic units as they emerged from the QSR NVivo coding. A larger area shows more coding references. In descending order, the codes are as follows: 1) Personality traits (180 references), 2) Need for practical implementation of theory (100 references), 3) Attractive business idea (62 references) 4) Positive intention for self-employment (47 references), 5) increased entrepreneurial intention (due to the entrepreneurship course) (53 references) and 6) Intention to implement the initial business idea (43 references). During the third stage, the codes given to the interview data were summarized into themes and sub-themes. This was done by combining different codes and searching for possible patterns emerging from the data. Some of the initial codes formed the main themes, while others formed the subthemes. Figure 3 below shows a cluster analysis of codes based on verbal relevance.

Figure 3: Items clustered by word similarity (in Greek)

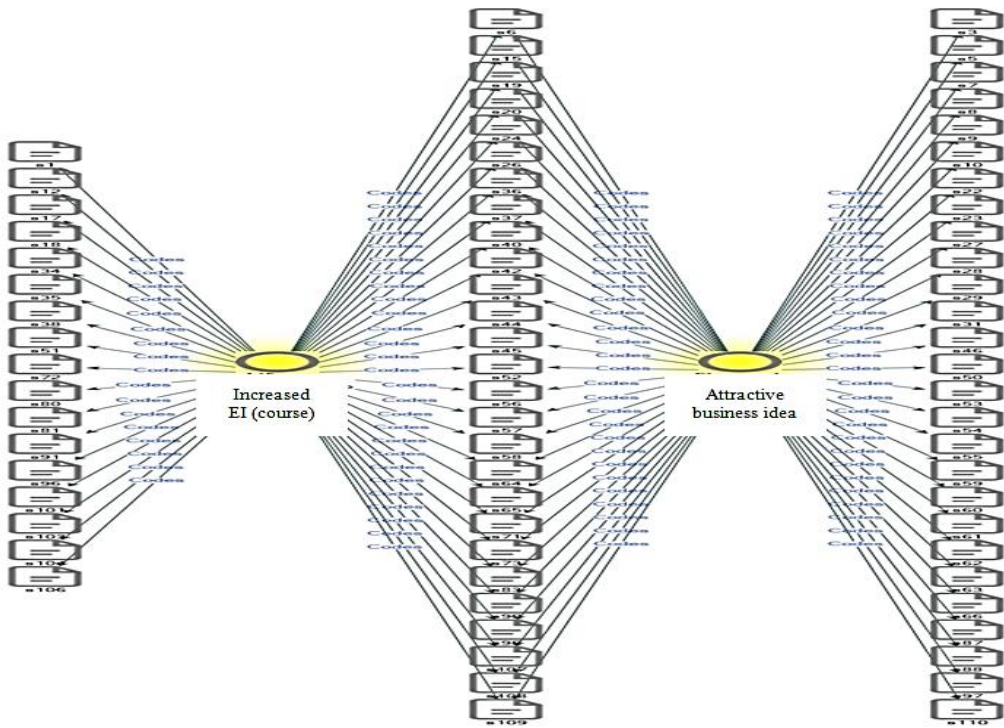


Source: authors' own work

The node cluster diagram (Figure 3) shows high-order themes. These themes clearly show trends which also appear in the propositions. We see that, within the cycle there is a strong correlation between an “innovative and attractive entrepreneurial idea” (1) and “individuals' intention to implement it in the future” and thus to work as self-employed. Correspondingly, a non-attractive entrepreneurial idea is strongly associated with a decrease in individuals' intention to become an entrepreneur. We can also observe a strong correlation of “students' perception of the support that they receive from their University” with the “decrease or increase of entrepreneurial intention” (2). After coding the interviews, relationships between certain thematic categories emerged. Some important correlations based on the number of references are:

