Lecture Notes in Networks and Systems 1218

Marcin Hernes
Jaroslaw Wątróbski
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Emerging Challenges in Intelligent Management Information Systems

Proceedings of 27th European Conference on Artificial Intelligence ECAI 2024 - IMIS Workshop. Volume 2

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Editors

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ISSN 2367-3370 ISSN 2367-3389 (electronic)
Lecture Notes in Networks and Systems
ISBN 978-3-031-78467-5 ISBN 978-3-031-78468-2 (eBook)
https://doi.org/10.1007/978-3-031-78468-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume contains the second part of proceedings of the ECAI 2024 Workshop on Intelligent Management Information Systems (IMIS 2024). IMIS 2024 was part of the 27th European Conference on Artificial Intelligence ECAI 2024, held in Santiago de Compostela from October 19, 2024, to October 24, 2023.

Following the topics of IMIS 2024, this book discusses emerging challenges related to implementing artificial intelligence in Management Information Systems. The book is devoted to models, methods, and approaches addressing the development of artificial intelligence solution for improving the functionality of information systems that supports management. The main focus is put on machine learning, including deep learning to support business processes, artificial intelligence for financial systems and cryptocurrencies, intelligent human-computer interfaces, knowledge management in business organizations, hybrid artificial intelligence, and multiple criteria decision analysis methods. The book has an interdisciplinary character; therefore, it is intended for a broad scope of readers, including researchers, students, managers and employees of business organizations, software developers, IT, and management specialists.

The volume is divided into three major parts covering the main issues related to the topic.

Part I deals with the knowledge management in intelligent information systems.

Maciej Pondel, Iwona Chomiak—Orsa, Małgorzata Sobińska, Wojciech Grzelak, Artur Kotwica, Andrzej Małowiecki, Kamila Łuczak, Andrzej Greńczuk, Peter Busch, David Chudán, and Petr Berka ("AI Tools for Knowledge Management—Knowledge Base Creation via LLM and RAG for AI Assistant") present how efficiently create a knowledge base for an AI-powered assistant. Processes refer to questions answering from students at the Wroclaw University of Economics and Business. As part of a practical study, a database of 350 sample questions generated by actual students was collected, which was then analyzed using language models, which then identified key topics in the AI agent's knowledge base.

Iouri Semenov and Izabela Auguściak ("Building the enterprises capacity through specialized Self-Learning knowledge platforms (SLKP) connected to omnichannel networks") discuss the concept of self-learning knowledge exchange platforms, i.e. SlKP (Self-learning Knowledge Platform). The results of simulation studies indicating the possibility of selecting eight trends in the development of the TSL industry are quoted, which can assist managers in making strategic decisions.

Zbigniew Pietrzykowski, Mirosław Wielgosz, Paulina Hatłas-Sowińska, Leszek Misztal, Anna Pańka, Marcin Breitsprecher, Piotr Borkowski, Paweł Banaś, Piotr Wołejsza, and Jarosław Chomski ("Communication in encounter situations of autonomous and non-autonomous ships") propose decision-making algorithms for communication in collision situations, where negotiations aimed at mutual agreement of appropriate maneuvres are taken into account. Simulated encounters of an autonomous

and non-autonomous ship for selected scenarios allowed us to assess whether the executed communication processes proceeded correctly. A system of this type can enable communication between a navigator and an autonomous ship using natural language.

Bartosz Szczesny and Wieslawa Gryncewicz ("Between 0 and 1. Exploring the Algorithmic Restraints and the Potential of Quantum Computing in the Financial Sector") explore the theoretical potential of quantum computing to address complex mathematical problems in the financial sector. Authors investigate the transformative impact of quantum computing on key areas such as portfolio optimization, option pricing, risk management, and algorithmic trading strategies. Additionally, authors discuss the implications of quantum computing for financial cybersecurity, highlighting the development of quantum-resistant cryptographic protocols and they provide also a roadmap for integrating quantum technologies into financial practices, thereby enhancing decision-making processes and improving overall efficiency.

Wojciech Drożdż and Krystian Redżeb ("Possibilities of Using AI in DSO Sector") explore the transformative potential of artificial intelligence technologies in the Distribution System Operators sector. They highlights advancements in predictive maintenance, demand forecasting, and energy management, emphasizing how AI can optimize energy distribution and enhance operational efficiency. Results demonstrate the effectiveness of AI in addressing engineering challenges, optimizing energy usage, and improving fault diagnosis in energy systems. The discussion addresses ongoing research challenges, including cybersecurity measures, data quality, and ethical considerations, underscoring the need for interdisciplinary collaboration to fully leverage AI's benefits in the energy sector.

Iwona Chomiak-Orsa, Klaudia Smoląg, Marek Szajt, and Zuzana Hajduová ("Digital competences and the use of social media by Polish students—comparative analysis in 2018–2024") demonstrate the relationship between the use of social media and the digital competences of Polish students. The main conclusion of the research is a higher assessment of digital competences of students using social media and a change in students' preferences regarding the use of specific social networking sites. The results showed that students use Tik Tok, X, and Instagram more often and are more cautious in assessing their own digital competences.

Marta Starostka-Patyk, Marek Szajt, and Helena Kościelniak ("Cognitive technologies in logistics customer service management—the case of e-commerce") investigate the role of cognitive technologies in managing logistics customer service in the e-commerce sector. The study presents empirical research conducted among Polish e-commerce users in 2024, analyzing the impact of these technologies from the customer's perspective. The findings indicate that cognitive technologies significantly improve customer experience by providing personalized product recommendations and efficient problem-solving through chatbots.

Witold Chmielarz and Anna Sołtysik-Piorunkiewicz ("Conditions of Building a Career in the IT Sector from the Point of View of Students of Selected Universities in Poland") explore students' perspectives on their future careers in the IT profession. Additionally, the study compares differences in the desire to pursue a career as an IT specialist between students from the two universities in Poland. The article analyzed students' perceptions of the current IT market and trends, focusing on the challenges

and fears associated with working in the IT industry. The analysis of the results enabled the authors to assess the level of IT career awareness among the students and understand how respondents' opinions differ in both universities.

Witold Chmielarz and Anna Sołtysik-Piorunkiewicz ("Conditions of Building a Career in the IT Sector from the Point of View of Students of Selected Universities in Poland") explore students' perspectives on their future careers in the IT profession. Additionally, the study compares differences in the desire to pursue a career as an IT specialist between students from the two universities in Poland. The article analyzed students' perceptions of the current IT market and trends, focusing on the challenges and fears associated with working in the IT industry. The analysis of the results enabled the authors to assess the level of IT career awareness among the students and understand how respondents' opinions differ in both universities.

Joanna Tylkowska-Drożdż ("Artificial Intelligence as a Factor in Career Development in Musical Art: Case of Students of the Academy of Art in Szczecin") investigates the role of artificial intelligence as a catalyst for career advancement among students at the Academy of Art in Szczecin, exploring how emerging technologies are reshaping educational paradigms and professional trajectories in the field of music.

Agnieszka Siennicka, Agnieszka Matera-Witkiewicz, Maciej Pondel, and Iwona Chomiak-Orsa ("Artificial Intelligence in Medical Field—Practical Observations from the Perspective of Medical University") analyze the main reasons determining the need to digitize information resources used by medical entities such as hospitals and academic centers in order to share knowledge and provide innovative solutions. Authors discuss the emergence of digital medicine centers and the methodologies used to create them, shedding light on the multifaceted nature of medical data, including electronic health records, biobank repositories, and clinical trial datasets.

Part II is devoted to application of machine learning in management information systems.

Boleslaw Borkowski, Marek Karwanski, Wieslaw Szczesny, and Monika Krawiec ("Bitcoin volatility forecasting using statistical analysis and AI models—a comparative study") present comparative analysis of the effectiveness of two analytical cultures: statistical analysis and data modeling, and algorithmic AI analysis to forecast volatility of Bitcoin obtain by using Exponentially Weighted Moving Averages (EWMA). The study has shown that on a shorter time horizon a statistical analysis resulted in a better fit than AI methods (LSTM and LSTM+x). Conversely, LSTM+x was better at a longer time period when data displays higher volatility and higher peaks. In conclusion, both methods are applicable in predicting volatility of cryptocurrencies.

Agata Kozina, Michał Nadolny, and Marcin Hernes ("Effectiveness of automatic data transformation in deep learning model for leasing decision support process") developed the method of automatic data transformation and shown that this method gives as good results as manual transformation, however, it allows to perform the operation without unnecessary waste of time and effort. The results show that the automatic transformation produces statistically indistinguishable machine-learning effects as the manual transformation.

Andrzej Dudek, Marcin Pełka, Krzysztof Lutosławski, Marcin Hernes, Piotr Tutak, and Ewa Walaszczyk ("Clustering customers' behavior of an online store offering e-learning courses using machine learning") developed a method for clustering customers'

behavior of an online store offering e-learning courses using machine learning. The main contribution of the research is performing the clustering in the context of retention of customers' behavior of an online store offering e-learning courses. The K-Means, self-organizing map and Decision tree methods have been used in this research. The research results demonstrated that the primary factors influencing customer segment membership are the recency and monetary score columns, suggesting these should be examined in promotion profiling.

Ewa Walaszczyk, Michał Nadolny, Artur Rot, Paweł Golec, and Mykola Dyvak ("Prediction of the importance of factors influencing co-sharing attitudes using machine learning") analyze the possibility of classifying co-sharing survey respondents depending on their method of assessing each decision-making factor separately using selected machine learning methods. XGBoost, decision trees, and LightGBM models were used. The input data were the respondents' characteristics, and the output data was the importance of eight factors in the co-sharing decision-making process. The presented research shows that there is a possibility of predicting the importance of decision-making factors based on respondents' characteristics. The research results may be essential for smaller companies that do not have the funds or time to take extensive market surveys.

Part III is devoted to multiple criteria decision analysis and computational methods for management information systems.

Bartosz Paradowski, Arkadiusz Marchewka, and Wojciech Sałabun ("Exploring the mechanism of compromise in novel ICRA method: An In-depth Analysis") conducted a simulation to examine the ICRA compromise mechanism across different similarity of initial rankings, considering both preference values and ranking-based compromise seeking. The findings demonstrate the ICRA procedure's significant potential, allowing the compromise process to be tailored to the decision maker's expectations. Preference values are identified as the preferred initial assessment method in the compromise process, as rankings can lead to a partial loss of information.

Kateryna Czerniachowska and Philippe Krajsic ("Grass cutter heuristics for knapsack-like problems of resource allocation") present innovative grass-cutter heuristics devised to address knapsack-like resource allocation problems incorporating product categorization. These heuristics are designed to streamline the solution process, enhancing efficiency, and profitability.

Joanna Kołodziejczyk, Zdzisław Szyjewski, and Wojciech Sałabun ("Markovian Consensus Based on Local Alternatives' Relation") proposed technique for rank consensus based on a stochastic Markov process that follows a probability pattern derived from pairwise rankings. A directed graph describes the transition frequency directly from one alternative to another. The consensus is achieved as a stationary distribution of a Markov chain in discrete time.

Karol Kuczera and Damian Dziembek ("Application of Rough set Theory to Improve the Efficiency of Higher Education Systems") analyzed the possibility of application of the Rough Set Theory to improve the efficiency of the higher education system. The attempts to induce decision rules revealed interesting relationships between the characteristics of the examples included in the decision table and the students' success (graduate) or failure (dropout). The study verifies the usefulness of the Rough Set Theory to

build a rule base for decision-making in order to increase the efficiency and effectiveness of higher education.

Łukasz Lemieszewski, Piotr Borkowski, Szymon Prochacki, Piotr Puzio, and Evgeny Ochin ("Distances between successive vehicle position measure-ments in the decision rule for an intelligent GNSS signal spoofing detection system using a single antenna") present the concept of a decision rule for the needs of an intelligent GNSS signal spoofing detection system using a single antenna. This significantly reduces the dead zone of GNSS spoofing detection using a single antenna. The proposed approach was positively verified in tests conducted in real conditions.

Oliwia Mróz-Malik ("Methodical aspects of offshore wind energy transformation modelling in Poland") explores the methodological aspects of modelling the contribution of offshore wind energy to Poland's energy transition, focusing on economic, social, and environmental factors. Using simulation techniques and real data, this study aims to provide a comprehensive framework for assessing the potential for offshore wind energy participation in Poland's economic development and energy system transformation. The paper will be complemented by an excerpted assessment of the challenges of integrating offshore wind energy into the Polish energy system.

Kateryna Czerniachowska, Krzysztof Lutosławski, and Bogdan Franczyk ("Heuristics for flexible job shop scheduling problem with simultaneous tasks execution on different workplaces of a single machine") investigate the flexible job shop scheduling problem on multiworkplace machines that can serve several workplaces simultaneously. Authors developed four heuristics for the production of the product elements for the cases if the sequence of products in an order is determined and not determined. Heuristics were evaluated by comparing the obtained solution with the optimal solution provided by the CPLEX solver.

We want to express our gratitude to all the authors for their interesting, novel, and inspiring contributions. Peer reviewers also deserve deep appreciation because their insightful and constructive remarks and suggestions have considerably improved many contributions. Last but not least, we wish to thank prof. Janusz Kacprzyk for his help in implementing and finishing this large publication project on time, maintaining the highest publication standards.

September 2024

Marcin Hernes
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Contents

Knowledge Management in Intelligent Information Systems

AI Tools for Knowledge Management – Knowledge Base Creation via LLM and RAG for AI Assistant

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Abstract. AI assistants allow the automation of routine tasks performed by humans, thereby supporting the optimization of business processes within enterprises. By leveraging large language models (LLMs), they help retrieve relevant content and knowledge to undertake activities within business processes. Assistants also aid in preparing content constituting the output of individual steps in business processes. The development of an assistant using generative artificial intelligence to support and automate student service processes in the dean's office work area is a very innovative solution. It should be noted that this area of the university's activities has not used advanced technological solutions so far. Thus, the special contribution of the article is to explore such a possibility and develop a prototype solution. This article aims to show how efficiently create a knowledge base for an AI-powered assistant. For this paper, processes refer to questions answering from students at the Wroclaw University of Economics and Business. As part of a practical study, a database of 350 sample questions generated by actual students was collected, which was then analyzed using language models, which then identified key topics in the AI agent's knowledge base.

Keywords: Artificial Intelligence (AI) · Knowledge Management (KM) · Higher Education (HE) · Large Language Model (LLM) · Retrieval Augmented Generation (RAG)

1 Introduction

Proper organizational functioning is made possible by efficient management, a key element of which is communication - both in the internal and external environment. In the educational context, a particular aspect of communication is the communication and

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 3–15, 2024.
https://doi.org/10.1007/978-3-031-78468-2_1

distribution of knowledge. The KM system operating in an organization is responsible for effective cooperation between different entities. KM is an extremely time-consuming process involving many resources; one way to improve such processes is through information and communication technologies (ICT). A particularly relevant example of technology is artificial intelligence (AI). Information systems (IS) that support communication in organizations are developing at an increasingly high rate, gaining newer and newer functionalities using AI.

An important aspect in the context of using AI to improve communication is building chatbots. A chatbot as a computer program allows a user to converse with a system that simulates a human conversation. Chatbots permit users to obtain basic information from a selected area, or handle simple business matters - such as filing a complaint or renewing a contract. AI Assistant is a more advanced application than a chatbot. Apart from conducting conversations, it is capable of applying reasoning to provide users with recommendations for actions or assisting in decision-making processes.

Returning to the educational context, the appropriate distribution of information and knowledge is an especially important aspect of higher education [1, 2]. The wide range of information students seek reduces the efficiency of other university processes. When searching for answers to issues that bother them, they turn to the dean's office staff or academic teachers, who try to provide correct answers. Improving this process can be an AI assistant, who, after asking a question from any area of the university's operation, will provide a speedy outcome to the student. The purpose of this article is to design a knowledge base for an AI assistant to support KM at the university; its task is to answer students' questions about the operation of the university based on the information provided to it. To achieve the stated goal gained via the literature and conducted empirically, we will answer the following questions:

RQ1. What questions about the functioning of the university do students most often ask the dean's office staff and academic staff?

RQ2. How to carry out the process of preparing the knowledge base of the AI assistant so that it can address the actual questions of its future users?

We begin with an introduction that presents the research problem, research questions, and purpose of the paper. The following section covers the theoretical background in which the we address the topics of KM in processes using ICT, as well as the role of the AI assistant in KM. Next, the we present the methodology, followed by the results of the study. The article ends with a discussion and conclusions.

The solution proposed by the authors is fully innovative. The main determinants of the search for such a solution is the lack of use of advanced information technologies in the area of supporting the work of deans' offices. In the case of Polish universities, this area of functioning as well as other processes related to serving students do not use available technological solutions. Thus, proposing a solution using generative artificial intelligence may become a turning point in the way of automating deans' office.

2 Theoretical Background

2.1 Knowledge Management in Business Processes Using ICT

KM has been a well-known topic for many years, but in the rapidly developing economy, it is taking on a new dimension and is defined as a series of activities aimed at identifying, preserving, disseminating, and supporting both explicit and tacit knowledge to increase the overall efficiency of an organization. Contemporary approaches to KM should consider technological and organizational aspects, which pose challenges related to the continuous improvement of KM systems in organizations transitioning to business models based on ICT and AI tools. AI technologies have tremendous transformational potential, akin to the Industrial Revolution, and can significantly impact knowledge management [1–4]. AI enables the optimization of existing processes, automation, improvement of information quality, and human interaction, as highlighted by numerous studies. Table 1 presents the evolution to gathering and sharing knowledge.

KM evolution underwent various stages - from the pre-industrial era, through the printing era, digitization, and the internet, up to the current day - i.e., dominated by AI systems. Each of these stages being characterized by different media for storing knowledge, ease of replication, media capacity, and quality and speed of information retrieval.

Table 1. Key Eras of knowledge gathering and access.

		Key Eras of Knowledge Gathering and Access				
		Preindustrial Era	Print Era	Digitization Era	Internet Era	AI Era
Knowledge management aspect	Key Medium	Human memory	Books Magazines Academic boards	Computer files databases	Web	AI Systems
	Ease of Knowledge Replication	Limited	Significant	Excellent	Excellent	Excellent
	Medium Capacity	Limited	Unlimited	Unlimited	Unlimited	Unlimited
	Search Speed	High	Low	High	High	High
	Search Quality	Very Good (Natural Language)	Highly limited	Good	Very Good (Speed and Large Knowledge Bases)	Outstanding (Natural Language, Contextuality, Reasoning)

Organizations of various types face significant challenges in wisely and safely adopting the latest technological advancements into their business models, ensuring minimal

negative consequences - both in terms of information security and social impact [5–7]. It is undoubtedly worth considering the use of AI mechanisms in the context of optimizing certain processes that until now had to be handled/implemented in less efficient ways.

Researchers highlight the benefits of human-robot collaboration [8]. Increasingly, studies indicate very specific effects of AI applications which encompass a wide range of technologies, including machine translation, chatbots, and self-learning algorithms, allowing individuals to better understand their environment and act accordingly [9, 10]. Organizations are adopting technological innovations in AI to adapt to their ecosystem while developing and optimizing their strategic and competitive advantages. On the basis of 500 case studies, Wamba-Taguimdje et al., showed AI contributed to improving outcomes at both the organizational (financial, marketing, and administrative) and process levels [11]. Both Zebec as well as Bachiller et al. argue AI can play a key role in business process management (BPM), enabling greater flexibility and automation, traditionally limited by rigid definitions and routines [12].

Chakraborti et al. describe the transition from Robotic Process Automation (RPA) to Intelligent Process Automation (IPA), where AI and machine learning improve business process outcomes [13]. Bachiller et al. [1, 2] identify how AI involving Large Language Models (LLMs) can improve BPM in tertiary as well as primary and secondary educational domains [1, 2]. Loureiro et al. provide a review of research on AI in the business context, identifying the main trends and challenges and propose an agenda for future research [14].

Ribeiro emphasizes that in recent years, AI algorithms and Machine Learning (ML) approaches have been successfully applied in trade, industry, and digital services. AI is used in classification, optimization, clustering, prediction, and pattern identification. Within RPA, AI is implemented in various contexts, such as enterprise resource planning (ERP), accounting, and human resource (HR) management, to classify, recognize, and categorize data [15].

Despite growing interest, organizations struggle to adopt and effectively leverage AI in their operations. There lacks coherent understanding of how AI technologies create business value and the type of value to be expected, necessitating a holistic approach to the topic. Enholm et al. emphasize the need for a better understanding of how AI generates business value; they highlight the importance of identifying key factors influencing the adoption and use of AI in organizations and propose further research on AI utilization to fully exploit its potential in various business contexts [16]. Alternatively Chowdhury et al. show organizations need to look beyond technical resources, and put their emphasis on developing non-technical ones such as human skills, competencies, leadership, team coordination, organizational culture, and an innovation mindset, governance strategy, and AI-employee integration strategies to benefit from AI adoption [17]. While Dwivedi et al. combine the collective insights of many leading experts to highlight the significant opportunities, realistic assessment of impact, challenges, and potential research agendas arising from the rapid emergence of AI across a range of domains such as business and management, the public sector, science, and technology [18]. Although much AI literature exists, there are still many challenges and management/KM implications that could and should be addressed in future studies. Here, we focus on KM in a HE institution,

specifically on issues related to optimizing the processes of the dean's office operations using an AI assistant.