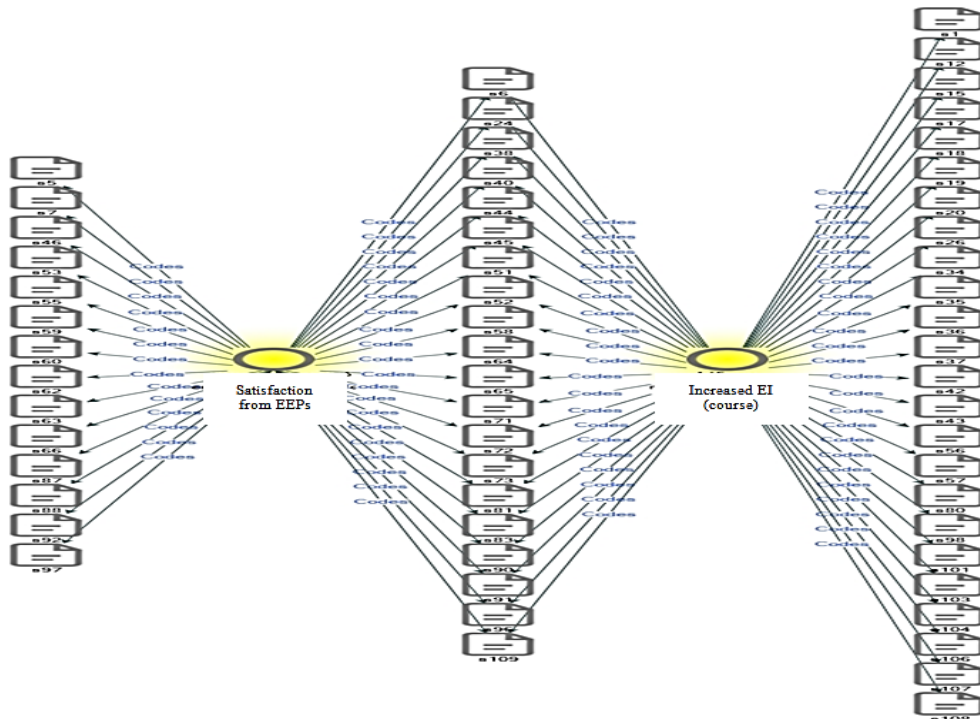
1. Attractive business idea and increased entrepreneurial intention, see Figure 4.
2. Entrepreneurship education and increased entrepreneurial intention, see Figure 5.

Figure 4: Attractive business idea and increased entrepreneurial intention



Source: authors' own work

Figure 5: Entrepreneurship education and increased entrepreneurial intention



Source: authors' own work

At the fourth stage, the themes were re-examined, so that there are no overlaps and any need to merge or separate them can be identified. No new codes needed to be included. At the fifth stage, the redefinition and naming of topics took place. After the data was thematically mapped, the substance and dimension of each theme and sub-theme was determined and ensured that there was no overlap.

The names of the final analysis's themes were chosen at this stage to be thorough and provide the reader a general understanding of what each theme entails. Based on the research questions, the smaller thematic categories were then divided into three related theme axes, as shown in Table 2.

Table 2: Thematic axes

Thematic axis	Categories
1st thematic axis: Entrepreneurship education.	1.1. Appropriate educational methods 1.2. Personal characteristics of the teacher and students 1.3. Feeling of support from the University 1.4. Practical application of theory 1.5. Attractive entrepreneurial idea
2nd thematic axis: Personal characteristics of students	2.1. Risk aversion 2.2. Need for professional autonomy 2.3. Need for profitability 2.4. Self confidence 2.5. Lack of confidence and needed knowledge
3rd thematic axis: Family and friends (social environment)	3.1. Father's occupation 3.2. Existence of self-employed persons in the social environment of students

Source: authors' own work

The sixth stage refers to the final analysis. The initial goal was to identify phrases that would lead first to organizing the thematic categories and then to condensing the content of the interviews. The independent documents (i.e., the students' interviews) that were investigated were also the units of analysis. In this way, the above system of thematic categories and subcategories emerged, which responds to the purpose of the research, the research objectives, and the research questions. As we can see from students' answers their entrepreneurial intention has been generally increased. In most of the answers, the students stated that they were satisfied with the entrepreneurship course, which significantly contributed to the increase of their entrepreneurial intention. Others commented on the tutor's and on the methods used during the course, such as the invitation of external speakers from the labor market, the use of case studies and videos etc. In groups where their members were quite close each other they easily agreed on a final business idea that seemed attractive to all of them. In this case, almost all respondents answered that they intend to continue and implement their initial entrepreneurial idea in practice with perhaps only small changes due to changes in the external environment. Some responses are the following:

S101: *"I am interested in being entrepreneur, as well as various seminars related to entrepreneurship and marketing had a great impact on me.... I am influenced by the various case studies which are the reality and not hypotheses or theories. My entrepreneurial intention has changed dramatically since I have been taking the course of entrepreneurship and innovation..."*. Additionally, S103: *"...my opinion about the University and especially the tutors I met is the best, they do their work with a lot of love, the right atmosphere and most of them have students who are interested in their field and create very meaningful student-mentor relationships. I still believe this course will help me to start a business in the future. My entrepreneurial intention increased after attending the entrepreneurship course while at the same time it gave me a plan to improve my weaknesses."*

In cases where some of the group members did not find the business idea attractive, they either stated that their entrepreneurial intention decreased, or they maybe think to become entrepreneurs but with a different idea. Specifically: S14: *"No, I do not want to be an entrepreneur, especially with this entrepreneurial idea, because it was a group idea, and I couldn't support it. ...I am not interested in this idea because it was referring to a map app or library (I don't remember exactly) and I don't think the world doesn't need something like that"*. In addition, many responses revealed a lack of self-confidence in one's abilities to become an entrepreneur. These individuals showed decreased entrepreneurial intentions. For instance: S4: *"My entrepreneurial intention has decreased to the present due to lack of work experience and self-confidence to do this, due to the risk that exists and the need for development. I also think that I do not have the needed skills yet. I believe that I should cultivate more of my personal skills."* while, S46 says: *"...My entrepreneurial intention has decreased*

as there is insecurity regarding the unpredictable external environment... I believe I have enough theoretical knowledge, however, I do not know to what extent it is completely implementable in reality”.