2.2 AI and LLM as a Support for Knowledge Management Processes

Generative AI is a type of AI that can create new content, such as text, graphics, and music, in a manner akin to human creativity, and is usually based on deep learning techniques [19]. LLMs are a subset of generative AI, designed to understand and generate natural-looking text, and is achieved by training on vast datasets containing diverse language patterns [20]. Numerous different LLM models exist differing mainly by size and capabilities [21]. An essential concept for adapting LLMs is RAG (Retrieval Augmented Generation), which enables the model to dynamically access and incorporate external knowledge sources to enhance the answers [22]. Prompt engineering is the process of refining instructions for generative AI to create desired outputs. There are many approaches to prompt engineering, ranging from simple zero-shot prompting [23] to complex techniques such as self-consistency [24] or ReAct [25].

Modern information technologies, including AI, LLMs, and methods based on knowledge reconstruction (involving RAG), play a pivotal role in KM. AI, leveraging advanced ML algorithms, facilitate the analysis of extensive datasets, thereby uncovering hidden patterns and trends. These technologies enhance KM processes by automating tasks related to the collection, storage, and dissemination of information.

LLMs such as GPT-4 (Generative Pretrained Transformer 4) can process natural language (NL), which allows them to efficiently retrieve and interpret information from a variety of sources. Thanks to LLM, it is possible to generate personalized answers to questions, translate texts and summarize documents; such functions significantly contribute to improving the effectiveness of KM in organizations. Aguinis et al. show how generative AI - particularly ChatGPT, can be a helpful HRM assistant in both strategic and operational tasks; for this to happen, they note the need to create valuable suggestions resulting in specific, helpful, and practical HRM recommendations. Accordingly, they present eight guidelines for creating high-quality and effective prompts and illustrate their general usefulness across eight critical HRM domains. They also provide recommendations on how to implement a critical verification process to check ChatGPT suggestions [26].

Thirunavukarasu ponders the validity of implementing an AI assistant, for the development of LLMs with extraordinary performance on unseen tasks introduces the possibility of AI assistants contributing to healthcare delivery. LLMs such as GPT-4, OpenAI and Med-PaLM (Pathways Language Model) 2 (Google) are pre-trained on billions of human-generated words in context, before being refined to optimize answers to queries generated by users. When confronted with qualified doctors working in their spare time to answer patients' questions on a social media (SM) platform, ChatGPT provided more accurate and empathetic answers [27].

RAG integrates language models with databases, enabling the creation of more precise and contextualized responses to user queries. RAG allows for dynamic updating of information, which is especially important in a rapidly changing environment. Murugan et al., see great potential for RAG and evaluate an AI assistant developed using OpenAI's GPT-4 for interpreting pharmacogenomic (PGx) testing results, to improve

decision-making and knowledge sharing in clinical genetics and enhance patient care with equitable access. The AI assistant employs RAG which combines retrieval and generative techniques, by harnessing a knowledge base (KB) comprising data from the Clinical Pharmacogenetics Implementation Consortium (CPIC) and uses context-aware GPT-4 to generate tailored responses to user queries from this KB, which is further refined through prompt engineering and guardrails. The integration of context-aware GPT-4 with RAG significantly enhanced the AI assistant's utility. RAG's ability to incorporate domain specific CPIC data including recent literature, proved beneficial. In summary, IT - especially AI, LLM and RAG, offers powerful tools to support KM processes, enabling the automation of routine tasks, improving the precision of information searches and providing personalized, up-to-date data, leading to increased efficiency and innovation in organizations [28].

3 Methodology

In the proposal presented in this article, the knowledge base of AI Assistant will consist of substantive articles describing various aspects of the university's functioning. To avoid the need to create separate articles addressing each of the collected questions, the questions will be grouped using a clustering algorithm. This way, each cluster will represent a series of thematically related questions. The authors of the knowledge base will prepare a list of articles that will correspond to the number of clusters. Each article will need to thematically cover the series of questions grouped in one cluster. We will refer to the grouped questions concerning the same area as "topics" in the subsequent sections. The Knowledge Base in our case will be created in the next stage using a CMS-class tool, which will gather a set of text-based articles addressing various topics identified at the current stage. The content will undergo embedding to enable the AI assistant to perform semantic searches for relevant articles and use them in constructing responses to user questions.

We identified topics to be covered in the AI assistant's knowledge base performing the following steps:

1. A survey was conducted among students at the *Wroclaw University of Economics and Business*. Based on their experience and knowledge about the university, students were asked to enter questions (in Polish) they could ask the AI Assistant.
2. The gathered questions included many typographical errors. Grammatical corrections were applied to the questions. This task was performed using the GPT-3.5-turbo model (provided by the OpenAI API) with the following system prompt: "Correct the indicated question in terms of Polish grammar and spelling. Keep the final form of the question." The prompt was given in English, while the user prompt was the original question.
3. We verified the correctness of the question transformations to calculate the quality of the process.
4. Keywords were identified in every question by the GPT-3.5-turbo model. The system prompt was in Polish as it included the desired grammar necessary for expressing certain concepts only able to be conveyed in the Polish language.

5. We decided to standardize the keywords by grouping them according to their meanings. The main goal was to eliminate situations where synonyms with a low frequency of occurrences existed on the list of keywords.
6. Both the question and keywords were concatenated into one string to combine them and enhance the information contained in the question.
7. The concatenated question and keywords were transformed into a vector of numbers using a word embedding technique. To generate the embeddings, we used the model *text-embedding-ada-002* provided by the OpenAI API.
8. Clustering of embeddings was performed. The embedding model resulted in a vector of 1536 dimensions. We selected the Agglomerative Clustering algorithm and its implementation in the scikit-learn library. These vectors were divided into groups by the clustering algorithm to identify repeating questions or groups of similar questions addressing the same topic.
9. Visualization of clusters and analysis of questions that were grouped together into one cluster were performed. To visualize the 1536-dimensional vectors, using the PCA algorithm we transformed the multidimensional structure into two dimensions (X, Y).

4 Research Results

We gathered 351 sample questions from students. An example of a raw question transformation into a corrected one is presented in Table 2. It has been shown that the submitted questions contain typographical errors that are easy to make in Polish as well as grammatical imperfections, which have been corrected by the language model.

Table 2. Example of a question transformation.

Raw question	Question corrected by GPT3.5
gdzie znalezc sylabus	Gdzie znaleźć sylabus?
Czy jest możliwość i jak zmienić grupę z angielskiego?	Czy jest możliwość zmiany grupy z angielskiego i jak to zrobić?

Twenty-three questions (among 351) were indicated as not properly transformed, which represented 6.6% of possible errors, which did not significantly impact the overall task. We believe using GPT-4.0 and applying a better prompt could decrease the number of errors. Example results of keyword generation are presented in Table 3. Generated keywords increased the informativeness of every question.

An example of word embedding is illustrated in Fig. 1, which shows the embedding for a selected question combined with keywords. The entire embedding is a vector of 1543 dimensions, so only a slice of the vector is presented.

As a result of clustering, 44 clusters were generated. The Agglomerative Clustering algorithm works by initially treating each data point as its own cluster and then iteratively merging the closest pairs of clusters. This process continues until all points are merged into a single cluster, forming a hierarchical tree known as a dendrogram. By setting

Table 3. Examples of keyword generation.

Question	Keywords generated by GPT3.5
Kiedy dany prowadzący prowadzi konsultacje?	prowadzący, konsultacje, terminy
Jak złożyć podanie o stypendium, jakie są terminy?	podanie, stypendium, terminy

Questions and Keywords	Embedding
Pytanie: Czy byłaby możliwość zmiany promotora? Jakie są procedure związane z tym? Słowa kluczowe: zmiana, promotor, procedura	[-0.006374822463840246, -0.012457904405891895, 0.016536053270101547, -0.0135193401947617 53, -0.033245909959077835, 0.025002710521221 16, 0.0037057145964354277, -0.0032091364264488 22, -0.031979635357856 75, -0.0010583322728052735, 0.025673091411590576, 0.025151684880256653, 0.0020018308423459 53, 0.007448672316968441, 0.008323892019689083, 0.015108390711247921, 0.04134013131260872, 0.005347526156588068, -0.005418909247964621, 0.002878601662814617, -0.017640938982367516, -0.01089368388056755, -0.0021228715777397156, 0.009037722833454609, -0.016113961111547947, -0.002256327075683746, 0.02084386907517 91, -0.028280125930905342, -0.004000558052212, -0.014711128547787666, 0.023984724655747414, 0.010732295922935009, -0.020570751279592514, 0.0022128764539957047, -0.026467615738511086, -0.051693785935640335, 0.006412065587937832, -0.010608151555506134, 0.0016697441460564733, -0.017653353512287 14, 0.010639186948537827, 0.037739939987659454, 0.017851985991001 13, -0.03294796124100685, 0.0023820234928280115, 0.011917876079578535, 0.012749644927680492, -0.010167437605559826, -0.005316489841789007, 0.021141815930604935, 0.009186696261157526, 0.009763968177139759, 0.001459474326111 3763, -0.024890981614589 69, -0.026790391653776 17, -0.028727047145366 67, 0.012551013380289078, 0.021712880581617355, -0.006672769319266081, -0.012364796362817287, 0.006244470365345478, 0.010589529760181904, -0.017591280862689018, 0.026219327002763748, -0.009348084218800068, 0.008683910593390465, -0.016573296859860 42, 0.019577594473958015, -0.021874267607927322, 0.002001830842345953, 0.037715110927820206, 0.025002710521221 16, 0.011787524446845055, -0.005912384018301964, 0.014810443855822086, -0.011179216206073761, 0.000659517885651 4394, 0.006315853446722031, -0.006616903934627771, 0.017491966485977173, 0.010347447358071804, -0.014363523572683334, -0.037839256227016 45, 0.009056344628334045, 0.029968492686748505, 0.014077991247177124, 0.001456370693631 4702, 0.007852142676711082, -0.016846414655447006, -0.008485279045999 05, 0.001013329834677279, 0.024158528074622154, 0.019590009003877 64, 0.022979155182838 44, 0.005657887551933527, 0.010068122297525406, 0.001945965690538 2872, 0.021774953231215477, 0.016660196706652 64,

Fig. 1. Example embedding for a selected question combined with keywords.

a parameter called "distance_threshold", the algorithm can autonomously determine the number of clusters based on the specified distance criteria for merging clusters. The value of the distance_threshold indicator was set to 0.7. The authors set it experimentally by analyzing the results of different runs of the clustering process. The selection of the optimal clustering algorithm and the best number of clusters will be the subject of further research (Table 4).

Table 4. Characteristics of the obtained clusters

Characteristic	Value
Number of clusters	44
Highest number of questions in one cluster	23
Lowest number of questions in one cluster	3
Median number of questions in clusters	7
Average number of questions in clusters	8

The exact number of questions in each cluster is presented in Fig. 2.

The main assumption for these clusters was that they should include questions addressed to the same topic. A few selected questions with their PCA embeddings and cluster assignment, are shown in Table 5.

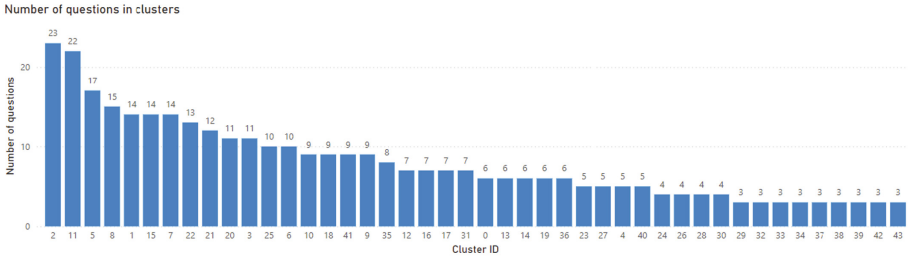

Fig. 2. Distribution of the number of questions among clusters.

Table 5. Selected questions, cluster and PCA 2-dimensional vector.

Question	Cluster ID	PCA1	PCA2
146: W jaki sposób mogę otrzymać elektroniczną legitymację?	42	-0.1324652355676581	-0.01849903804948404
45: Jak wygenerować elektroniczną legitymację w mObywatelu?	42	-0.1077208520460859	-0.00795975971132409
76: Jak zdobyć elektroniczną legitymację?	42	-0.1243237302352788	-0.01851443701784298
248: Kto jest opiekunem mojego kierunku studiów?	43	0.007144760546571336	-0.01569973549860784
249: Kto jest opiekunem kierunku studiów?	43	0.01699823092338883	-0.0180610786159721
323: Kto jest opiekunem kierunku Informatyka w Biznesie?	43	0.03012104482264039	0.03949675750685954

Visualization of the presented questions (where color represents the cluster id – i.e., a topic), is presented in Fig. 3. Questions provided by students, divided into topics, help to understand the key areas of the KB for the AI Assistant.

A visualization of 5 selected clusters along with the full questions are shown in Fig. 4 (including all questions would render the figure illegible). This selected cluster presentation is useful in the final KB generation. Knowing what questions cover the same topic, it is possible to generate a content of a specific article.

The final construction of the knowledge base based on the defined topics will be the subject of further project work.

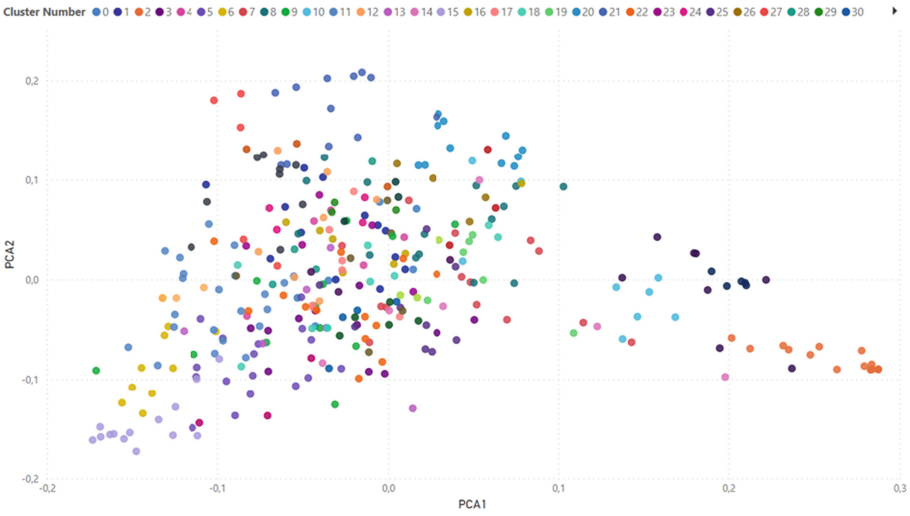

Fig. 3. Questions delivered by students divided into topics.

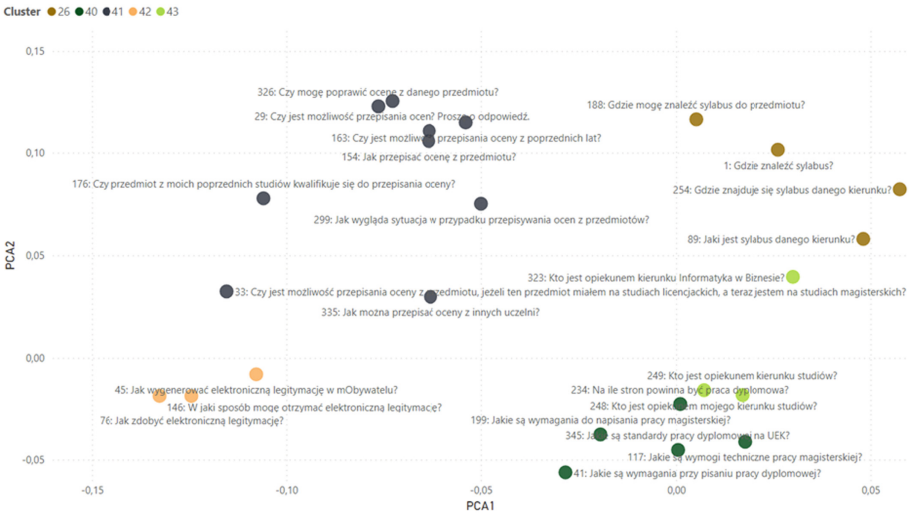

Fig. 4. Selected clusters presentation.

5 Discussion and Conclusions

The aim here was to show the process of designing a KB for an AI assistant to support KM at the university, where the purpose was to answer student questions about the functioning of the university, currently being asked of the dean's office staff or their academic teachers. Summarizing the research conducted, we answer the stated questions:

RQ1. What questions about the functioning of the university do students most often ask the dean's office staff and academic staff?

The application of the described method helped extract 351 questions from the database, covering 44 key areas that should be included in the KB to enable the AI assistant to assist students solve their problems.

RQ2. How to carry out the process of preparing the knowledge base of the AI assistant so that it can address the actual questions of its future users?

Asking participants in business processes about their potential needs for support from an AI Assistant is the most effective way to identify areas of operation for the AI Assistant. The large number of collected questions necessitates automation in their analysis. The proposed method, based on embedding and clustering techniques, allowed for the aggregation and extraction of key topics that should be described in the KB in subsequent steps.

We encountered some limitations when conducting the study. Asking students about their potential problems related to handling matters at the University is relatively easy and quickly yields satisfactory results. However, for supporting other business processes, especially in the areas of customer interactions, a different method should be developed to gather knowledge about areas to be covered by the AI Assistant. Furthermore, the applied method allowed for the development of topics for the AI Assistant's operation. Currently, we are not yet able to evaluate the quality of the AI Assistant's performance. Future research will involve defining the method of operation for an AI Assistant based on LLM and RAG, building a prototype AI Assistant, and evaluating its performance. Two additional economic universities (Prague and Varna) will be involved in the development and verification of the assistant, which will allow us to assess whether the applied approach is universal in terms of both language and the specific work requirements of other economic universities.

Acknowledgments. This study was funded by Wroclaw University of Economics and Business (internal grant).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Building the Enterprises Capacity Through Specialized-Self-Learning Knowledge Platforms (SLKP) Connected to Omnichannel Networks

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Abstract. Since the beginning of the 21st century, we have been observing various changes that shape the reality in the business world described by the term VUCA (*Volatility Uncertainty Complexity Ambiguity).* The manifestations of these changes are noted in all areas of the economy, including the service markets, which creates risks and opportunities for development, especially for companies involved in e-commerce activities. This requires from the employees of these enterprises not only hard skills *(Hard Skills)* and soft skills *(Soft Skills)*, but also the ability to cooperate in a team, with business-partners and customers, creative thinking, openness to change, knowledge of good practices, the ability to make the right decisions. Employees are expected to be knowledgeable and highly skilled, and company management is expected to manage their cognitive and creative potential efficiently in order to achieve synergies in B2B, B2C and C2B relationships. The article discusses the concept of *self-learning* knowledge exchange platforms, i.e. SlKP (*Self-learning Knowledge Platform*). The results of simulation studies indicating the possibility of selecting eight trends in the development of the TSL industry are quoted, which can assist managers in making strategic decisions.

Keywords: T&L market · Information transfers · Implicit and explicit knowledge · Synergy

1 Introduction

Fluctuations in demand, constraints and complications in obtaining new sources of energy resources and raw materials, increases in the cost of doing business are all factors contributing to turbulence in both the business-environment and the consumer sector. The observed instability results in disruptions in information flows and delays in decision-making processes, a phenomenon described as VUCA (*Volatility, Uncertainty, Complexity, Ambiguity*). One of its effects is a change in the priority of TSL companies from the pursuit of maximum profitability of business processes to the priority of sequentially strengthening the intellectual and creative potential of staff. (Yas et al. 2021) The rationale for this shift in priorities has pointed to the exponential growth of information generated in the global economy to between 2.5 and 3.0 quintillion bytes of data per day (Durairaj 2020). Such utilitarianism creates a barrier to increasing the efficiency

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 16–29, 2024.
https://doi.org/10.1007/978-3-031-78468-2_2

of the management of the production processes of material goods and services, hinders the achievement of corporate goals, and leads to a loss of competitive capacity. In this aspect, all companies can be divided into three groups:

Group 1. They do not synchronise digital and paper information streams increasing the risk of overlooking the knowledge provided. They have to constantly check the information provided increasing the time-consumption of decision-making processes.

Group 2. Synchronise information streams, but employees lack motivation to share, increasing the likelihood of asymmetric information being exchanged at the risk of losing the trust of business-partners.

Group 3. Synchronise information flows and knowledge is used in teamwork, but there is a lack of ideas to motivate employees to acquire new soft skills to enlarge intellectual, cognitive and creative potential (Kazanoglu and Abedin 2020).

The improvement of this situation has been achieved in three stages:

Stage 1 Develop and apply i.e. MAS (*Multi Agent Systems*) for team members to acquire new skills and qualifications ensuring that everyone has access to knowledge. Results (Saatcioglu 2009), (Grabara, 2013): barrier-free development of managers' potential, reducing tensions by matching employees to their jobs, strengthening existing and creating new business relationships. Achieving these effects required a number of studies, including *Electronic Data Interchange* (EDI) techniques, AS2 transmission protocols, SFTP, WebService, OFTP, (Jiang et al. 2021). The development of ISO 9241-11:2018 has formed an additional basis for (Saberi et al. 2022) (Goonatilleke and Hatiing 2022):

- focusing companies on targeted activity, handing over the rest to subcontractors;
- motivating managers to apply the information transmission and search engine *optimisation (*SEO) standards *(Search Engine Optimisation*);
- eliminating time constraints (24/7) in B2B, B2C relationships;
- joint use of intellectual and cognitive resources;
- the provision of services in various modes, including online, offline and hibernation.

At the turn of the 20th and 21st centuries, the spread of MAS was hampered because many companies were reluctant to enter into cooperative relationships fearing loss of control over business processes, being forced to make unfavourable decisions, losing confidential information. The second reason was the development of the concept of i.e. BDP (*Big Data Platform*) information platforms (Alicke 2016) providing relative independence for business-partners.

Stage 2 The BDP concept has been implemented according to the principle of collecting in its databases only the information that is needed and can be immediately sent to the interested party in P2P (*Peer -to- Peer*) mode and the possibility of supplementing the transmitted information to the full satisfaction of the supplicant. BDP concepts are based on ISO 23354:2020 (E) and have found application in the TSL industry in the form of LISS (*Logistics Information Service Systems*) (Stroumpoulis et al. 2021) (Table 1).

An analysis of the experience gained in Phases 1 and 2 identified both their strengths and weaknesses. In an environment of stiffer competition, the problem of access to knowledge gained not only by cooperating business-partners, but also by companies from related industries, which is not guaranteed by MAS and BDP, arose. The expansion of the range of tasks performed, the differentiation of requirements for the transmission of

Table 1. Types of information available in the LISS (Authors' elaboration)

Characteristics of the information collected in the LISS			
Types of information	Characteristics	Information synergy effects	Reasons for synergy effects
Marketing	EMPIRICAL INFORMATION It informs about the demand and supply market situation, supporting the decision-making process	Effects are created as added value when integrated with service and industry information	Dependent on market developments
Industrial	FACTUAL INFORMATION Informs about the characteristics and properties of the manufactured good	Effects created in manufacturing processes when integrated with science-based marketing and service knowledge	Dependent on the progress of technical and technological development
Services	PROCESSUAL INFORMATION - *Informs* about the added value of a good as a result of the creation of a service in the course of offering, delivering and servicing the good	Effects created in service processes after the integration of service and marketing information based on scientific insight	Dependent on changes in customer needs /digital services/
Scientific research	STRUCTURED INFORMATION It informs research findings, is rigorous and systematic, and has a high degree of generalisability	Effects produced by statistical and simulation studies arising from cause-and-effect relationships	Depend on research methods and techniques

information, and the limited access to expertise, initiated the next stage of development. Aiming to close the information gaps, the authors focused their attention on studies of information support for collaboration in B2B, B2C relationships (Kot et al. 2011; Arsawan et al. 2020). The research was based on the results of an analysis of the TSL industry on the SME segment. We will move on to step 3 on SLKPs.

2 Types of Knowledge and Modes of Acquiring It

Most modern companies are customer-oriented and direct a significant part of their investment towards customer acquisition and retention (Saatcioglu 2009). In contrast, those that invest in developing the creative potential of staff and base decision-making on a sequence of CKD (*Concept-Knowledge-Decision)* activities during which the manager needs (Baena-Rojas et al. 2023) are winners:

– continuous access to knowledge about good practices and new technologies;
– support during the exchange of messages with business partners and customers;
– information about the decision-making process.

In order to potentiate the usefulness of SIKPs, it is proposed to ensure both their multichannel nature and the multifaceted nature of the scientific, research, marketing, industrial and logistics knowledge acquired. Its accumulation enables synergies to be achieved through synthesis:

– *in the marketing aspect:* knowledge of market changes and techniques for responding to change;
– *in the industrial aspect:* knowledge of the production performance data of industrial companies and their ability to eliminate bottlenecks;
– *the logistics aspect*: knowledge of sourcing, supply chains, transport service providers, location of logistics centres.

Three types of knowledge need to be distinguished in the pursuit of synergy effects:

1. *Explicit Knowledge (EK).* It is a codified knowledge that can be easily found and collected, shared with other employees and partners. Examples of EK are the information contained in the results of case studies, reports and reports, operating manuals, company development strategies and specifications of manufactured products. It provides the basis for effective managerial decisions even in highly turbulent business-environment conditions (Jacyna and Semenov 2020; Poper 2022).
2. *Implicit Knowledge (IK).* It is knowledge acquired after certain procedures have been performed. It is collected in general inaccessible files or knowledge bases
3. *Tacit Knowledge (TK).* Is knowledge that is difficult to acquire as it relates to the experience and skills acquired by employees. It is transferred on a *person-to-person basis*. It is extremely valuable and its acquisition creates real value for any company, providing an opportunity for competitive advantage.

An analysis of the literature identified gaps in content as a result of omitted issues:

– incremental opportunities as a result of the joint use of knowledge resources;
– achieve synergy effects as a result of the application of explicit and discoverable knowledge, which increases the quality of decision-making;
– the lack of a workshop useful for designing sector-specific knowledge-sharing platforms adapted to specific market tasks;
– the urgent need to develop and implement industry-specific platforms for knowledge exchange in a turbulent business environment.

Table 2. Types of knowledge used in TSL companies (Authors' elaboration)

Knowledge used as information support in the TSL industry			
Explicit knowledge		Implicit knowledge	
Redesigned on an ongoing basis / open access/	Cyclical conversion / exclusive access /	Recast in codified mode	Converted in non-codified mode
Requires verification and structuring of knowledge	Requires an analysis of the completeness of knowledge	Knowledge exchange possible	Knowledge sharing is not possible
High risk of data overload	High risk of data shortage	Obtained by gaining access	Acquired by logical deduction
Access via EDI (Electronic Data Interchange) transmission and communication protocols including AS2, SFTP, WebService, OFTP		Harmonisation of forms of knowledge transfer	Access through tools (data mining, knowledge discovery)
Synergy effects of collected knowledge	Multiplier effects in accumulated knowledge	Possible aggregation and processing	Aggregation and processing are not possible

The research began with a clustering of the knowledge needed by managers (Tab 2).

Stage two focused on analysing the *question-answer* process of knowledge acquisition. Three hypotheses were defined during the analyses:

Hypothesis 1. In a stable business-environment, answers to frequently repeated questions can be templated.

Hypothesis 2. In an unstable business-environment, companies reduce their level of confidence in the reliability of the information they receive.

Hypothesis 3. In a low-trust environment, companies seek synergies in their relationships with the business-environment in order to increase their chances of maintaining their position in the occupied market segment.

Based on the results of the analyses performed, it was concluded that there were two main types of questions.

Questions of the first type (often referred to as questions to inform) are distinguished by the fact that the answer or negation of the answer follows from the structure of the question, which exhausts the need to create the answer anew, as it can be found in the BOS (*Library of Template Answers*). It is shaped by the rules allowing to introduce new knowledge into template questions without changing the overall content. *In questions of the second type* (dialogue questions), only the direction of the answers is outlined, as a result of which answer shaping is required each time. The shaping of the answer is carried out using "*IF-Then*" rules, allowing a preliminary version of the answer to

be developed or a message to be sent about its absence. Shaped according to the "*max completeness*" criterion (Table 3) viz:

- create in the initial response encouragement for further discussion;
- conveying synthetic knowledge in the final response, opening up a transition for the supplicant from a state of '*no knowledge*' to a state of 'a *certain level of knowledge*'.

Table 3. Clusters of template responses located in BOS (Authors' elaboration)

Clusters answers	Characteristics of the clusters (Canned Response Templates)	Handover time
Sentences/for information/	They do not cover details. May entail further questions e.g.: *I'm sorry but I'm not sure what you mean by "…". Could you please rephrase or provide more context*?	19.2 ms
Extended /dialogue/	They are traditionally referred to as '*essay answers*'. They start with an introduction and lead the stakeholder to make their own inferences based on their personal knowledge. They may entail further questions for the SIKP, such as: *Give reasons for or against; Emphasise the differences; Explain key process or events; Why is it important? What things led to /caused this /*	30.9 ms
Complete/to be informed/	Include all characteristics of a phenomenon, event, process	241, 2 ms

In order to meet the above criterion, adaptive technologies built on the principle of a two-level hierarchy are proposed. At the top level, there should be a software block that controls the process of shaping the initial version of the set of knowledge search rules, the subsequent creation of an answer to an unusual question and its sending to the stakeholder. If he or she is not satisfied with the knowledge provided, the question is passed to an adaptive control algorithm, which makes adjustments to the applied early set of rules, extending it to a dimension that ensures the acquisition of the knowledge sought by the stakeholder. Solving the problems associated with the implementation of SIKPs (Fig. 1) requires research into both the characteristics of their operation and the enrichment of the company's business value chain (Balzer et al.2020). Achieved by:

– establishing standardised rules for the transfer and use of knowledge;
– sharing knowledge of innovative techniques and technologies and the possibility of implementing them to produce new quality products/services;
– the use of user authentication mechanisms according to the commonly applied principle of "*to whom it is not allowed, it is forbidden*"

One of the main features identified in the process of this research is the categorisation of template responses provided to the stakeholder in a short P2P interval. The model

used to analyse the chances of correct responses in template format and non-template format:

$$P_{ij} = w_{ij}[\gamma_0 + \sum_{k=1}^{K} \gamma_k] \times [P_{ij}(S_{0i}) + P_{ij}(C_{0i})] \quad (1)$$

where:

P_{ij}— chance to give the i-th user the correct answer to his j-th question.
$_0\gamma$— i-user's acceptance rate of the 0-stage response to its formation.
γk— rate of acceptance by the i-user of the response at k stages of its formation.
$P_{ij}\ (S)_{0i}$— chance of randomly giving the user the correct answer to his j-question.
$P_{ij}\ (C_{0j})$— chance to give the user the correct answer to his j-question.
w_{ij}— an indicator of the value of the knowledge transferred to the i-petent, which takes a value from 0 (the knowledge gained is not useful) to 1 (the knowledge gained is completely useful).

The instrument for changing the settings of the criteria set is at a lower level of SlKP. The Q/A control tool makes adjustments to the original criteria set based on the feedback principle, compensating for possible errors during the acquisition of tacit knowledge at each time t. We will mark such control of the set of criteria as u_t, which can be described by the equation:

$$u_t = f\left(u_{t-1}, \theta_{t,}, t\right) \quad (2)$$

where

u_t— a set of criteria shaped according to the results obtained from the backpressure;
u_{t-1}— the original set of criteria formed;
$\Theta_t = X_0 - X_t$— the value of the current error during knowledge acquisition.

Achieving synergies amplifies the intellectual, cognitive and creative resources of managers, contributing to the development of the SlKPs concept (Fig. 1).

The execution of the research started with the SlKPs clustering with the claim (Williams et al. 2008) that this is necessary as a step to ensure that the risk of failure of the research process is reduced. Therefore, consideration was given to:

A. Functional requirements:
   - the ability to discover tacit knowledge (new ideas, innovations),
   - the degree to which the organisation is open to conversation with the recipients of this knowledge.

B. Functional limitations, including prohibiting both user interference with the set of rules used to acquire new knowledge and discouraging the user from continuing the conversation.

The SIKP concept can be implemented in three architecture clusters:

1. *Basic architecture.* It does not have an adaptation block and the chance of its users obtaining the knowledge they are looking for varies between [0.0–0.2]. The value of

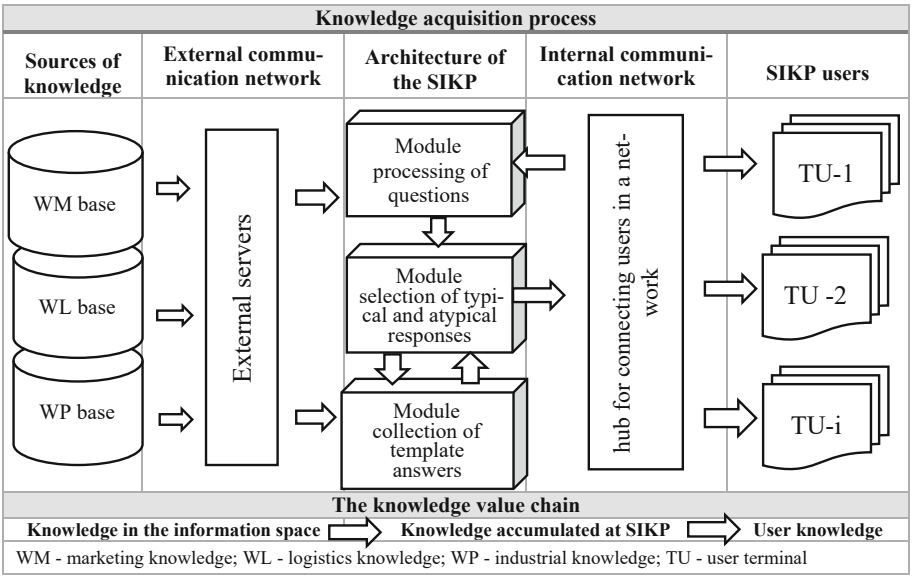

Fig.1. Mapping the knowledge value chain based on the SIKP (Authors' elaboration)

the SIKP effectiveness indicator (*knowledge transferred is sufficient and satisfactory*) is close to zero. Such platforms require a major system upgrade or replacement with more effective solutions.

2. *Architecture with an adaptive block*. Oriented towards the exchange of continuously updated knowledge without self-learning mechanisms and the discovery of tacit knowledge. The user's chance of obtaining the knowledge sought varies between [0.3–0.8], with a SIKP success rate value close to '75%'.

Advanced architecture. Equipped with an adaptive block, self-learning mechanism and acquisition of new knowledge. The user's chance of obtaining the desired knowledge varies between [0.9–1.0] and the success rate is almost 100%. It provides a variety of information services, which increases the number of its users. The result is a tightening of requirements for the quality of services, the choice of communication network as well as the technology for exchanging knowledge with business partners (Nickerson et al. 2013). The SIKP has both cognitive (cognitive) and informational functions, including about ideas, concepts, statistics, etc. When the multi-faceted principle of such platforms is applied, possible synergies may arise from the use of template responses tested in previous interactions and the extraction of tacit knowledge (Fig. 2).

The growth of interest in SIKPs is linked to their agility, and the discovery of new knowledge creates the rationale for upgrading them as a result of change:

- *standardised knowledge* necessary as a result of the variability of interest, e.g. the ability to ensure security in business relationships or the use of environmentally friendly transport/handling technologies, etc., is of low risk, as this type of knowledge is largely unclassified;

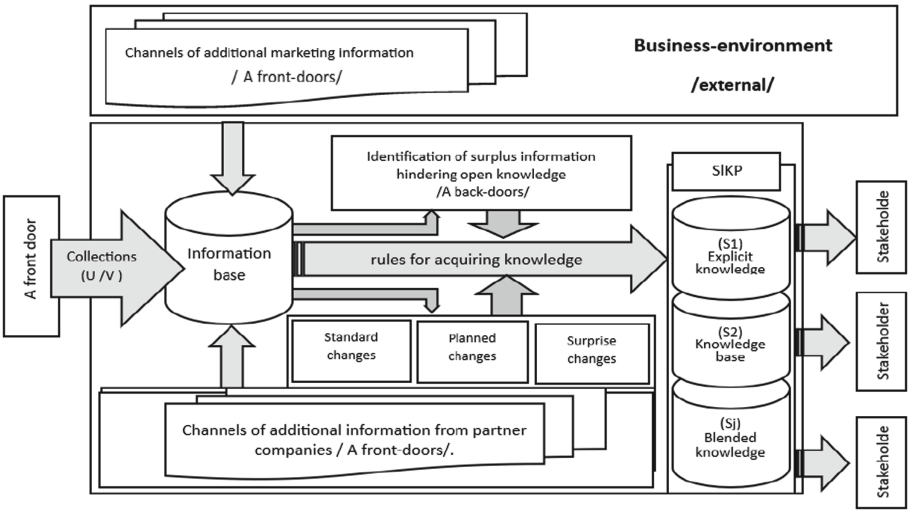

Fig. 2. Architecture concept SIKP. (Authors' elaboration)

- *planned,* carried out at scheduled intervals, and aimed at preventing an increase in stakeholder dissatisfaction; they require adequate advance notice;
- *unexpected*, concerning, for example, the emergence of new knowledge of innovative technologies available on the market that may strengthen the company's market position; they also include synergy effects that may have negative effects; they are subject to a high level of risk.

3 Research Background/Research Background/

Knowledge acquisition methods <W > direct from collections of accumulated information $<I(x)>$ are based on the assumption that their effectiveness is a function of the value of the acquired information <X > assessed against the state of knowledge $<W_0>$ before processing the data collected at the time of the t:

$$W = F_1[I(x), W_0, t], t \leq T_{ad} \tag{3}$$

$I(x)$— collection of collected information,
$F1$— how to interpret the data collected,
W_0— the state of knowledge prior to processing the collected information,
T— the time available to acquire new knowledge,
T_{ad}— the time allowed to acquire new knowledge.

One of the most effective methods for detecting tacit knowledge can be considered the correlation analysis method, according to which a sign of tacit knowledge is the absence of a logical sequence of relations linking recorded facts to their causes. Once the existence of such relationships is indicated, the possibility of identifying tacit knowledge is assessed by discovering codified knowledge according to the hypothesis that explicit

and tacit facts may come from a single source, which can be reconstructed by detecting cause-effect relationships (ZPS) (Bogardus 2014). Most often, IK/CT knowledge lies at the interface of marketing as well as logistical information (Kalinin et al. 2015). The advantage of this is that synergies can be achieved which is much needed in a volatile business-environment situation. The ZPS diagram model can be described as Eq. (3) (Vandenburgh 2020):

$$M_{ps} = \langle U, V, E, S \rangle \tag{4}$$

where

U— collection of exogenous parameters whose values are shaped by the business-environment;
V— set of parameters endogenous, whose values are shaped within the company;
E— the set of mechanisms shaping the possible effects of changes in endogenous parameters in relation to changes in parameter values U or V;
S— a set of parameters for possible effects.

The extraction of causal relationships is based on assessments of the probabilities of exogenous parameters influencing the effects of observed events, or on finding some relationship between them, the standard form of which is the claim that the probability of any event (external or internal) generates the probability of effects:

1. In the study of exogenous parameters (*zbiorU*):

$$P[U_0\{(E)\backslash \mathrm{S}\} > \mathrm{P}(U)] \tag{5}$$

2. For the study of endogenous parameters ((*zbior* V):

$$P[V_0\{(E)\backslash \mathrm{S}\} > \mathrm{P}(V)] \tag{6}$$

In some studies, instead of analytical relationships (3–5), the authors focus on analysing these relationships in the form of graphs (topological models). Then the variables (U/V) are denoted by vertices, and variables (x)—as edges. This is how I create ZPS diagrams (Guo et al. 2016; Vandenburgh 2023), which map the relationships of business-environment variables with the effects of their influences. Such a diagram contains a set of vertices interconnected by edges such that each edge ends/begins at some vertex. The connections are causal in nature. The arrows of the graph indicate the direction of causality, for example an arrow connecting a vertex $(U/V)_i$ with a certain effect $(S)_j$ indicates that a change in the parameters of $(U/V)_i$ with a certain probability will cause a change in the effect $(S)_j$. A formal indication:

$$(U/V)_i \rightarrow (S)_j \tag{7}$$

is complicated if the variables (U/V) are not connected to $(S)_j$ paths reflecting at least one executive function from the set of (E). Diagram creation processes based on a number of the following rules, including:

Rule 1 The process of creating ZPS diagrams is based on procedures for adding or removing excess information (not current, outdated, not reliable), which should be possible at each stage of the search for new knowledge. According to this rule, diagrams can be developed as causal cycles or contain acyclic graphs. More precise:

- adding information $(U/V)_i$—(marketing or logistics) to complete the ZPS diagram is described by a logical relationship:

$$\left\{P\left[Y(U/V)_0\right] \rightarrow (S) = P\left[Y(U/V)_i \rightarrow (S)_j, (U/V)_1, (U/V)_2\right]\right\} \quad (8)$$

- removing information that is out of date or of doubtful reliability $(U/V)_i$ makes it difficult to identify the relationship between (U/V) i (S) i.e. the recovery of new knowledge is described by a logical relationship (9);

$$\left\{P\left[Y(U/V)_0\right] \rightarrow (S), (U/V)_1, (U/V)_2 = P\left[Y(U/V)_i \rightarrow (S)_j, (U/V)_1\right]\right\} \quad (9)$$

Rule 2. Complementing ZPS diagrams with missing information can be done from any available source through a variety of channels.

Rule 3: The number of information channels should be supplemented so that some knowledge is not lost through gaps in the CED. When the set of marketing or logistical information is insufficient to indicate the pathways in relation (6), a section of the diagram should be removed or the missing information should be filled in.

Rule 4. If some data is not available in the information channel we are using, we have to use other transmission channels / Resulting from the [*The front-door principle*] (MacKinnon et al., 2020):

$$\left\{P(U/V) \rightarrow [S(X)],\ (U/V) = \prod(U/V) \rightarrow [S(X)], (U/V)\right\} \quad (10)$$

Rule 5: To find a reliable relationship $(U/V) - (S)$ we need to make sure that we close all the so-called 'back doors' to eliminate statistical noise, leaving all other channels (front doors) open. [*The back-door principle*] (Pearl 2012).