On the other hand, individuals with high confidence, some of them due to the father's self-employment or due to their personal professional experience feel ready to undertake the entrepreneurial risk. Those students often referred to their leadership and organizational skills and extroversion and showed an increase in entrepreneurial intention as they consider self-employment as a highly creative and profitable process. Some answers include: S66: *“Personally, being an entrepreneur means realizing your own ideas and expectations and organizing your plans as you prefer...In general, I am a person who likes to take on goals and see them through and implement my own ideas, but due to my inexperience there is a fear of failure and this is something that worries me. Failure, on the other hand, is of course a source of knowledge...”* Similarly, S83: *“During the course I understood the concept of entrepreneurship and what an entrepreneur means. Being an entrepreneur means total freedom and autonomy to create the work and life I want. With this freedom, comes a great responsibility for something that really means a lot to me and is worth it...If you want to be your own boss, then you have to be willing to work sometimes late at night or even on weekends. You will definitely have your ups and downs with many emotions. Some are addicted to this "game"...I believe all the positive characteristics of my personality will develop and I will really show myself first what I can really achieve!...”*

5. Conclusion

Entrepreneurship helps economies and leads to social welfare. Knowing the elements that influence people's entrepreneurial intention is important for determining how interested people are in establishing a new venture. The purpose of this study was to identify determinants that caused changes in students' entrepreneurial intention through a qualitative study. The research was implemented after the completion of an entrepreneurship course and during the last semester of their studies to evaluate and compare the entrepreneurial intention of students when attended the entrepreneurship course and after its completion. The first key result of the study is that the personality related factors such as self-confidence, risk-taking need for achievement and autonomy as so as individuals' background related factors mainly the impact of entrepreneurship education and teaching methods used, have caused changes in individuals' entrepreneurial intention from the beginning of their studies until their completion. Another important factor was the attractiveness of their initial entrepreneurial idea which had presented in the beginning of their studies (3rd semester). Students who had a good coordination, shared the same vision, and still believe that they came up to something very innovative have increased their intention to make it practice, while there were students who already work in their entrepreneurial idea in practice. These findings confirm previous studies such as Do and Dadvari (2017), Mahfud et al. (2020), Barba-Sánchez, et al. (2022), Wiklund et al. (2019) and Barba-Sánchez and Atienza-Sahuquillo (2017) regarding the personal characteristics (mainly the openness to experience and the risk tolerance) that mainly impact on people' entrepreneurial intention. They also highlight a research topic for further investigation which is the impact of the entrepreneurial idea and its attractiveness on the students' entrepreneurial intention. The present study also confirms findings such as those of Sahinidis et al. (2019), Nowiński and Haddoud (2019), Puni et al. (2018) and Xanthopoulou and Sahinidis (2022) regarding the vital role of education. Finally, the current research adds the entrepreneurial idea as a determinant which influences the intention of students to be self-employed. An entrepreneurial idea which seems attractive and innovative from the beginning of the studies until their completion seems to increase the possibility for someone to show a greater entrepreneurial intention and turn it into action after finishing his/her studies. Thus, we recommend that it is important for tutors to use interesting methods which will help students be more innovative and enthusiastic about their ideas. It would also be helpful to coordinate with people from the labor market who have already been entrepreneurs to discuss the real needs of such a choice and get inspired of realistic and innovative entrepreneurial ideas. Universities are advised to facilitate an entrepreneurship ecosystem consisting of members who share the same vision of entrepreneurship. A variety of institutions that support entrepreneurship, such as incubators, need to be well connected with the Universities to create a supportive environment for the future entrepreneurs. For example,

entrepreneurship tutors could refer students with high entrepreneurial intentions to other organizational units of the university that can further support them in turning their intentions into actions. It should also be considered the cohesion of the teams and how these influences entrepreneurial intentions of students. The present research has several limitations that should be discussed. First, it was initially implemented to students who attended an entrepreneurship course at a single Greek university. There are also differences between business administration departments compared to those in other scientific fields without a business background (Turner and Gianiodis, 2018). Regarding the methodology, studies with larger research sample should follow. Another methodological issue is that interviews were conducted almost a year after the completion of the entrepreneurship course and were therefore based on the retrospective views of the respondents. Conducting multiple interviews on a regular basis, for example by using video diaries during and after the entrepreneurship course, would provide more significant insights into students' entrepreneurial intention over time. Despite these limitations, this study represents an essential step in advancing the emerging debate on student's entrepreneurial intention and the factors that can change it.

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