4 Results of Applied Research/Applied Research/

The research was based on literature studies and a cause-and-effect diagram (CED) (Vallet-Bellmun and Rivera-Torres 2018; Kounkel 2023), and an illustration of the research results obtained is shown in Fig. 3. After analysing these results, eight most likely trends in the T&L market were selected (Fig. 4), which are examples of template answers to recurring questions, e.g. which *trends will be key in the development of the T&L industry in the short, medium or long term?*

Trend 1 *Withdrawal of weak players from the logistics services market.*
Trend 2 *More quick and precise On-Board Diagnostic Truck's System with remote access*
Trend 3 *Self-diagnosis and maintenance for problem -solving of unmanned vehicles*
Trend 4 *Humanless technology development, e.g. AOF (Automated Order Fulfilment).*
Trend 5 *Real-time tracking systems for increase traceability in supply chains*
Trend 6 *Digital supply chains equipped in machine-machine communication/4.0 industry/*
Trend 7 *AI-based touchless tech according principle "eyes off /hands off".*
Trend 8 *Super AI-based system prevent bid rigging and deliberate distortion of information.*

The research carried out can be used by company managers as a guide for decision-making short-medium-long trends in the development of target markets.

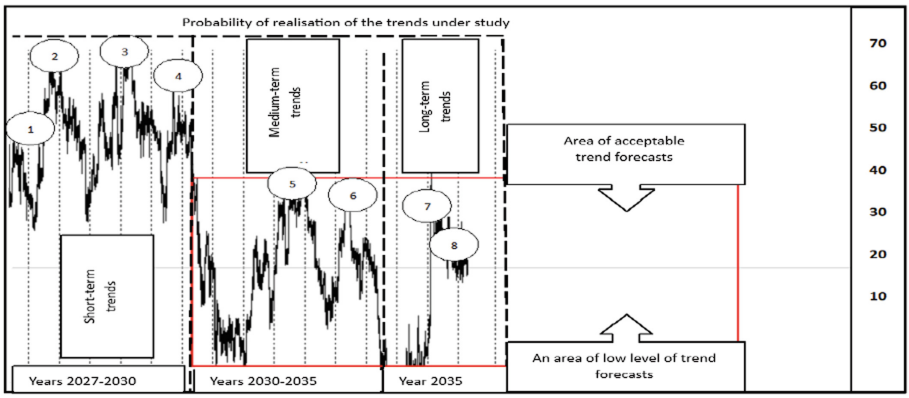

Fig. 3. Simulation studies results using a CED. (Authors' elaboration)

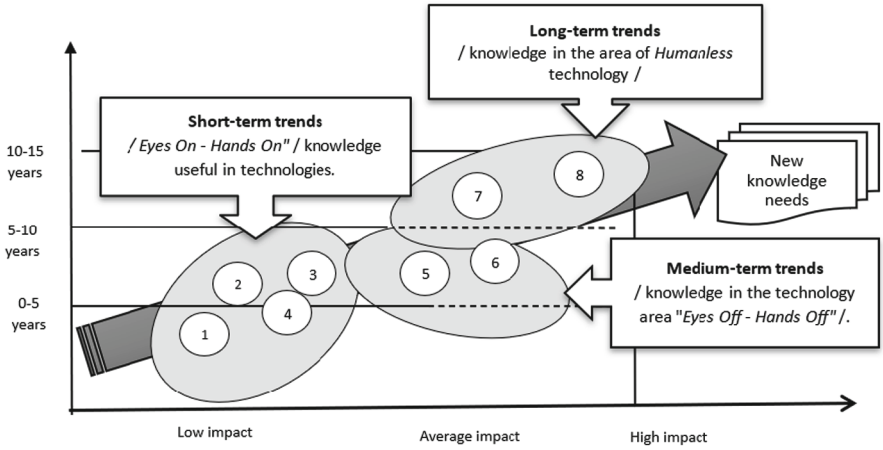

Fig. 4. Trends influencing changes in the logistics industry. (Authors' elaboration)

5 Conclusion

1. The proposed method of knowledge extraction by constructing template answers using cause-and-effect algorithms in the processing of large data sets and their gradual transformation into answers containing the knowledge sought by users based on the structuring principles of accumulated marketing/logistics information.
2. The validity of the research carried out was confirmed by interviews from which it emerged that companies that fail to meet contractual requirements as a result of adequate managers knowledge lack are faced with:

   – rebuilding a relationship with an injured client requires gaining their trust, as clients may behave more reasonably and rationally after an injury compared to their previous behaviour;

- the customer's satisfaction with the repair of all the damage caused to him as a result of poor quality information support during order fulfilment may not guarantee the rebuilding of this customer's loyalty;
- the lack of willingness of customers to cooperate can have chain consequences.

Acknowledgments. The authors would like to thank the managers of IT and T&L industries for taking part in the questionnaire survey.

Conflicts of Interest The authors declare no conflicts of interest

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Communication in Encounter Situations of Autonomous and Non-autonomous Ships

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Abstract. Research on autonomous ships is in progress in many centres around the world. It is expected that soon these ships will gradually start entering service. More and more encounters at sea will involve manned vessels, including leisure boats and yachts, and autonomous ships. In such cases communication is carried out on the manned vessel by a navigator, and on the autonomous vessel an information system acts a virtual navigator. Part of the present research has focused on an analysis of the communication between human navigators during ship encounters. Based on this, the concept of a virtual navigator has been developed using methods and tools of artificial intelligence. The authors propose decision-making algorithms for communication in collision situations, where negotiations aimed at mutual agreement of appropriate manoeuvres are taken into account. Simulated encounters of an autonomous and non-autonomous ship for selected scenarios allowed us to assess whether the executed communication processes proceeded correctly. A system of this type can enable communication between a navigator and an autonomous ship using natural language.

Keywords: autonomous ship · virtual navigator · human-machine communication · navigation · collision avoidance

1 Introduction

The rapid progress of work on autonomous and remotely operated ships brings closer the moment of large-scale introduction of these vessels into shipping. At the same time, it remains indisputable that manned ships will continue to be operated for many years to come. This means that in addition to encounters between manned vessels, there will be more encounters between two and more manned, remotely-controlled and autonomous vessels in all possible combinations.

In addition to technical problems, much attention is being paid to raising situational awareness for making the right decisions in the process ship conduct and collision avoidance. Reliable, up-to-date and accurate information on own ship and other ships and their planned actions is a prerequisite for right decision making. This becomes vital in difficult navigational conditions and emergency situations. Situational awareness has been

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 30–41, 2024.
https://doi.org/10.1007/978-3-031-78468-2_3

enhanced by navigation systems and equipment installed on ships, including radars with automatic echo tracking (ARPA), global satellite navigation system GNSS, automatic ship identification systems (AIS) and other. The results of major marine accidents investigations show that they are often due to human errors, related to the lack of information, misinterpretation of the situation, failure to take into account the intentions and possible manoeuvres of the other vessels. This also applies to remotely operated vessels. In the case of autonomous ships, these will be system malfunctions caused by similar reasons. The automation of communication processes, including the manner and style of communication between ships, can significantly reduce these errors and their consequences. ICT technologies and artificial intelligence methods and tools are increasingly being used for this purpose. The issues of improving and automating the communication processes of manned ships have been addressed and presented by various authors. Also, the processes of communication between autonomous ships are the subject of research and analysis. It is crucial for the safety of shipping to ensure effective communication between manned and autonomous vessels, including exchanges between unmanned vessels operators.

Technically speaking, a modern vessel equipped with an autopilot and other navigational devices can sail across the ocean from point A to point B. However, there are several challenges, including severe weather and other objects. Currently, the most common collision avoidance system is ARPA (Automatic Radar Plotting Aids). The user can manually acquire targets for tracking. Automatic acquisition zones can be set. The user can receive reports on targets, which include CPA (closest point of approach) and TCPA (time to closest point of approach). Based on visual observation (if possible), an ARPA report and the COLREGs (collision regulations), it is possible to determine the appropriate behaviour (action to be taken or maintaining the present course and speed) [1]. There are also well-known collision avoidance systems, such as NAVDEC [2], that can assess collision situations and advise appropriate action to pass all targets within an assumed safe distance and while satisfying applicable COLREG criteria [3, 4]. Such systems can form the basis for autonomous systems regardless of autonomy degree, as specified by the International Maritime Organization IMO. An example is the AVAL autonomous navigation system [5]. What is required is continuous and effective communication to maintain up-to-date navigational data necessary to assess the situation and generate solutions.

Automation of communication processes between ships and between ships and land centres has been addressed many times. The authors in [6] introduce a general concept of a system for automatic exchange of ship-to-ship communications in shipping. An ontological structure of messages was introduced and its description in XML was proposed. The concept formed the basis for further research in information visualization, manual, semi-automatic and automatic message generation, message encoding (sender) and decoding (receiver). This concept for manned ship communications, including marine navigation ontology and communication ontology was developed in [7] and other works.

One direction of the research into the development and operation of autonomous ships is to ensure effective communication. One of the main challenges is to ensure effective communication in avoiding collisions and resolving collision situations. The rapid progress in the construction of autonomous ships has necessitated the assurance of effective ship-to-ship and ship-to-Remote Operation Centre (ROC) communications.

These issues were considered, among others, in [8] and referred to the effective exchange of information on ship's movement parameters and the present navigation situation. In the case of ship-ROC communication, the considerations included the possibility of taking control of and steering an autonomous ship. The proposed solutions did not address mutual arrangements and negotiation processes.

The need to build a communication system that accounts for intentions of other vessels and preliminary proposals were, inter alia, presented in [9]. An interesting direction of research is the work on systems that implement the process of communication like that conducted by navigators, using methods and tools from the field of natural language processing (NLP), on which chatbots are based, such as ChatGPT. In paper [10] the authors present preliminary concepts of their use for dialogues between an autonomous ship and the navigator of a manned vessel.

When autonomous ships interact with traditionally manned vessels, their behaviour must be properly interpreted on the bridge of the manned vessel [11]. This should be significantly assured by the automatic communication systems presently being developed. The corresponding research, related to natural language processing, is in progress. Automatic communication systems allow creating linguistic models of the language used by those in command of the ship. The ontologies of communication and navigation are important components of such systems. Integration of language models and the ontologies will contribute to safer and rule-compliant communication between autonomous and traditional vessels. The use of selected artificial intelligence methods will link commands from the bridge to the communication and navigation ontology.

The linking of linguistic models produced using NLP and the ontology is a key to ensure a reliable solution, as the internal ontological rules enable the exchange of communications compliant with the applicable regulations. The combination of NLP and ontology can make it possible to improve the level of safety in maritime shipping.

The current state of knowledge confirms that the field of maritime transport requires an unambiguous and ontology-based communication system. The use of ontologies and semantic models expands the possibilities for collecting and processing information. To date, ontology has been used to build several semantic models to describe the condition and behaviour of ships at sea. Wen et al. [12] proposed using the ontology to build a semantic ship behaviour model (SMSB) based on a dynamic Bayesian network (DBN) to help represent and understand ship behaviour. Van Hage et al. [13] used an ontology to build a simple event model (SEM) to infer ship behaviour at different levels of abstraction, integrating knowledge from the network. This case is particularly interesting as it shows that ship position data are not sufficient for a navigator to fully understand the situation at sea. Hagaseth et al. [14] used existing semantic tools to extract original meanings from maritime rule texts to enhance rule consistency and support compliance and enforcement by ship and port operators. The use of ontology-based information access techniques has also been used to enhance security and cybersecurity in ports [15].

This paper extends the solutions for communication between autonomous ships to include autonomous ship - non-autonomous ship communication. For this purpose, an additional analysis of communication between navigators in manned ship encounters was carried out. The ontologies of marine navigation and communication have been broadened. This required the addition of communication rules while maintaining the

consistency of the system. The concept of a virtual navigator has been developed using artificial intelligence methods and tools. The authors propose decision-making algorithms for communication processes in collision situations. Negotiation processes related to the agreement of manoeuvres have been taken into account. The article focuses on the verification of the system.

The simulation of encounters between autonomous and non-autonomous ships was carried out for selected scenarios in order to assess the correctness of the realized communication processes.

Section 2 presents the concept and model of the communication system of autonomous and non-autonomous ships. Section 3 characterizes the implementation of communication processes taking place on autonomous and non-autonomous ships. In Sect. 4 the developed system has been verified. Conclusions from the conducted research are formulated Sect. 5.

2 The Communication System for Autonomous and Non-autonomous Ships

The concept of the communication system of autonomous and non-autonomous ships is shown in Fig. 1. In the manned ship system, a block of navigation equipment is distinguished. Its task is to acquire and share information used by the navigator to analyse and evaluate the navigational situation, make and execute decisions, performing manoeuvres manually or using the autopilot. At the same time, the navigator monitors the effectiveness of the actions by observing the navigational situation. The communication process is carried out using the graphic user interface (GUI). The process can be implemented as voice communication - speech analysis and synthesis. The message is prepared in the EDM/CD block. This is aimed at composing a correct message using a predefined commonly understood syntax using the information contained in these sentences. When a message is received, the system should be able to read the message and transmit it directly to the operator.

The communication system of an autonomous ship features a similar block of navigation equipment. Navigational information is sent to the virtual operator module. The module carries out decision-making processes on the basis of messages sent from the EDM/CD block via the Communication Unit block and navigational information from the Navigation Equipment block. The negotiation processes are controlled by the virtual navigator module via the Communication Unit block. The interface for systems of communication with other ships is in the EDM/CD block, similar to that of the manned ship.

3 Implementation of Communication Processes

The considerations below address communication processes on autonomous ships and manned ships.

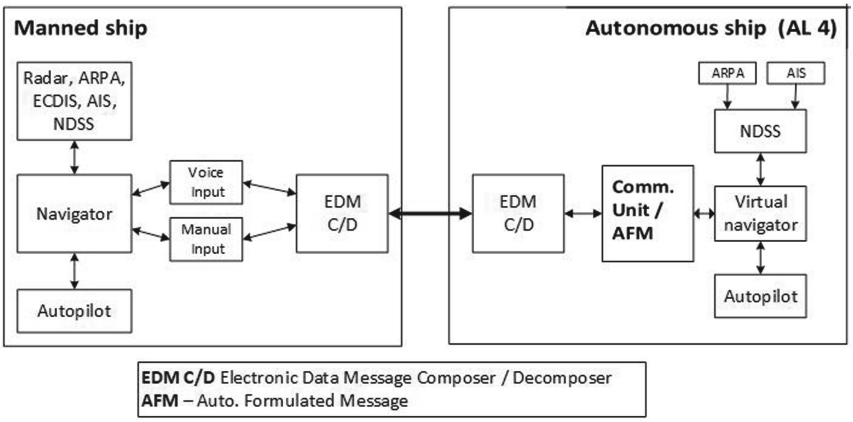


Fig. 1. General idea of autonomous and non-autonomous ships communication (AL 4).

3.1 Communication on an Autonomous Ship

The implementation of the processes of ship-to-ship communication involves the selective acquisition of information, including intentions, as well as its automatic interpretation. When ships have divergent objectives, negotiation processes should be initiated. For the communication to run correctly, information transmitted internally between systems as well as externally between ships has to be processed. Appropriate mechanisms based on facts and rules contained in the knowledge base are used for inference [2].

On an autonomous ship the communication process is carried out by a virtual navigator (Fig. 1), in which the inference module is an essential component. The inference module is a multithreaded program written in C++. It consists of elements responsible for:

- inner communication between other information elements of the autonomous vessel (systems responsible for acquiring information such as AIS and ARPA, navigator's decision support systems (NDSS) and others),
- outer communication responsible for exchanging messages with other ships (manned and autonomous),
- inference.

Each of these elements is a separate software thread, exchanging information with the other elements via a shared memory area (context), storing all facts (parameters) about the state of the system, used for current inference. The information stored in the shared memory area is adjusted and normalized to be stored in the form consistent with the ontology presented earlier.

The threads responsible for the internal communication between the other information elements of the autonomous vessel are responsible for acquiring data from the ship's internal systems: they monitor the data coming in through the internal network and update the relevant parameters in the shared memory. In addition, the thread associated with the NDSS, in addition to receiving information sent by this system, also sends

appropriately formulated queries to the NDSS when a parameter appearing in the shared memory commands such an action.

The thread handling external communication receives messages coming from outside, filters them in terms of addressee (own ship, another ship) and correctness, and then stores the messages in the form of appropriately formulated parameters in the shared memory. Its another function is to send outgoing messages generated by the inference thread.

The last of the threads - the inference thread - working in a loop and using a rule base (rules), makes inferences on the basis of facts (parameters) stored in the shared memory. The results of inference become new facts (parameters) stored in the memory and provide the basis for the operation of the other elements and for subsequent stages of inference.

Inference is based on the processing of rules contained in the knowledge base and using data stored in the shared memory area. The following stages can be distinguished in the inference process:

- defining a set of rules U (a subset of rules from the knowledge base) whose premises are facts stored in the shared memory area;
- applying a verification strategy to select from the set U the rules to be be used in the inference (creating a set W);
- running the rules from the set W and storing the inference results in the shared memory area;
- removing the rules used from the set W;
- if the set W is not empty, inference should be repeated.

In the initial stage of inference, the navigation situation is identified and the phase of the encounter is determined. There are five phases of encounter determined mainly on the basis of the distance between ships: phase 1 observation; phases 2, 3 and 4 - actions of each ship to prevent collision; phase 5 - coordinated actions of ships, without which collision avoidance is impossible.

For example, phase 2 occurs when there is a risk of collision or close-quarters situation. In this phase the stand-on vessel should maintain her present course and speed. The give-way vessel should perform an anti-collision manoeuvre.

In order for external communication to proceed unambiguously, rules have been written in the knowledge base for assigning the generated message to the corresponding type and category of message.

3.2 Communication on a Non-autonomous Ship

In the case of a non-autonomous ship, communication is carried out by the navigator using a manual operator interface (manual input/output, Fig. 1). Figure 2 shows the process of creating a message using the above interface. First, it is necessary to identify the ontology of the communication. In the presented example, the type of message Question and a category were selected. The next step is to specify the content of the message from the navigation ontology menu. After selecting the option: send, the created message is displayed along with the date and time.

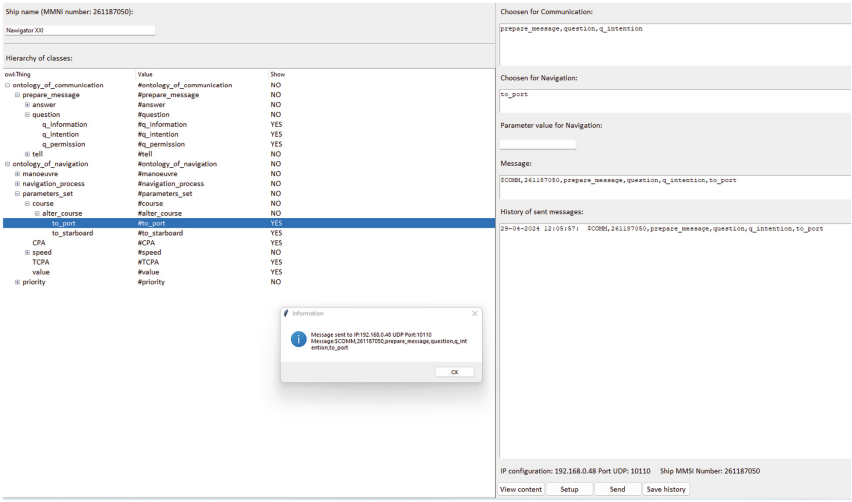


Fig. 2. Message formation using the operator's interface.

4 Verification of the Communication System

The correctness of the proposed communication system was tested in the Transas Navi-Sailor 4000 ECDIS laboratory with an additional AIS signal recording module developed at the Maritime University of Szczecin. The non-autonomous vessel was controlled by an expert navigator. For the autonomous vessel, the NAVDEC system [2] was used to analyse the navigational situation and make navigational decisions.

Various ship encounter scenarios have been considered. This article presents typical, common situations of a meeting where two ships sea each other and are on crossing courses:

1) autonomous ship (A) has the right of way, manned non-autonomous ship (B) must give way (COLREGs, rules 15, 16);
2) non-autonomous ship (B) has priority of way, autonomous ship (A) must give way (COLREGs, rules 15, 16).

Scenario 1: manned ship B must give way:
Autonomous ship – A (m/v Charlie has the right of way):

- course 180°;
- speed 15.5 knots.

Manned ship – B (must give way):

- course 270°;
- speed 15.5 knots.

Collision / close-quarters situation, CPA = 0.01 Nm.

The encounter.

Once the ships reach 8 Nm distance the autonomous ship commences communication:

1) On ship A the inference conclusion (due to entering phase 2 of the encounter):
   prepare_message,question,q_intention,manoeuvre_other
2) Ship A sends this message:
   question,q_intention,manoeuvre_other
3) On ship B, received message is displayed:
   message_received,question,q_intention,manoeuvre_own
4) Ship's B nawigator, using the interface, creates and sends a meaasge:
   prepare_message,answer,a_intention,15,right
5) Ship B receives this message:
   message_received,answer,a_intention,15,right
6) On ship A the message is processed to conform with the premises of the rules:
   message_received,answer,a_intention,manoeuvre_other_value
7) Ship A has this inference conclusion:
   prepare_message,tell,t_permission,manoeuvre_other_value,true
8) Ship A sends this message:
   tell,t_permission,15,right,true.

Figure 3 presents an exchange of messages between ships A and B in scenario 1, using the UML language (sequence diagram).

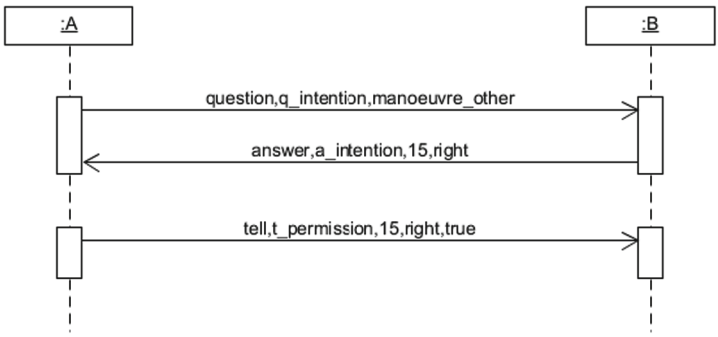
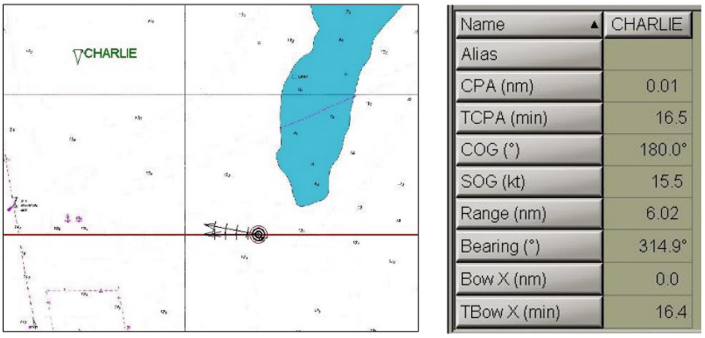


Fig. 3. Exchange of messages between ships A and B in scenario 1 – UML sequence diagram.

Figure 4 shows two screenshots of an ECDIS simulator. They contain a navigational situation on a chart (a) and the window of stand-on ship movement parameters (b).

The manoeuvre was agreed upon early enough. The manned vessel, giving way, in accordance with COLREGs, turns to starboard and proceeds on course 310°, and after reaching the desired CPA = 1 Nm, returns to the previous course. The trajectories of both vessels, illustrated in Fig. 5, are based on AIS data recorded during the experiment.



a) b)

Fig. 4. Initial situation in scenario 1: a) as displayed by ECDIS; b) ship B movement parameters.

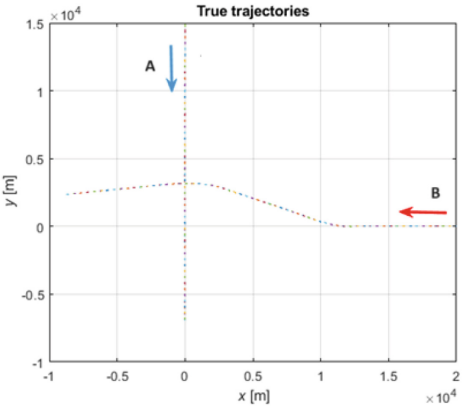


Fig. 5. Trajectories of both ships in scenario 1.

Scenario 2 - autonomous ship must give way.
Autonomous ship – A (m/v Charlie without the right of way):
Autonomous vessel _A (must give way):

- course 000°;
- speed 15.5 knots.

Manned vessel – B (m/v Bretagne has the right of way):

- course 270°;
- speed 15.5 knots.

The encounter.
When the distance is less than 8 Nm, the autonomous vessel begins communication:

1) On ship A, the conclusion of inference (resulting from entering phase 2 of the encounter and lack of priority):

prepare_message,tell,t_intention,manoeuvre_own

2) From ship A a message is sent, supplemented by the NDSS recommended manoeuvre:
   tell,t_intention,30,right
3) On ship B, the received message is displayed:
   message_received,tell,t_intention,30,right
4) Navigator on ship B using the interface prepares and sends a message:
   prepare_message,tell,t_permission,30,right,true
5) Ship A receives this message:
   message_received,tell,t_permission,30,right,true
6) On ship A, the message is processed into the form according to the rule premises:
   message_received,tell,t_permission,manoeuvre_own_value,true
7) On ship A, the inference conclusion after the maneuvers were carried out and the collision situation ended:
   prepare_message,tell,t_information,manoeuvre_own_end
8) Ship A sends this message:
   tell,t_information,manoeuvre_own_end
9) On ship B, the message is received and displayed:
   message_received,tell,t_information,manoeuvre_other_end

Figure 6 presents an exchange of messages between ships A and B in scenario 1, using the UML language (sequence diagram).

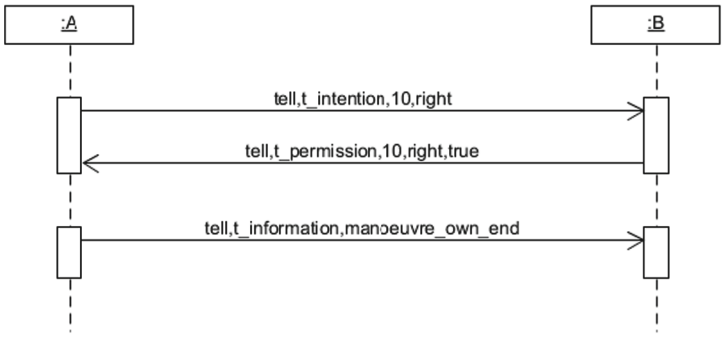
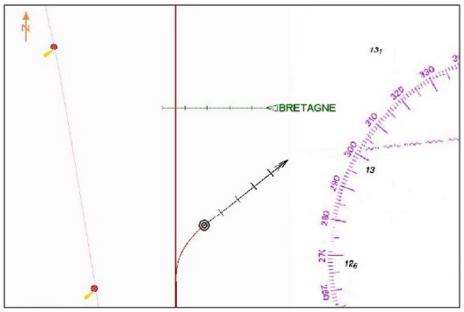


Fig. 6. Exchange of messages between ships A and B in scenario 2 – UML sequence diagram.

In this encounter, too, the ships agreed on the manoeuvre sufficiently early. The autonomous vessel makes a starboard turn to give way.

Figure 7 shows two screenshots of the ECDIS simulator. They depict the situation on the chart (a) during the manoeuvre and the window of movement parameters of the vessel having the right of way (b). The noticeable effectiveness of the manoeuvre is confirmed by the CPA = 1.04 NM in the window of movement parameters of vessel B (BRETAGNE).

The trajectories of both ships shown in Fig. 8 are based on AIS data recorded during the experiment.



Name	BRETAGNE
Alias	
CPA (nm)	1.04
TCPA (min)	2.5
COG (°)	270.0°
SOG (kt)	15.6
Range (nm)	1.60
Bearing (°)	30.8°
Bow X (nm)	3.1
TBow X (min)	-3.7

a) b)

Fig. 7. Scenario 2 – situation during the manoeuvre; a) as shown by ECDIS; b) ship B movement parameters.

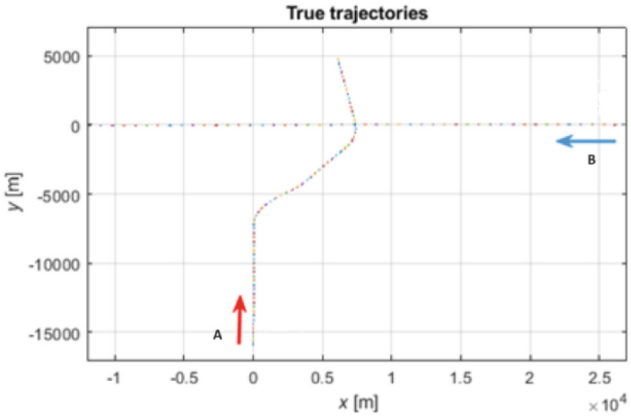


Fig. 8. Ships' trajectories – scenario 2.

5 Conclusions

The presented communication system is applicable on autonomous and non-autonomous ships. The system, based on the ontology of communication and navigation, has the capability to generate unambiguous solutions in cases where Collision Regulations might be interpreted differently, which was confirmed in simulation studies. This will contribute to increasing navigators' trust in autonomous vessels and may enhance shipping safety. The authors intend to further develop the communication and navigation ontologies. It will be necessary to develop new or adapt existing communication systems for automated communication. The introduction of such a system will require proper identification of the autonomous vessel, and, among other things, additional designation of the autonomous vessel and its degree of autonomy, e.g. in the AIS system.

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Between 0 and 1. Exploring the Algorithmic Restraints and the Potential of Quantum Computing in the Financial Sector

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Abstract. This article explores the theoretical potential of quantum computing to address complex mathematical problems in the financial sector. Through a comprehensive theoretical analysis, leveraging insights from recent advancements and collaborative efforts, we investigate the transformative impact of quantum computing on key areas such as portfolio optimization, option pricing, risk management, and algorithmic trading strategies. Additionally, we discuss the implications of quantum computing for financial cybersecurity, highlighting the development of quantum-resistant cryptographic protocols. By synthesizing findings from nearly 40 scientific articles, industry reports, and case studies, we provide also a roadmap for integrating quantum technologies into financial practices, thereby enhancing decision-making processes and improving overall efficiency.

Keywords: Quantum Computing · Financial Mathematics · Portfolio Optimization · Option Pricing · Risk Management · Algorithmic Trading · Post-Quantum Cryptography

1 Introduction

The financial industry struggles with numerous intricate mathematical problems that are fundamental to its operations, such as portfolio optimization, option pricing, risk management, and the development of algorithmic trading strategies. These challenges are intensified by the increasing complexity and scale of financial markets, where traditional computational methods often fall short, resulting in inefficiencies and inferior decision-making. The beginning of quantum computing indicates a potential revolution in financial mathematics, promising exponential speedups and enhanced computational capabilities that could dramatically transform the landscape.

Financial analysis, a foundation of the industry, relies heavily on the accurate and timely interpretation of data to support investment decisions, assess risk, and optimize asset allocation. Over the decades, advancements in technology have significantly shaped financial practices. The introduction of electronic trading platforms in the late 20th century revolutionized market operations by enabling faster transactions and broader market access. More recently, the integration of big data analytics and artificial intelligence has

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 42–51, 2024.
https://doi.org/10.1007/978-3-031-78468-2_4

further refined predictive models and trading strategies, pushing the boundaries of what traditional computational methods can achieve.

From the introduction of the telegraph and ticker tape in the 19th century to the development of high-frequency trading systems in the 21st century, each technological leap has brought about significant changes. Today, as quantum computing stands on the horizon, the financial industry is ready for another transformative shift. Addressing the complex challenges of financial mathematics with the unparalleled computational power of quantum technology could lead to unprecedented advancements in financial analysis, risk management, and trading strategies, ultimately redefining the future of finance.

1.1 Purpose

The purpose of this article is to explore the potential of quantum computing to address these complex mathematical problems in the financial sector through a theoretical analysis. Based on the authors' initial research investigating the probability of success in various applications of quantum computing [1], this article focuses exclusively on the financial sector. It aims to provide a comprehensive overview of how quantum computing can be leveraged to solve key financial challenges, discuss the implications for cybersecurity, and highlight the development of quantum-resistant cryptographic protocols. By synthesizing insights from recent advancements and collaborative efforts, this article also seeks to offer a roadmap for integrating quantum technologies into financial practices, thereby enhancing decision-making processes and improving overall efficiency by supporting business practice with theoretical background.

1.2 Methodology

To achieve this, a thorough theoretical analysis was conducted, encompassing a wide array of scientific articles, industry reports, and case studies on the application of quantum computing in finance. In total, over 100 scientific and business articles were reviewed, with almost 40 being selected based on their relevance, rigor, and contribution to the understanding of quantum computing in financial applications. Key areas of focus included the mathematical foundations of financial problems, existing classical approaches and their limitations, and the emerging quantum algorithms that promise to address these limitations. The selection criteria prioritized recent publications, peer-reviewed journals, and works that demonstrated practical implementations or theoretical advancements in quantum computing for finance. Additionally, the review covered the development of post-quantum cryptographic protocols and the potential cybersecurity implications of quantum advancements.

The study begins with an analysis of the theoretical background in the field of quantum computing and finance, leveraging the current progress and challenges tackled by the new technology described. The Results section describes the current state of highly impacted areas of finance, enshrouded with promising results of currently held studies. Finally, a roadmap for practical quantum computing implementation in financial practices is proposed by the authors with an emphasis on cybersecurity matters. The conclusion synthesizes the results, confirming the promise of quantum computing while

acknowledging existing technological and practical obstacles, and presents implementation examples that confirm the real potential of the theoretical assumptions described. The article stresses the need for continued research and collaboration to fully realize the potential of quantum computing in finance and importance of investigation of practical applications attempts to supplement the scientific research and verify its practicality.

2 Results

In the complex landscape of finance, mathematical challenges overflow, stretching from optimizing portfolios to pricing complex derivatives and managing risks [2, 3]. These challenges often need solving by computationally intensive optimization problems, estimating probabilities, and analyzing vast datasets in real-time [4]. However, classical computing methodologies encounter significant hurdles when addressing these problems efficiently, primarily due to their inherent computational complexity [5]. Recognizing the limitations of classical approaches, there is a burgeoning interest in alternative computational paradigms capable of delivering faster and more scalable solutions [6]. Quantum computing, leveraging the principles of quantum mechanics, emerges as a promising avenue to overcome these challenges [7].

At the heart of quantum computing lies the qubit, the fundamental unit of quantum information, which can exist in a superposition of states, enabling simultaneous processing of multiple computational paths [8]. Furthermore, quantum entanglement allows qubits to exhibit correlated behaviour even when separated by vast distances, offering unique capabilities for distributed computation and communication [9]. Quantum algorithms leverage these quantum phenomena to perform computations with exponential speedup compared to classical algorithms, particularly in domains such as optimization, cryptography, and machine learning [10]. Notable examples of such algorithms include Shor's algorithm for integer factorization and Grover's algorithm for unstructured search, both of which demonstrate the potential of quantum computing to solve problems exponentially faster than their classical counterparts.

Shor's algorithm stands as a seminal achievement in the realm of quantum computing, offering a groundbreaking approach to factorizing large integers in polynomial time, a task believed to be intractable for classical computers. [10] The algorithm hinges on the fundamental principle of quantum parallelism, leveraging the quantum Fourier transform (QFT) to efficiently identify the periodicity of a function modulo N, where N is the number to be factored. Central to Shor's algorithm is the modular exponentiation function, which computes $ax \bmod N$, crucial for determining the order of an element modulo N. By employing quantum operations such as quantum Fourier transforms and modular exponentiation on qubits, Shor's algorithm effectively reduces the problem of integer factorization to a polynomial-time quantum computation, yielding the prime factors of the input number with high probability. [11].

The following one, Grover's algorithm, stands out as a hallmark achievement in quantum computing, providing a quadratic speedup over classical algorithms for unstructured search problems. [12] At its core, it harnesses quantum parallelism and amplitude amplification to efficiently locate a marked item among a database of NN items. The algorithm operates on a quantum state encoding the search space, iteratively applying a series of

oracle and diffusion operators to enhance the probability amplitude of the target state while suppressing others. [12].

To better understand the impact of quantum technology on particular aspects of finance, a brief description of the key areas has been introduced next. Each section follows the order of description of current methodologies and/or used algorithms and resources, their actual issues and efficiency gaps, followed by the potential in quantum computing implementation that offers progress in the related field.

2.1 Portfolio Optimization

The challenge of Portfolio Optimization involves constructing investment portfolios that maximize returns while minimizing risks. It is often formulated as a mathematical optimization problem where the objective is to find the optimal allocation of assets given certain constraints.

The most widely used formulation is the mean-variance optimization introduced by Harry Markowitz. It aims to find the portfolio with the highest expected return for a given level of risk, where risk is measured by the variance of portfolio returns.

As of now, mean-variance optimization has been successfully applied in portfolio management, providing a framework for investors to balance risk and return effectively [2].

One of the recurring limitations is the sensitivity of the optimization results to input parameters such as expected returns and covariance matrix estimates. In practice, these inputs are often subject to estimation errors, leading to suboptimal portfolios [13].

Taamallah and Vos explored a multi-objective portfolio optimization using a quantum annealer, focusing on optimizing portfolios of loans while meeting specific return and risk objectives alongside environmental constraints [14]. Citi and Classiq have implemented quantum algorithms on Amazon Braket to optimize portfolios, highlighting the flexibility of QAOA in handling constraints more efficiently compared to classical methods [15].

2.2 Option Pricing

The next field of finance, Option pricing, involves estimating the fair value of financial derivatives, such as options, based on various factors such as underlying asset prices, time to expiration, and volatility.

The Black-Scholes-Merton (BSM) model is a widely used formula for pricing European options. It provides a closed-form solution based on assumptions of continuous trading, constant volatility, and risk-free interest rates. The BSM model has revolutionized option pricing and facilitated the development of option markets worldwide [3].

Despite successes, the BSM model assumes constant volatility and does not account for market frictions such as transaction costs and liquidity risk. This can lead to mispricing, especially during periods of market stress [4]. Research by Orús et al. has shown that quantum algorithms can be utilized to accelerate Monte Carlo simulations, which are integral to option pricing. This approach reduces computation time while maintaining accuracy, making it feasible to price options in real-time trading environments [16].

Further development of the algorithm and growth of datasets may lead to a requirement of a permanent technology switch.

2.3 Risk Management

Another highly impacted area is Risk management, which involves identifying, assessing, and mitigating financial risks associated with investments, loans, and other financial transactions. Value at Risk (VaR) is a popular measure used to quantify the maximum potential loss of a portfolio at a given confidence level over a specified time horizon. VaR has become a standard tool in risk management, providing a quantitative measure of downside risk that helps institutions set capital reserves and manage exposure to market fluctuations [17].

One limitation of VaR is its inability to capture extreme events or tail risks adequately. During the 2008 financial crisis, VaR models failed to predict the magnitude of losses experienced by financial institutions, highlighting their shortcomings [18].

Rebentrost et al. have shown that quantum machine learning algorithms can significantly improve the detection of risk factors by analyzing large datasets more efficiently than classical algorithms. This advancement allows for real-time risk assessment and better predictive modeling, which are critical for maintaining financial stability [19]. Described improvements have the potential to ensure precision of decision-making and affect the analytical outcomes.

2.4 Algorithmic Trading Strategies

Algorithmic trading strategies leverage mathematical models and computational algorithms to execute trades automatically, seeking to exploit market inefficiencies and generate profits. Various algorithms are used, including trend-following strategies, mean reversion strategies, and machine learning-based approaches.

Algorithmic trading has significantly increased market liquidity and efficiency, reducing transaction costs and providing better price discovery [20].

High-frequency trading (HFT) strategies, a subset of algorithmic trading, have been associated with market manipulation, flash crashes, and systemic risks [21]. Zhou and Wang demonstrated that quantum circuits for Szegedy quantum walks could effectively be applied to dense circulant and circulant-like operators, which are common in financial data analysis [22]. Studies by Liu et al. have highlighted the use of quantum neural networks to analyse time series data, providing better predictive models for financial forecasting [23]. This capability is particularly useful in identifying trends and making informed investment decisions. Research by Yu et al. has explored quantum algorithms for cryptographic applications, ensuring secure communication and transactions in financial systems [24]. The coexistence of classical computing and quantum computing is still at an early stage, leaving plenty of questions unanswered.

3 Roadmap for Integrating Quantum Technologies into Financial Practices

To effectively integrate quantum technologies into financial practices and enhance decision-making processes, authors propose a structured roadmap that outlines the necessary steps and considerations. In opposition to the theoretical background described in previous chapters, the roadmap is designed to guide finance-driven institutions, in leveraging the transformative potential of quantum computing, in a practical way defining the requirements and necessary steps to ensure successful transformation. The roadmap consists of the following steps:

1. **Identify Strategic Objectives**
   Begin by aligning quantum technology investments with the organization's strategic goals. Define and measure the impact of project realization on all affected areas of the company. This alignment ensures that quantum initiatives support the overall business strategy and deliver measurable value.
2. **Evaluate Quantum Readiness**
   Assess the current technological infrastructure and capabilities to determine readiness for quantum integration. This includes evaluating the existing data architecture, computational resources, and workforce skills. Identify gaps that need to be addressed to support quantum computing technologies.
3. **Invest in Research and Development**
   Allocate resources for internal R&D to explore and develop quantum algorithms tailored to specific financial applications. Collaborate with academic institutions, research centres, and quantum technology companies to stay at the forefront of advancements. This collaboration fosters innovation and accelerates the development of practical quantum solutions.
4. **Pilot Projects and Proof of Concepts**
   Implement pilot projects to test the feasibility and impact of quantum solutions on real-world financial problems. These small-scale implementations provide valuable insights into the performance, scalability, and integration challenges of quantum technologies. Successful pilots can then be scaled up gradually [25].
5. **Develop Talent and Expertise**
   Invest in training and development programs to build a workforce skilled in quantum computing. This includes upskilling existing employees and recruiting new talent with expertise in quantum technologies. A knowledgeable team is essential for effectively implementing and managing quantum solutions [26].
6. **Establish Partnerships and Ecosystems**
   Form strategic partnerships with technology providers, industry consortia, and regulatory bodies. These partnerships facilitate access to cutting-edge quantum technologies, foster collaborative innovation, and ensure compliance with evolving regulations. Engaging in industry ecosystems also provides a platform for sharing best practices and learning from peers [27].
7. **Focus on Cybersecurity and Risk Management**

Quantum computing introduces new cybersecurity challenges. Develop robust security frameworks to protect sensitive data and ensure the integrity of quantum systems. Implement quantum-safe encryption methods and continuously monitor for emerging threats.

8. **Monitor and Alter**
   Continuously monitor the performance and impact of quantum initiatives. Use data-driven insights to refine strategies, optimize implementations, and adapt to technological advancements. Flexibility and agility are crucial in navigating the rapidly evolving quantum landscape [28].

By following this roadmap, it is possible to strategically integrate quantum technologies, enhancing decision-making processes and improving overall efficiency. This structured approach ensures that investments in quantum computing should deliver significant business value while positioning the organization at the forefront of technological innovation.

It is important to note that the financial industry also needs to prepare for the post-quantum era by transitioning to quantum-resistant cryptographic algorithms to safeguard sensitive data and transactions [29]. Furthermore, quantum computing has implications for quantum-safe key distribution protocols, such as quantum key distribution (QKD), which offer the promise of secure communication channels immune to quantum attacks [30].

Traditional cryptographic systems, such as RSA and ECC, rely on the hardness of certain mathematical problems like integer factorization and discrete logarithms for their security [31]. To address this vulnerability, researchers are actively developing post-quantum cryptographic algorithms that remain secure even in the presence of quantum adversaries. Lattice-based cryptography, in particular, has emerged as a promising candidate for post-quantum security due to its strong mathematical foundation and resistance to quantum attacks [32]. By advancing the development of quantum-resistant cryptographic protocols, the aim is to fortify the security infrastructure of financial systems and protect sensitive data from emerging quantum threats.

4 Conclusion

This article has delved into the confluence of quantum computing and the financial sector, highlighting the challenges and opportunities this emerging technology brings. The financial industry is inherently complex, grappling with intricate mathematical problems in areas such as portfolio optimization, option pricing, risk management, and algorithmic trading strategies. Traditional computational methods often fall short in efficiently solving these problems due to their computational intensity and scale.

Quantum computing, however, introduces a transformative paradigm shift with its potential to offer exponential computational power. By leveraging quantum algorithms, financial institutions can significantly enhance portfolio management, improve pricing accuracy, optimize risk mitigation strategies, and develop more effective trading algorithms. Quantum computing's ability to handle and process vast amounts of data at unprecedented speeds positions it as a powerful tool for solving some of the most complex financial challenges.

Moreover, quantum computing has profound implications for financial cybersecurity. The advent of quantum computing necessitates the development of quantum-resistant cryptographic protocols to protect sensitive data and ensure secure transactions. As quantum computing capabilities advance, so too must the security measures to safeguard financial systems against new types of cyber threats.

Collaborative efforts among academia, industry, and regulatory bodies are crucial in overcoming these challenges. Such collaborations are essential for developing and refining quantum technologies, ensuring their practical applicability and integration into financial practices. As quantum computing continues to evolve, its integration into financial systems promises to lead to more sophisticated, data-driven decision-making processes, heralding a new era of innovation and resilience in the financial sector.

Recent years have seen significant advances in exploring quantum computing's potential within the financial industry, with notable collaborations and research initiatives aimed at leveraging quantum algorithms for complex financial problems. Proving the concept, JPMorgan Chase & Co., in partnership with IBM Quantum, has focused on optimization problems such as portfolio optimization and risk management, demonstrating early successes in solving smaller-scale problems that hint at future scalability [33]. Similarly, Goldman Sachs has teamed up with QC Ware to explore quantum computing for pricing and risk management of financial derivatives, achieving preliminary results that show promise in reducing computational times for complex pricing models [34]. Barclays, also collaborating with IBM Quantum, has made headway in portfolio optimization and algorithmic trading strategies, although they have encountered significant challenges related to error rates and the need for more robust quantum hardware [35]. Additionally, research on quantum computing for credit risk analysis has highlighted the potential for more accurate risk assessments, yet practical implementation remains hindered by current limitations in quantum coherence and error correction [36]. Various startups, such as Cambridge Quantum Computing and 1QBit, are developing quantum algorithms and platforms tailored to financial applications, advancing the field despite facing issues such as the scalability of quantum systems and integration with existing financial infrastructures [37]. These efforts collectively underscore both the achievements and the ongoing challenges in bringing quantum computing to practical financial applications, with the need for further advancements in quantum hardware and error mitigation techniques to realize its full potential.

In conclusion, while the road to fully realizing the potential of quantum computing in finance is fraught with challenges, the progress made thus far is promising. Continued research, development, and collaboration will be key in harnessing the transformative power of quantum computing, ultimately reshaping the future of financial decision-making and operations.

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Possibilities of Using AI in DSO Sector

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Abstract. This paper explores the transformative potential of artificial intelligence (AI) technologies in the Distribution System Operators (DSOs) sector. It highlights advancements in predictive maintenance, demand forecasting, and energy management, emphasizing how AI can optimize energy distribution and enhance operational efficiency. The methodology includes a comprehensive literature review, data collection from various sources, and the application of machine learning algorithms for cybersecurity and energy optimization. Results demonstrate the effectiveness of AI in addressing engineering challenges, optimizing energy usage, and improving fault diagnosis in energy systems. The discussion addresses ongoing research challenges, including cybersecurity measures, data quality, and ethical considerations, underscoring the need for interdisciplinary collaboration to fully leverage AI's benefits in the energy sector.

Keywords: Artificial Intelligence · Machine Learning · Distribution System Operators · Predictive Maintenance · Energy Management · Cybersecurity · Renewable Energy · Data Science

1 Introduction

Artificial intelligence technologies, such as machine learning, deep learning, and natural language processing bring advancements in predictive maintenance, demand prediction, and energy management. Predictive maintenance empowered by AI algorithms allows DSOs to anticipate equipment failures ahead of time, reducing downtime and maintenance expenses. This predictive ability is critical for the functioning of electrical infrastructure [1].

Moreover, AI-driven demand forecasting can analyze data from smart meters and other sources to forecast consumption patterns accurately. This foresight enables effective energy distribution and load management, minimizing waste and ensuring a steady energy supply [2]. Artificial intelligence covers technologies like machine learning, deep learning, and natural language processing that can process large datasets to reveal patterns, make predictions, and streamline operations [3].

The integration of AI in the DSO industry offers advantages such as enhancing predictive maintenance practices, refining demand forecasting methods, optimizing energy distribution processes, and transforming customer service through intelligent automation. This document seeks to delve into the future potentials of AI within the DSO sector

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 52–68, 2024.
https://doi.org/10.1007/978-3-031-78468-2_5

by presenting a comprehensive overview of how it can revolutionize different aspects of DSO operations [4].

AI technologies are currently being used to predict equipment failures, forecast energy demand, and improve customer interactions. The paper will also explore the potential of AI, such as its integration with emerging technologies like blockchain and its role in managing renewable energy sources [5]. While there are promising opportunities, the implementation of AI in the DSO sector faces challenges. Issues like data privacy concerns, high initial costs, and the need for skills are barriers to widespread adoption. The paper will examine these challenges and suggest solutions to facilitate the effective use of AI in the DSO sector [6].

In conclusion, as the energy landscape evolves, incorporating AI technologies into DSO operations is set to enhance efficiency, reliability, and sustainability in electricity distribution. By embracing AI, DSOs can navigate energy systems complexities and meet the increasing demands of consumers and regulators [7].

2 Methodology

2.1 Literature Review

The methodology commenced with a comprehensive literature review to identify existing research and advancements in the application of AI algorithms to engineering challenges within the energy industry. This review encompassed a wide range of sources, including peer-reviewed academic journals, conference proceedings, industry reports, and pertinent case studies. The primary focus areas included cybersecurity, energy optimization, load forecasting, fault diagnosis, and the application of AI in renewable energy systems [8]. By synthesizing insights from these diverse sources, the literature review established a robust foundational understanding of the current landscape, pinpointing knowledge gaps, and laying the groundwork for subsequent research phases [9].

2.2 Data Collection and Analysis

Data collection was a critical component, involving the acquisition of both historical and real-time datasets from various energy systems. Key data sources included:

- Phasor Measurement Units (PMUs): Utilized for capturing real-time voltage and current data across power systems, aiding in anomaly detection and system monitoring [10].
- Smart Meters: Deployed to record detailed customer energy consumption patterns, essential for analyzing usage trends and detecting energy theft [11].
- Sensor Networks: Employed to gather comprehensive data on energy usage and system performance, providing a granular view of operational dynamics [12].
- Public Databases and Repositories: Leveraged to access extensive datasets on energy production, consumption, and related cybersecurity incidents, facilitating broad-scale analysis [13].

The collected data underwent rigorous pre-processing steps, including data cleaning, normalization, and transformation, to ensure its suitability for subsequent analysis. Pre-processing was vital for eliminating noise and inconsistencies, thereby enhancing the reliability of the analytical outcomes [14]. The processed data was then subjected to various statistical and machine learning techniques to extract meaningful patterns, trends, and insights pertinent to the study's objectives [15].

2.3 Machine Learning and AI Techniques

A diverse array of machine learning (ML) and artificial intelligence (AI) algorithms were employed to address specific research questions, particularly those related to enhancing cybersecurity and optimizing energy usage. The techniques used included:

- Random Forest (RF) and AdaBoost Classifiers: These algorithms were applied to detect and classify cyber-attacks using data from PMUs and system logs. The combination of RF's robustness to overfitting and AdaBoost's boosting capabilities resulted in highly accurate predictions [16].
- Support Vector Machines (SVM): SVMs were utilized to identify data injection attacks in peer-to-peer energy transactions involving connected electric vehicles (CEVs). The algorithm's effectiveness in high-dimensional spaces made it suitable for this task [17].
- Ensemble Learning Models: Various ensemble methods, such as Boosting, Categorical Boosting, Extreme Boosting, and Light Boosting, were employed to predict energy theft by analyzing customer consumption patterns. These models leveraged the strength of multiple classifiers to enhance predictive accuracy [18].
- K-means Clustering: This technique was used for anomaly detection in cyber-physical systems (CPS) by examining information flow within control authorities. K-means clustering facilitated the identification of irregular patterns indicative of security breaches [19].
- Analytical Hierarchy Process (AHP) with Fuzzy Sets and TOPSIS Technique: These methods were applied to assess cybersecurity in industrial control systems, focusing on the evaluation and enhancement of intrusion detection and prevention mechanisms [20].

2.4 Case Studies and Examples to Illustrate the Practical Applications of AI Algorithms, Several Case Studies Were Conducted:

- Cybersecurity in the Energy Internet of Things (eIoT): This case study analyzed the vulnerabilities and security challenges inherent in eIoT systems. The application of Random Forest and XGBoost algorithms revealed novel insights into simulating and detecting theft attacks within these systems [21].
- Energy Theft Detection in Smart Grids: This study utilized machine learning classifiers to predict legitimate and suspicious energy usage patterns. The effectiveness of ensemble learning models in identifying instances of energy theft underscored their potential in maintaining grid security and integrity [22].

- Optimization of Energy Usage: Evolutionary algorithms were employed to optimize the movement paths of palletizing robots in industrial settings. Additionally, ant colony optimization techniques were applied to enhance batch processing schedules, demonstrating significant energy savings and efficiency improvements [23].

3 Results

3.1 AI Algorithms for Engineering Challenges in the Energy Industry

3.1.1 Cybersecurity

The security of systems is crucial for the operation of the energy sector. It involves a mix of issues that need collaboration across fields such as technology, law, society, processes, and organizations. Cybersecurity is closely linked to safeguarding information, often described by characteristics outlined in literature. With the integration of Internet-connected devices (IoT) in the energy sector, there is an increase in risks and vulnerabilities. Recent studies suggest that ensuring cybersecurity for IoT requires an approach that covers all components of a system [24]. Significant progress has been achieved by using AI technologies like machine learning (ML) to enhance the security of IT systems. Research shows how different AI methods effectively boost cybersecurity for energy-related systems [25].

Today's power systems consist of both digital and physical aspects, having specific cybersecurity needs. By viewing them as cyber-physical systems (CPSs), researchers can apply ML techniques to detect anomalies [26]. Anomalous detection in CPSs faces hurdles such as processing large datasets and keeping models up to date. With the multitude of factors impacting energy production and usage, this study makes a contribution to bolstering cybersecurity in the energy industry [27].

In an investigation, a machine learning (ML) model was developed that identifies attacks on energy systems using data and logs gathered by phasor measurement units. This model employs a Random Forest (RF) as an AdaBoost classifier and utilizes a weighted voting technique for predictions, proving more effective than other ML algorithms in pinpointing cyber assaults [28].

The concept of Energy Internet of Things (eIoT) aims to improve the management of energy systems but also introduces fresh vulnerabilities and security challenges. EIoT setups, comprising network devices, sensor networks, embedded systems, transmission media, and data analysis software, can be scrutinized using various methods [29]. One study involving RF-based ML unveiled an attack on the ML model through XGBoost on the platform, exposing a novel vulnerability that permits pilfering AI models generated during the learning process [30].

Furthermore, studies underscore the promise of ML in uncovering instances of energy theft. Machine learning models have been used to identify energy theft in grids by analyzing customer consumption patterns. Various classifiers like boosting, categorical boosting, extreme boosting, light boosting, RF, and extra trees have been tested, showcasing their effectiveness in predicting both legitimate and suspicious energy usage patterns [31].

Securing monitoring and control systems is vital for ensuring the security of the energy sector. Research has utilized the Analytical Hierarchy Process (AHP) along

with fuzzy sets and the TOPSIS technique to assess cybersecurity in industrial control systems. The study emphasized the challenges of preventing and detecting attacks on control systems, including threats like zero-day rootkits, highlighting the necessity for intrusion detection algorithms and showcasing the potential of machine learning in this realm [32].

Another investigation explored the application of the support vector machine (SVM) algorithm to combat data injection attacks in peer-to-peer energy transactions involving Connected Electric Vehicles (CEV). Employing the SVM algorithm was found to enhance cybersecurity in electricity trading between CEV buyers and sellers, revealing that injecting data into machine learning algorithms could significantly impair performance or even disrupt the system [33].

Table 1 presents a summary of how artificial intelligence algorithms being utilized to bolster cybersecurity across various sectors, within the energy industry. In the table each row represents a combination of a cybersecurity domain, a specific engineering challenge and the AI method used to tackle that challenge.

Table 1. Uses of AI Algorithms in Cybersecurity

Cybersecurity domains	Engineering problems	AI algorithms
Detection of cyber anomalies	Data flow in a single Balancing Authority	k-means clustering
Detection of cyberattacks	Prediction using historical data and phasor measurement logs	Random Forest weighted voting method
Detection of cyber anomalies	Data flow in a single Balancing Authority	k-means clustering
Detection of cyberattacks	Prediction using historical data and phasor measurement logs	Random Forest weighted voting method
Cybersecurity of energy systems	Analyzing impacts on monitoring and control systems	Fuzzy based AHP and TOPSIS
Cybersecurity of connected vehicles	Detection of false data injection	SVM

When it comes to identifying anomalies in Cyber Physical Networks, the main focus is on how information flows within a Control Authority, which plays a role in ensuring the reliability and integrity of energy distribution. The utilization of the k-means clustering technique plays a role in detecting and categorizing irregularities that could indicate security breaches or system malfunctions [34]. In the realm of recognizing cyberattacks, there is a focus on predicting cyber threats using past data and phasor measurement records. The exploration of combining Random Forest (RF) with a voting method presents a strategy for forecasting and addressing cyberattacks, thereby bolstering the resilience of energy systems against such activities [35].

The security aspect of eIoT (Energy Internet of Things) systems is tackled through simulating theft incidents within energy management frameworks. The application of

Random Forest and XGBoost algorithms sheds light on the intricacy and vulnerabilities inherent in eIoT systems, emphasizing the necessity of AI models to protect these advanced infrastructures [34]. Concerning Unauthorized Energy Use Detection, the focal point is on modeling and anticipating energy consumption within Smart Networks. Research on Ensemble Machine Learning demonstrates effectiveness in identifying patterns of energy theft, which is vital for ensuring effective distribution of energy resources [36].

The protection of energy systems from cyber threats involves assessing the impact on control units, which play a role in monitoring and managing energy systems in real time. Using Fuzzy AHP and TOPSIS techniques offers a framework for evaluating and enhancing the cybersecurity measures needed to safeguard these components [7]. In the realm of cybersecurity for vehicles, a key challenge is identifying data injections that can greatly disrupt decentralized energy trading systems operations. The application of the Support Vector Machine (SVM) algorithm emphasizes the importance of AI methods in detecting and mitigating attacks involving data injections, helping ensure the integrity of peer-to-peer energy transactions involving vehicles [28].

The details presented in Table 1 demonstrate the sophisticated uses of AI algorithms in tackling cybersecurity issues within the energy industry. Each entry showcases engineering challenges and AI techniques employed and emphasizes the critical role of cybersecurity in upholding the stability and efficiency of contemporary energy systems.

3.1.2 Optimizing Energy Usage and Reducing Power Losses

Optimizing energy usage and reducing power losses are pivotal for energy systems to achieve efficiency while minimizing environmental impact. These efforts bring about both benefits and contribute to environmental sustainability. AI has been successfully used to achieve these goals in a variety of industries.

In the industrial sector, evolutionary algorithms have been employed to improve the movement path of robots that palletize items, leading to a significant decrease in energy consumption, emphasizing AI's potential to boost the energy efficiency of tasks [8]. Within manufacturing, integrated ant colony approaches have been utilized to optimize energy management, balancing production efficiency and energy expenses, showcasing how AI can enhance energy utilization in settings [13].

Addressing power distribution losses, bat-inspired algorithms combined with blockchain technology have been used to identify optimal locations for reactive power devices in radial power grids. This innovative approach significantly diminished power wastage, highlighting AI's efficacy in improving the performance of power networks [37]. For optimizing energy usage, simulated annealing techniques have been employed to plan energy paths for UAVs conducting transmission tower inspections, resulting in decreased energy consumption and underscoring AI's role in optimizing energy utilization across applications such as UAV missions [38].

In Smart Homes, a combination of machine learning, Big Data, and IoT has been used to develop energy management systems. By utilizing decision tree models, the system notably reduced energy consumption, underscoring the effectiveness of AI in controlling energy usage [39]. Enhancing 5G Network Efficiency involved utilizing long short-term memory (LSTM) networks to forecast network traffic patterns, achieving superior

energy efficiency compared to conventional approaches [15]. Finally, the optimization of HVAC systems was achieved by introducing ML-based HVAC controllers integrating ML engines for activity detection employing random forests, demonstrating a significant decrease in energy usage compared to on/off controllers, emphasizing the potential of AI in optimizing heating, ventilation, and air conditioning systems [40].

Table 2 provides an analysis of AI algorithms implemented across energy saving sectors. Each entry, in the table addresses an engineering challenge details the AI technique employed to tackle it and includes references that illustrate the innovative application of AI in enhancing energy efficiency.

Table 2. AI Applications, for Energy Efficiency and Power Reduction

Energy efficiency areas	Technical challenges	AI methods
Robotics in Manufacturing	Enhancing the path of palletizing robots	Evolutionary Algorithm Variation
Manufacturing Industry	Optimizing sequences for batch processing equipment	Combination of Ant Colony Techniques
Reducing Electrical Power Losses	Positioning of power devices	Inspired by Bat Algorithms
Energy Management Systems	Efficient energy usage for UAVs during tower inspections	Utilizing Simulated Annealing Methodology
Smart Home Technologies	Development of advanced home automation systems	Decision Tree Models
5G Network Enhancements	Forecasting arrival times of data packets	Long Short-Term Memory Networks
Energy Consumption Response	Integrating HVAC systems with machine learning for activity recognition	Random Forest Algorithm

The application of AI algorithms in optimizing energy efficiency and reducing power losses demonstrates significant potential across various sectors, as illustrated in Table 3. Each AI method presents unique advantages tailored to specific technical challenges, leading to substantial improvements in energy management and sustainability. Robotics in Manufacturing: Evolutionary algorithms have shown remarkable efficacy in enhancing the path of palletizing robots. This optimization leads to reduced energy consumption while maintaining high performance efficiency. The implementation of these algorithms in industrial robotics underscores the capability of AI to refine automation processes, yielding energy savings and operational streamlining [20].

Manufacturing Industry: The use of a hybrid Ant Colony Optimization (ACO) approach addresses the challenge of balancing production schedules and energy costs in batch processing equipment. By mimicking the foraging behavior of ants, this method effectively reduces energy usage during manufacturing activities, highlighting AI's role in achieving streamlined and energy-efficient production workflows [14].

Reducing Electrical Power Losses: The Bat Algorithm (BA), inspired by echolocation techniques, has been effectively utilized to position power devices optimally, thereby reducing electrical power losses and enhancing voltage stability. This approach underscores the innovative use of bio-inspired algorithms in addressing complex power distribution challenges [8].

Energy Management Systems: Simulated annealing methodology has been successfully applied to optimize energy usage for UAVs during transmission tower inspections. This technique facilitates the discovery of optimal energy routes, significantly reducing energy consumption and highlighting AI's role in efficient energy management for UAV operations [33].

Smart Home Technologies: Advanced home automation systems using decision tree models have demonstrated significant energy savings by regulating energy usage based on real-time data and user preferences. This integration of machine learning and IoT in smart homes showcases the potential of AI to drive energy conservation while maintaining user comfort [11].

5G Network Enhancements: Utilizing Long Short-Term Memory (LSTM) networks to forecast data packet arrival times has resulted in improved network performance and energy efficiency in 5G networks. This demonstrates the potential of AI to optimize complex network operations and reduce energy consumption in telecommunications [21].

Energy Consumption Response: Integrating HVAC systems with Random Forest algorithms for activity recognition has significantly boosted energy efficiency. These AI-driven HVAC systems adjust energy usage based on real-time activity information, illustrating the practical applications of machine learning in enhancing energy efficiency in residential and commercial buildings [31].

Overall, the diverse applications of AI in energy management, as evidenced in these studies, underscore the transformative impact of advanced algorithms on energy efficiency and sustainability. By leveraging AI techniques, substantial progress can be made in optimizing energy utilization, reducing consumption, and contributing to a more sustainable future.

3.1.3 Forecasting Electricity Loads

Microgrid Load Prediction Artificial Intelligence Technique Used: Self-Organizing Maps (SOM) Main Aspects: In their study, researchers applied Self-Organizing Maps to predict electricity consumption patterns in isolated microgrids. SOMs are a type of neural network that employs unsupervised learning to create simplified representations of complex data while preserving the original structure. These maps are particularly efficient for estimating electricity usage in microgrids by clustering and detecting patterns in datasets, which aids in the design of energy distribution strategies. This methodology proves beneficial for microgrids, which are compact energy systems commonly found in remote or rural regions [38].

Regional Electricity Consumption Forecasting Artificial Intelligence Technique Employed: Adaptive Neuro-Fuzzy Inference System (ANFIS) Main Aspects: ANFIS combines neural network learning capabilities with fuzzy logic's human-like reasoning approach. By incorporating gradient and least squares techniques, the hybrid ANFIS

algorithm addresses the complexities and uncertainties in electricity consumption forecasts. This method has demonstrated high accuracy in predicting electricity demands, surpassing comparative models. ANFIS's ability to adjust and refine its parameters based on input data makes it well-suited for predicting energy consumption in dynamic and uncertain environments [25].

In a study comparing various machine learning algorithms for short-term load forecasting, including SVR, XGBoost, AdaBoost, Random Forest, LightGBM, Deep Learning Regression (DLR), Bi-Directional Long Short Term Memory (Bi-LSTM), and Gated Recurrent Unit (GRU), it was found that DLR outperformed others for one-hour-ahead predictions. Each algorithm has its strengths: SVR is known for its resistance to overfitting, XGBoost and AdaBoost are ensemble methods that combine multiple models to enhance accuracy, RF is useful for managing large datasets with high dimensionality, LightGBM is designed for speed and efficiency, and Bi-LSTM and GRU excel in time series prediction [40].

Prediction of Building Load AI Method: Multivariate Long Short Term Memory (MV LSTM) with Mixture Attention Mechanism Key Features: Researchers created a multivariate LSTM network for predicting energy loads in buildings. LSTM networks, a type of recurrent neural network (RNN), can grasp long-term relationships, making them suitable for time series prediction tasks. The MV LSTM model used in this study incorporates a Mixture Attention Mechanism to improve the model's ability to focus on relevant features within the input data, enhancing prediction accuracy and delivering understandable outcomes. This is particularly advantageous in building load prediction scenarios, where factors like weather conditions, occupancy patterns, and building attributes impact energy consumption [36].

Table 3 presented illustrates the application of AI techniques in diagnosing and detecting faults across various energy systems. Each AI method offers unique capabilities and improvements, contributing significantly to maintaining the reliability, efficiency, and stability of these systems.

Identifying Problems in Power Transformers: Support Vector Machines (SVM) combined with Genetic Algorithms (GA) enhance the accuracy of fault classification in power transformers. This method's optimization of SVM parameters is crucial for precise fault diagnosis, improving operational efficiency and preventing severe disruptions in power supply [5].

Detecting Faults in Power Lines: Feed Forward Neural Networks with Backpropagation techniques have proven effective in identifying and categorizing faults in three-phase power lines. This approach highlights neural networks' robustness in handling complex and noisy data, leading to more accurate fault detection and categorization [11].

Spotting Faults in Thermal Power Plants: The use of a combination of machine learning algorithms, such as Extra Tree Classifier (ETC), SVM, k-Nearest Neighbor (k-NN), and Naive Bayes, reduces sensor requirements and enhances fault detection efficiency in thermal power plants. This multi-faceted approach ensures comprehensive and reliable fault identification [29].

Diagnosing Issues in Hydropower Plants: Bayesian Networks coupled with Moving Window Principal Component Analysis (MWPCA) offer an in-depth understanding

Table 3. Fault Diagnosis in Energy Systems

Area of issue detection	AI method	Key characteristics
Identifying Problems in Power Transformers	Support Vector Machines (SVM) with Genetic Algorithms (GA)	Enhanced accuracy in classifying issues by optimizing SVM parameters
Detecting Faults in Power Lines	Feed Forward Neural Networks with Backpropagation	Identification and categorization of faults in three-phase power lines
Spotting Faults in Thermal Power Plants	Extra Tree Classifier (ETC), SVM, k-Nearest Neighbor (k-NN), Naive Bayes	Reduced sensor requirements and enhanced efficiency in identifying faults
Diagnosing Issues in Hydropower Plants	Bayesian Networks with Moving Window Principal Component Analysis (MWPCA)	In-depth understanding of turbine failure progresssion and early problem detection

of turbine failure progression in hydropower plants. This combination allows for early problem detection, which is essential for maintaining system stability and preventing severe faults [7].

The deployment of AI in these contexts demonstrates its potential to revolutionize fault detection and diagnosis in energy systems. By leveraging the strengths of various AI techniques, significant improvements can be made in operational reliability and efficiency, ultimately contributing to the sustainability and resilience of energy infrastructures.

3.2 Renewable Energy and AI Techniques

Renewable energy plays a crucial role in ensuring the sustainability and advancement of energy systems. Artificial intelligence (AI) has been utilized across various energy sources such as solar, wind, hydro, geothermal, and biomass to boost their effectiveness and dependability.

Solar Energy Prediction: Machine learning methods like linear regression, k-nearest neighbors (k-NN), decision trees (DT), extreme gradient boosting, and different neural networks (MLP, ENN, LSTM) have been employed to predict solar farm energy production. These methods, particularly extreme gradient boosting, have shown high precision in solar energy forecasts [32].

Short Term Solar Forecasting: A combination of regression networks (GRNN), gray wolf optimizer (GWO), and self-organizing map algorithms have been used to enhance accuracy in insolation forecasting. This approach has improved the accuracy of short-term solar energy predictions [24].

Wind Energy Forecasting: An ensemble of neural networks (MVEW DNN) has been created for wind energy production forecasting. This method categorizes learning tasks into global perspectives, improving prediction accuracy and reducing costs [28].

Hydropower Capacity Forecasting: Machine learning regression methods like multilayer perceptron (MLP) networks, extreme learning machines (ELM), and support vector regression (SVR) have been used to anticipate the production capacity of hydropower plants. These techniques incorporate data to refine the precision of capacity estimations [32].

Reservoir Modeling: Machine learning algorithms simulate reservoir behavior by forecasting temperature and pressure patterns for wells, offering insights into the energy potential of reservoirs [38].

Biomass Energy Estimation: Various machine learning models such as random forests (RF), gradient tree boosting (GTB), adaptive boosting (AdB), kernel ridge regression (KRR), support vector machines (SVM), and k-nearest neighbors (k-NN) have been used to gauge the above-ground biomass of rapidly growing trees. Random forests have been highlighted as particularly effective for biomass prediction [11].

Improving Energy Distribution: Data science techniques have been crucial in optimizing energy distribution systems for enhancing efficiency and sustainability. Methods such as machine learning models and big data analytics have been applied to manage and analyze datasets from various sources, improve grid management, and predict energy production in real time [33]. Studies have shown the effectiveness of data mining and analysis in designing energy networks, especially during uncertain scenarios, ensuring energy efficiency and boosting the resilience of the overall network [16].

3.3 AI in Energy Distribution Systems in Poland

Polands energy sector is currently undergoing changes due, to a shift towards energy sources and the adoption of advanced technologies such as artificial intelligence (AI). This section delves into the status of energy distribution systems in Poland examining those incorporating AI and those that do not while discussing the advantages and challenges involved. As Poland strives to modernize its energy infrastructure AI plays a role in improving efficiency, reliability and sustainability.

AI enables real time monitoring and control of energy distribution helping operators balance supply and demand efficiently. This dynamic optimization results in reduced energy wastage and enhanced efficiency throughout the distribution grid. For example AI algorithms can analyze data from meters and grid sensors to forecast consumption trends and adjust distribution accordingly. This capability proves beneficial during demand periods by averting blackouts and ensuring a consistent energy supply.

AI plays a role, in maintenance, where it uses algorithms to analyze both historical and real time data to anticipate possible equipment failures before they happen. This proactive approach helps reduce downtime and maintenance expenses ensuring the reliability and longevity of infrastructure components. By foreseeing faults and planning maintenance in advance AI contributes to the operation of energy systems, which's essential for both providers and consumers. [43].

With the increasing prevalence of threats robust cybersecurity measures are imperative. AI improves the cybersecurity of energy distribution systems by detecting and addressing cyber threats compared to methods. AI powered solutions can spot patterns in network traffic that may indicate cyber attacks enabling swift action to mitigate these

risks. This is especially critical as energy systems become more interconnected and reliant on technologies heightening their susceptibility to cyber threats. [13].

Moreover energy companies, in Poland are embracing AI technology to enhance their operations. For instance PGE, an energy company in Poland utilizes AI for maintenance to minimize unplanned outages and maintenance expenses. This technology also aids in load forecasting enabling energy distribution and ensuring a power supply. Additionally AI is integrated into PGEs cybersecurity measures to bolster protection against threats.

Similarly TAURON Polska Energia leverages AI for smart grid management to improve energy distribution efficiency and reduce costs. Real time data analytics help in predicting and responding to changes in energy demand while optimizing grid infrastructure performance. This approach not enhances customer service. Also establishes TAURON as a frontrunner in AI application, within the Polish energy industry [44].

In 2023 Poland saw a rise, in its renewable energy sources contribution to the countries electricity reaching 27% compared to 21% in 2022. This growth was fueled by investments in wind and solar power with AI technologies playing a role in their management and optimization. The effective utilization of AI in managing energy has played a role in the consistent increase of renewable energy capacity in Poland showcasing the potential of AI to bolster sustainable energy transitions. Despite the progress made in integrating AI many traditional energy distribution systems in Poland still heavily rely on methods. [43].

Traditional systems lack the data analytics capabilities offered by AI leading to inefficiencies, in managing energy. The absence of real time monitoring and dynamic optimization makes it challenging for these systems to effectively balance supply and demand resulting in increased energy losses and diminished efficiency.

Traditional maintenance practices tend to be reactive addressing problems only after they arise. This reactive approach leads to downtimes and higher maintenance expenses compared to maintenance driven by AI. The inability to foresee and prevent equipment failures proactively results in disruptions. Escalated operational costs.

AI integrated systems show increased efficiency in managing energy leading to cost savings. Through maintenance powered by AI the chances of equipment failures are reduced, resulting in lower repair costs and less downtime. Notably AI driven optimizations at companies like PGE and TAURON have led to reductions in costs while enhancing the reliability of energy supply [45].

AI solutions offer cybersecurity measures that bolster the defense of infrastructure against potential threats. Real time detection and response to cyber threats play a role in upholding the integrity of energy distribution systems. In contrast traditional systems with cybersecurity capabilities face vulnerability, to cyber attacks potentially causing severe disruptions and financial harm.

This feature aligns, with Polands objective of boosting the proportion of energy in its energy blend. By 2030 its projected that Poland could produce as 70% of its electricity from renewable sources with AI playing a critical role in overseeing this shift. AI driven optimization of energy systems ensures utilization of existing resources contributing to the sustainability of the energy industry [43].

The incorporation of AI into Polands energy distribution systems signifies a step towards a more efficient, secure and sustainable energy framework. While traditional

systems encounter challenges embracing AI presents promising solutions to tackle these issues. Widening the use of AI across all energy distribution networks in Poland will be essential for achieving the countrys energy objectives and securing an dependable power supply.

Through leveraging the capabilities of AI Poland can enhance its energy distribution grids boost efficiencies and bolster the move towards renewable energy sources. Continuous investment in AI technologies and the formulation of policies will play a role, in propelling the modernization of Polands energy sector ultimately paving the way for a more sustainable and resilient energy future.

4 Discussion

In todays age safeguarding energy systems, with cybersecurity measures is crucial. It is vital to protect infrastructures from cyber threats like access and data breaches. A holistic cybersecurity approach blending security and computer science practices is essential. This includes using encryption techniques establishing security protocols and staying updated to combat evolving cyber risks. Educational programs emphasizing safety and safeguarding AI models from theft also play roles in a cybersecurity strategy.

Improving the performance of AI algorithms is necessary for their use in energy systems. This involves enhancing accuracy, speed and reliability through optimization methods and hybrid models. Ensuring that AI solutions can scale up to manage datasets and intricate energy networks is paramount. Creating AI structures of processing real time data from sources without compromising efficiency is crucial for successful large scale deployment.

Data quality and availability are pivotal for integrating AI in the energy industry. Efficient data collection approaches and dependable data management systems are essential, for maintaining high quality data. Automated data gathering processes, strong storage capabilities and reliable retrieval mechanisms support AI applications by ensuring consistent data.

Utilizing methods, like data imputation and anomaly detection helps maintain the accuracy of AI models when dealing with data. It is crucial to develop strong AI models to ensure their reliability and acceptance in the energy industry. Transparency in AI decision making fosters trust among stakeholders. Ensures compliance with standards and legal frameworks. To enhance the resilience of AI models against errors and adversarial attacks, rigorous testing, validation and optimization methods must be implemented. Ethical considerations such as promoting fairness and accountability are vital for the use of AI technologies.

Addressing the challenges in the energy sector necessitates collaboration across disciplines. Bringing together expertise from computer science, engineering, economics and social sciences is essential for creating AI solutions. Initiatives that promote research interdisciplinary training programs and supportive policy frameworks can drive innovation. Improve the efficacy of AI applications in energy systems.

The energy distribution field is experiencing a transformation with the integration of Artificial Intelligence (AI) leading to emerging trends that redefine approaches to

energy management. Studies have emphasized the increasing role of AI, in enhancing predictability and reliability of energy sources thereby aiding in planning and management.

Recent research, into the use of intelligence (AI) for energy forecasting has revealed a rise in publications and citations especially in countries like China, Germany and Saudi Arabia. This growth highlights the interest and collaboration in leveraging AI for energy distribution.

The application of AI in energy management is increasingly focused on predicting energy production through machine learning techniques. These approaches address the challenges posed by fluctuating conditions thereby improving the stability and reliability of energy systems. By providing forecasts of energy output AI technologies play a role in transforming energy systems.

Studies on emerging trends in risk management within energy projects have utilized advanced tools such as Citespace software to summarize key areas of focus and recent developments. This shift reflects the growing complexity and extended lifecycles of energy projects with AI serving as a tool in navigating these intricacies and uncertainties.

Integrating AI technologies into DSO operations has the potential to greatly boost efficiency, reliability and sustainability in electricity distribution. By utilizing AI for maintenance demand forecasting and energy management DSOs can navigate the complexities of energy systems and meet the growing demands of consumers and regulators. Nonetheless it is crucial to address challenges pertaining to cybersecurity, data quality and ethical considerations in order to fully capitalize on the benefits of AI. Through teamwork and continual innovation AI can play a role, in shaping the future of energy distribution by advancing towards more sustainable and resilient energy infrastructures.

In summary advancements in AI for energy distribution demonstrate progress, in forecasting, application development and risk management. These developments highlight the growing importance of AI in enhancing the efficiency, reliability and sustainability of energy systems. With progress AI is expected to drive innovation and optimize energy distribution within the Distribution System Operator (DSO) sector.

Acknowledgments. Co-financed by the Minister of Science under the "Regional Excellence Initiative" Program RID/SP/0046/2024/01.

Disclosure of Interests.. The authors have no competing interests to declare that are relevant to the content of this article.

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Digital Competences and the Use of Social Media by Polish Students – Comparative Analysis in 2018–2024

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Abstract. Digital competences and the use of social media are two key features that characterize modern society. The aim of this article is to demonstrate the relationship between the use of social media and the digital competences of Polish students. The article contains a presentation of the results of the authors' research carried out in 2018 and 2024, respectively, aimed at identifying and discussing changes that occurred during this period in the use of social media and the perception of digital competences by students of technical and economic faculties. The main conclusion of the research is a higher assessment of digital competences of students using social media and a change in students' preferences regarding the use of specific social networking sites. The results showed that students use Tik Tok, X (formerly Twitter) and Instagram more often and are more cautious in assessing their own digital competences.

Keywords: digital competences · IT competences · social media · comparative analysis · education

1 Introduction

In the modern world determined by information technologies, digital competences are one of the basic requirements enabling effective functioning in society. This applies to both the private and professional spheres. The evolution of IT solutions, the pace of life and the information overload have become key stimuli for the increase in the popularity and scope of use of social media. Popular platforms originally created for entertainment and sharing information between communities associated with specific interests have evolved into business spaces. Platforms such as Facebook, Instagram and YouTube have gone from being a space devoted to providing entertainment to becoming business platforms where business scaling has taken on a new, unimaginably wide scope. The ability to use social media, create information and marketing content or operate

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 69–83, 2024.
https://doi.org/10.1007/978-3-031-78468-2_6

accounts on websites is one of the modern digital competences required by employers. Moreover, a natural consequence of the evolution of social media has been the creation of solutions in this space supporting educational processes. More and more courses, trainings, workshops and webinars are carried out in this form. Based on the above observations, the authors of the article defined the research questions:

RQ 1: how has the use of social media by students evolved from 2018 to 2024?
RQ 2: how does the use of social media affect digital competences?
RQ 3: how has the level of digital competence among students changed from 2018 to 2024?

The aim of this article is to demonstrate the relationship between the use of social media and the digital competences of Polish students based on data from 2018 and 2024. The data was obtained from surveys conducted among students of technical and economic faculties at Polish universities located in the southern part of Poland.

2 Theoretical Background

The use of digital technologies has become an everyday occurrence in both private and professional life. Therefore, the level of digital awareness and digital competences is one of the most important educational problems.

This problem is discussed both in scientific studies and subjected to numerous social diagnoses. Scientific studies include numerous definitions of digital competences, which indicate various categories of skills that determine the degree and scope of the use of digital technologies [5, 12, 32, 36]. The definitions of digital competences most frequently quoted in the literature and their components are presented in Table 1.

Typology of categories developed and presented in the publication by van Laar et all. [45] is one of the most popular typologies mentioned in the literature devoted to the analysis of digital competences of society, both from the perspective of young people and students, as well as the sought-after competences of employees and digital skills assessed from the perspective of seniors and the digital exclusion of older populations. Individual categories are decomposed and analyzed in numerous scientific studies due to the extraordinary importance of this issue [23]. Technical maintenance skills for IT devices, which were the basis for digital competences, become basic knowledge that is acquired already at the stage of early preschool and school life [13]. Therefore, competences related to the conscious acquisition and processing of information are becoming more and more important [8]. Effective information management includes the ability to specify information needs, define sources of acquisition, select information and use it to implement planned tasks [3, 27, 40]. In the area of digital communication, the skills of acquiring and communicating with a wide range of recipients [48] and the ability to establish interactions regardless of distance and time are particularly important, which allows for the creation and strengthening of social relationships [20]. The ability to create communities around specific values and products [26, 47] by co-creating value for enterprises and sharing opinions allowing for the improvement of business processes, both in terms of product development and customer service [30], is becoming increasingly important, especially in business applications [7, 11]. The popularization of remote communication caused by the pandemic has shown the importance of digital communication

Table 1. Examples of digital competence categories in selected definitions

Author, year	Source	Criteria for assessing digital competences
Horton, 1983 [19]	*Information literacy vs. computer literacy*; Bulletin of the American Society for Information Science Vol. 9, No. 4, April	Ability to use a computer to collect and process data
Van Dijk, J. A. G. M. 2005 [44], 2006[43]	*The deepening divide: Inequality in the information society*; London, UK: Sage Publications	The level of access and use of technology assessed through the prism of: motivational accesses, material/physical accesses, skills accesses, usage accesses
Basil 2008 [4]	*Theorems of Information Literacy. A mathematical-like approach to the discourse of InformationLiteracy;* Consiglio Nazionale delle Ricerche	Two levels of assessment: technical use of information technology and information skills consisting in understanding processed resources
Kazibudzki, 2011 [22]	*Psychological and social aspects of effectiveness in business;* Przegląd Organizacji	Knowledge of available technologies, ability to use, technologically oriented attitude and practical experience
Claro et all., 2012 [14]	*Assessment of 21st century ICT skills in Chile: Test design and results from high school level students*; Computers & Educations	The level of technical service is treated as an absolute basis, while the level of digital competences is determined by the ability to understand, create and manage digital content
Tarkowski i in., 2015 [42]	*Taxonomy of functional digital competences and methodology for measuring the level of functional competences;* projekt DIGCOMP	Cataloging digital competences in five categories: information, communication, digital content creation, information security, problem solving
van Laar et all., 2020 [45]	*Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review*; SAGE Open	Categories: Information digital skills, communications digital skills, collaboration digital skills, critical thinking digital skills, creative digital skills, problem-solving digital skills

Source: Own elaboration

skills, which require awareness of time, space, communication and cultural differences. Communication across country and continental borders has highlighted cultural differences, time problems, and distinct perspectives and approaches to effective cooperation [41, 46].

Effective information management, which is the basis of modern digital competences, has increased the importance of critical thinking skills, which are necessary to quickly identify disinformation, false information or information excesses that introduce information noise [16, 41]. Sharing information and knowledge resources on a large scale causes a snowball phenomenon or a butterfly effect, which is particularly dangerous in the event of the spread of false, socially harmful or economically dangerous information.

Another category of digital skills that is increasingly analyzed are creative digital skills. These skills are of particular importance to employers, so students' resources in this area are increasingly analyzed and more and more courses are created to develop these competencies [24, 25, 29]. Creating digital products, digital content, virtual reality - all these tasks require digital creativity competences [6, 28].

Taking into account the type of information and communication technology that dominates everyone's everyday life, social media comes to the fore. These media play a significant role in exchanging information, establishing relationships and communicating [10]. The number of social media users is constantly growing. According to the Digital 2024 Global Overview report, at the beginning of 2024, there were over 5 billion active user identities on social media. Moreover, in 2023, as many as 266 million users started using social media for the first time. The average time that a "typical" social media user spends daily on using these solutions is also increasing. This time is 8 min longer compared to the previous report and now amounts to 2 h and 23 min [17].

Taking into account the fact that social media are a type of Internet platforms that strengthen the network of contacts [49] while allowing for the acquisition and creation of information and cooperation [31], it can be assumed that they are also an environment in which digital competences are developing. Moreover, as indicated by the research of Sobaih et al. Due to the ease of use and usefulness, students prefer using social media [39].

The above-mentioned categories of digital competences as well as their level among Polish students have been and are subject to numerous analyzes and research [32, 35, 42]. Research conducted by the authors of this article is also dedicated to this topic, the general results of which are presented in the following sections.

3 Research Methodology

3.1 Conception of the Research Procedure

In 2018, the authors of this article conducted research on the relationship between the use of social media by students and their assessment of their own digital competences [38]. In 2024, the authors planned to repeat the empirical research using the same questionnaire to obtain results that can be subjected to comparative analysis. Moreover, this research methodology allowed for the assessment of the evolution both in the level of use of social media by students as well as the relationship with their perception and assessment of

their own digital competences. 173 students took part in the first stage of the research, and 165 in the second stage.

The adopted research methodology allows for determining the directions and changes that took place during the period under study in the context of the use of social media and their impact on the perception of digital competences. The authors plan to conduct similar research on average every 5–6 years to identify trends in the research area in question. This approach makes it possible to compare subsequent (different) groups of students - depending on the duration of the course of study.

3.2 The Research Technique Applied

For the purposes of this study, survey research was conducted. The research tool was a self-constructed survey questionnaire consisting of a basic part and a summary. The research was conducted in 2018 and 2024 in a group of students of economics and technical universities located in the southern part of Poland.

The basic part of the survey consisted of 18 questions. The survey used closed and semi-open questions. Two questions used a 5-point Likert scale. The information sheet contained questions relating to such elements as gender, age, field and type of studies. The sample selection was stratified. The defined layer were students, the randomness concerned the fact that it could be filled in freely by a wide group of potential recipients to whom we addressed. The sample size in both stages was similar.

The study involved students of university, technical and economic faculties. Due to the duration of the teaching process, medical studies were omitted and, due to organizational problems, art schools were omitted. In 2024, the questionnaire was corrected in one point - instead of the previously existing (which currently does not exist in practice) "our class", the Tik Tok answer was placed in the cafeteria..

4 Results

At the beginning, we attempted to compare the results from two rounds of research in the use of various social media and communication platforms. Several media and communicators were taken into account, of which only those that were more frequently represented in the sample (at least 20 indications in each stage) were further analyzed (Fig. 1).

In 2018, the 'Nasza klasa' (Our class) platform still existed - although it was in the decline of its operation; in the 2024 study, we replaced it with the Tik Tok platform. What is clearly visible over the years examined is (naturally) a kind of wear and tear of the Facebook platform, not so much in popularity, but in use. Media offering shorter messages are becoming more and more popular - X (Twitter) and Tik Tok. Google plus and YouTube report poorer results. Google plus played such a small role in the current research that we omitted it in subsequent analyses (Table 2).

Both in the case of Facebook ($Z = 2.856$; $p = 0.010$) and Google plus ($Z = 3.643$; $p < 0.000$), these platforms were owned and used more often by the respondents in the first stage of the research. We observe the opposite situation in terms of owning ($Z = -6.676$; $p < 0.000$) and using X (Twitter) ($Z = -2.217$; $p = 0.027$). In turn, respondents

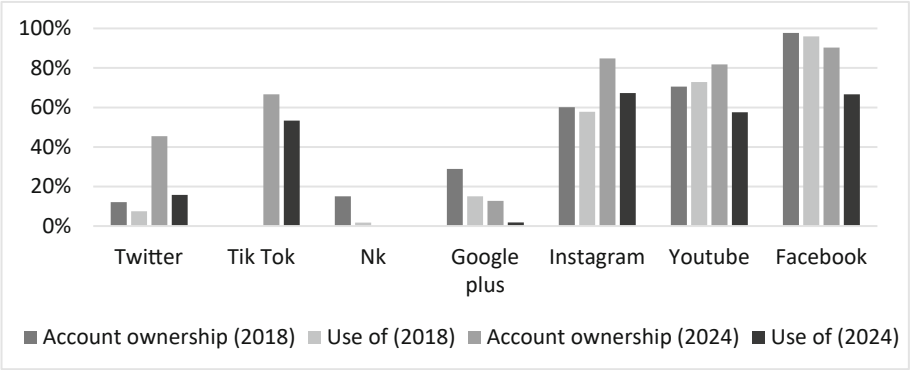

Fig. 1. Platforms with the highest share among respondents in the years 2018 i 2024.

Table 2. Values of the U-Mann-Whitney coefficient for the use of social media and the time of research implementation (2018 and 2024 edition of the study)

Variable	Statistics value		
	U	Z	p
Facebook account ownership	13 301.0*	2.586	0.010
Google plus account ownership	11 964.0*	3.643	0.000
X (Twitter) account ownership	9 604.0**	−6.676	0.000
Instagram account ownership	10 660.0**	−5.166	0.000
Youtube account ownership	12 577.5**	−2.542	0.011
Use of Facebook	10 175.0*	6.764	0.000
Use of Google plus	12 387.0*	4.327	0.000
Use of X (Twitter)	13 182.5**	−2.217	0.027
Use of Instagram	12 921.0	−1.793	0.073
Use of Youtube	12 322.0*	2.618	0.009
Use of Messenger	10 510.5*	3.723	0.000
Use of WhatsApp	9 624.5**	−4.677	0.000

** - higher result of respondents in 2018, ** - higher result of respondents in 2024*

in 2018 had more popular accounts on YouTube ($Z = -2.542$; $p = 0.011$), while currently using these accounts is more popular ($Z = -2.618$; $p = 0.009$). We are also probably observing a migration of users from Messenger ($Z = 3.723$; $p < 0.000$) to WhatsApp ($Z = -4.677$; $p < 0.000$) (Table 3).

People with a Google Plus account currently rate their competences significantly higher in 16 cases (an increase of 16). Users of Google plus, YouTube and Messenger rate their competences significantly higher in 10 cases compared to 3–5 higher ratings by users before the pandemic. Overall, significant differences for social media users

Table 3. Number of statistically significant differences in competence assessments broken down by research years and in aggregate

Variable	Competence assessment		
	2018	2024	Aggregate
Facebook account ownership	8	7	8
Google plus account ownership	0	16	22
X (Twitter) account ownership	0	1	2*
Instagram account ownership	5	7	12*
Youtube account ownership	4	5	38*
Use of Facebook	4	9	44
Use of Google plus	5	10	13/2*
Use of X (Twitter)	3	0	0
Use of Instagram	7	4	6*
Use of Youtube	3	10	4*
Use of Messenger	3	10	4*
Use of WhatsApp	7	1	0

* - *higher rating among non-users/have-nots*

are more pronounced (an increase from 49–80 cases). After aggregating the data, we observe a clear indication of positive (high) assessments of digital competences among Facebook users and negative assessments among YouTube account holders, and we will find similar conclusions in subsequent results (Table 4).

Five of the tested competencies: T11-using the basic functions of spreadsheet, T23-send an email with attachments, T26-creating websites, C6-organized file organization on your computer, C7-organize the information found by e.g. placing them in lists and tables; turned out to be insensitive to respondents' activity in social media. The most common influence was the active use of Facebook (37) and having a YouTube account (21). Interestingly, Facebook users rated their competences significantly higher, while people with a YouTube account rated their competences significantly lower. This may result, firstly, from greater knowledge about capabilities and possible competence gaps, or, more likely, merely having an account without using it does not confer competence. The list omitted having an Instagram account and the use of X, Instagram and YouTube due to the lack of statistically significant differences. Cluster analysis for both pre- and post-pandemic data shows a clear division into two clusters. In the first research period, the first one was slightly smaller, but over time it was expanded to include such competences as: T27-transfer photos from a digital camera to a computer, T23-send an email with attachments, T38-participate in online communities, e.g. Facebook or Instagram. The competencies that have been present in this cluster from the beginning are: T18- Programming in a specialist language, T32-connect to the Internet using a mobile phone, T33-order and buy tickets online, T37-using an electronic signature, C5-selection of the right information from the Internet, C7-organize the information

Table 4. Values of the U-Mann-Whitney statistics (significant) for comparisons of competences of respondents from groups using specific social media and not using them

Activities	Account ownership			Use of		
Competences	Facebook	Google plus	X (Twitter)	Youtube	Facebook	Google plus
T1			XX		X	
T2				XX	X	
T3				XX	X	
T4				XX	X	
T5			XX	XX	X	
T6		X			X	
T7	X				X	
T8		X		XX	X	
T9		X		XX	X	
T10		X				
T11						
T12				XX	X	
T13					X	
T14				XX	X	
T15					X	

(*continued*)

Table 4. (*continued*)

Activities	Account ownership			Use of		
T16				XX	X	
T17				XX	X	
T18	X				X	
T19				XX	X	
T20					X	
T21				XX	X	
T22	X				X	
T23						
T24					X	
T25					X	
T26						
T27				XX	X	
T28		X	XX	XX	X	
T29		X	XX		X	X
T30		X	XX	XX	X	X
T31						XX
T32	X				X	
T33	X				X	
T34		X			X	

(*continued*)

Table 4. (*continued*)

Activities	Account ownership			Use of		
T35			XX	XX	X	
T36					X	
T37						XX
T38					X	
C1	X				X	
C2				XX		
C3				XX		
C4				XX		
C5					X	
C6						
C7						
C8			XX		X	
C9				XX		
C10			XX	XX	X	
C11		X			X	

X - the indicated competence of owners/users was rated higher
XX - the indicated competence of owners/users was rated lower

found by e.g. placing them in lists and tables, C9-assess the security level of publishing information on the Internet, for example on Facebook. Taking into account the indicated group, we can treat it as containing competences responsible for the conscious use of electronic tools in everyday life.

5 Discussion and Conclusion

The basic issue affecting the results of the presented research is the change in students' preferences in the use of social media. In Poland, we observe a global trend of increasing popularity of Tik Tok, X (formerly Twitter) and Instagram. Short messages, films and messages are the basis of communication today. Especially if it concerns Generation Z [9].

Digital knowledge [1] and digital competences play a key role in the everyday life of modern people, which shape the standard of living in many dimensions. Moreover, technological progress, which can be observed in every area of life, forces people to constantly improve their skills and competences [11]. One of the significant ICT solutions are social media, which are a rich source of real-time information enabling immediate access and dissemination of information around the world [15, 18]. As Malik et.al emphasizes, social media and social networking sites are also a dynamic tool to stimulate students' creativity and academic performance, inspiring and motivating students [31]. Moreover, according to the research of Al.-Rahmi et al. The satisfaction of students using social media before the pandemic positively influenced their academic performance [2]. It is worth emphasizing here that the use of social media may have a negative impact on its users, leading to addiction [21, 34] (Fig. 2).

Our research has shown that using social media leads to higher self-assessment of digital competences among students. Here, a certain division is clearly visible (as confirmed by cluster analysis) into those treated as basically everyday activities and others, still considered as certain skills. When comparing competence assessments now and before the pandemic, greater caution is noted. In many cases, students currently rated their competences lower. This may be the result of facing reality during the pandemic as well as greater knowledge (e.g. acquired while using YouTube) regarding one's own capabilities and shortcomings. Also, studies by Silva-Quiroz et al. conducted among Chilean students showed an average level of digital competences [37].

The presented research concerned the relationship between the use of social media and digital competences among Polish students. The sample size in both the first and second studies was not large, which does not allow generalization of the conclusions, but only the indication of certain tendencies. Moreover, in both studies, students were guided only by self-assessment of their own digital competences, which were not verified in any way. Nevertheless, these results may be a valuable source of information for educational institutions, indicating the direction of the use of social media and students' perception of their own digital competences, which should translate into appropriate educational programs.

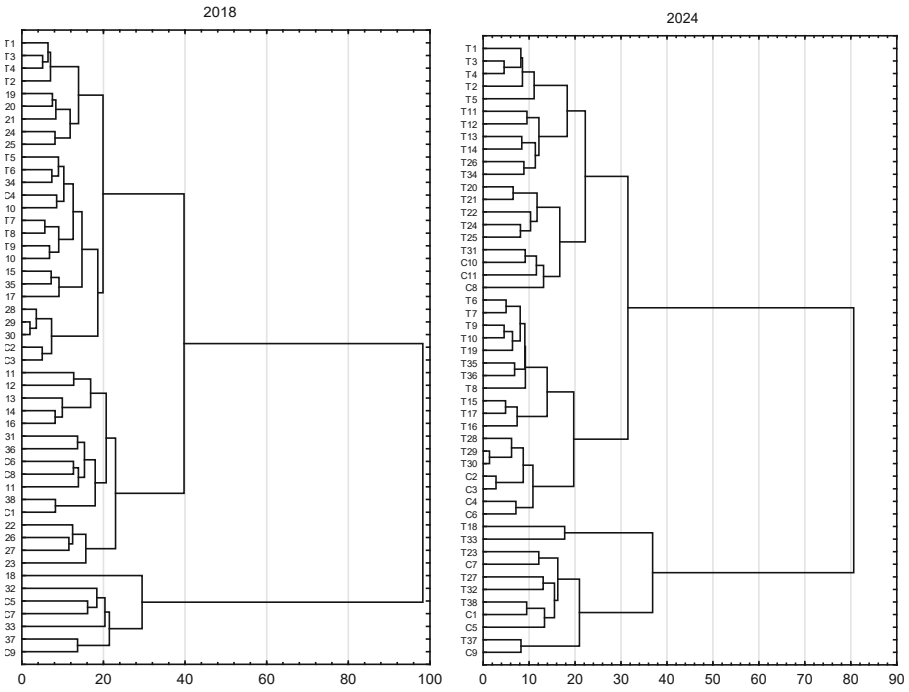

Fig. 2. Cluster analysis using the Ward method for information and IT competence assessments in 2018 and 2024 (Euclidean distance)

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Cognitive Technologies in Logistics Customer Service Management – The Case of E-commerce

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Abstract. This paper investigates the role of cognitive technologies in managing logistics customer service in the e-commerce sector. Cognitive technologies, including AI-driven recommendation systems and chatbots, are increasingly utilized to enhance operational efficiency and customer satisfaction. The study presents empirical research conducted among Polish e-commerce users in 2024, analyzing the impact of these technologies from the customer's perspective. The findings indicate that cognitive technologies significantly improve customer experience by providing personalized product recommendations and efficient problem-solving through chatbots. However, concerns regarding data privacy and the accuracy of chatbot responses were also highlighted. This research contributes to filling the literature gap by offering a comprehensive user-centric evaluation of cognitive technologies in e-commerce logistics.

Keywords: cognitive technologies · logistics · management · customer service · e-commerce

1 Introduction

Cognitive technologies are advanced systems that mimic, support, or extend human cognitive processes. These technologies encompass a wide range of tools, including artificial intelligence (AI) systems, machine learning, natural language processing, and pattern recognition, which are used to automate tasks requiring human perception, thinking, and decision-making [1]. They represent significant progress in the field of artificial intelligence, offering new possibilities for automation, data analysis, and decision-making. Their application can bring many benefits but also requires a responsible approach to their development and implementation to ensure compliance with social and ethical values [1].

Cognitive technologies are increasingly and widely used to support logistics processes. One of their popular applications is assisting in the management of logistics customer service processes, mainly through the use of recommendation systems and chatbots, which is particularly useful in the e-commerce industry.

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 84–95, 2024.
https://doi.org/10.1007/978-3-031-78468-2_7

This article presents content related to the use of cognitive technologies (recommendation systems and chatbots) in managing logistics customer service in the e-commerce industry. It presents research evaluating this subject matter from the perspective of the e-commerce user. This is particularly interesting because, from the perspective of enterprises using cognitive technologies in their operations, they are perceived favorably, with a positive impact on various business parameters [2]. However, from the perspective of the users of these technologies, i.e., the customers, comprehensive studies are lacking, as the literature analyzes this issue only fragmentarily. Therefore, this article will help fill this literature gap.

The main goal of the article is to analyze and evaluate the cognitive technologies used by the e-commerce industry from the perspective of its customers. To achieve this, theoretical background about cognitive technologies and their usage in logistics, methodology based on the survey questionnaire, research results made with advanced tools, and discussion and conclusions where similar research and this paper's main achievements are pointed out as well as the future research directions are mentioned.

2 Theoretical Background

2.1 Cognitive Technologies as a Support for Logistics

Cognitive technologies have wide-ranging applications in various fields, such as medicine, finance, customer service, logistics, and manufacturing [3]. One of the most significant aspects of cognitive technologies is their ability to learn and adapt based on empirical experiences gained through direct interaction with the environment. This enables them to automatically analyze real data and map business processes, thereby facilitating effective business process management [4].

With technological advancement, there is an increasing need to integrate cognitive technologies into logistics due to rising market demands. Implementing these technologies allows companies to improve operational efficiency, reduce costs, and enhance customer satisfaction, which positively impacts the competitive business environment [5].

Cognitive technologies have recently become an integral part of logistics improvements. Their advantages, including artificial intelligence (AI), machine learning, and big data analytics, enable companies to optimize operations by automating processes, streamlining decision-making, and improving customer service quality. AI-based algorithms and Internet of Things (IoT) sensors facilitate real-time shipment tracking and management, delay prediction, and route optimization, significantly enhancing operational efficiency [6]. Furthermore, cognitive technologies can streamline warehouse operations through automated picking systems and warehouse robots, leading to improved accuracy and reduced labor costs [7].

Moreover, the integration of artificial intelligence and cognitive computing in logistics systems allows for real-time data analysis, which is invaluable for effective business process management [3]. These technologies support various functionalities, such as creating strategic budget plans and identifying operational deviations, essential for maintaining competitiveness in a rapidly changing market environment. As cognitive

technologies continue to be utilized, businesses will be able to develop more responsive, efficient, and customer-oriented logistics operations.

2.2 Cognitive Technologies in e-commerce Logistics Customer Service

Cognitive technologies play a crucial role in managing logistics customer service. They utilize artificial intelligence (AI), machine learning, data analytics, and natural language processing to optimize logistics processes and improve customer service [7].

Cognitive technologies enable more effective data management and customer needs forecasting. Systems analyze both structured and unstructured data, which allows for the identification of customer behavior patterns and the prediction of future needs. This, in turn, enables the creation of more effective logistics customer service management strategies and faster, more accurate decision-making [8].

The introduction of cognitive technologies into logistics, including logistics customer service, brings significant benefits such as increased operational efficiency, improved customer service, and better data management. These technologies allow companies to deliver products faster, at a lower cost, and with greater customer satisfaction, which is a key competitive factor in a rapidly developing market [9].

Therefore, cognitive technologies are essential in the e-commerce industry. Currently, this is one of the fastest-growing economic sectors, driven by technological advancements and changes in consumer behavior, additionally requiring top-tier logistics customer service. E-commerce encompasses a wide range of activities, from retail sales of physical products to digital services, auction platforms, and marketplaces [10]. Here, cognitive technologies help manage the vast amounts of data generated by users, as AI and big data analytics enable e-commerce companies to analyze this data in real-time, allowing for a better understanding of customer needs and quicker responses to changing market trends [8]. Additionally, cognitive technologies in e-commerce improve transaction security and logistics management, including logistics customer service [11].

2.3 Recommender Systems and Chatbots in e-commerce

The most significant cognitive technologies in e-commerce are recommender systems and chatbots. AI-driven recommender systems and chatbots analyze user behavior data and support customers' decision-making processes by providing personalized product suggestions to enhance their satisfaction. From a logistics perspective, particularly in managing logistics customer service processes, recommender systems and chatbots significantly increase customer loyalty and their willingness to reuse e-commerce platforms [12].

Recommender systems play a key role in e-commerce by helping users discover products that may interest them based on their previous purchasing behavior and preferences. As the number of products available online grows and competition in the e-commerce market becomes more intense, effective recommender systems become essential for attracting and retaining customers.

Types of recommender systems include: content-based recommendations, where systems analyze the properties of products that users have already purchased or viewed

and suggest similar products [13]; collaborative filtering, where the system analyzes the behavior of many users to suggest products, with recommendations generated based on similarities between users [14]; and hybrid recommendations, where systems combine different approaches to increase recommendation accuracy, integrating content-based methods with collaborative filtering for better understanding of user preferences and providing more accurate suggestions [15].

Additionally, the use of machine learning in recommender systems significantly improves their performance. These algorithms can analyze vast amounts of data and provide personalized recommendations in real-time. Collaborative filtering algorithms analyze user data to find similarities and suggest products that may interest them [16]. In contrast, deep learning algorithms use advanced techniques, such as neural networks, to analyze user behavior patterns and generate more accurate recommendations. These algorithms are particularly effective in solving problems like cold start and data sparsity [17].

While recommender systems have many advantages, they are not without challenges. Cold start is a problem that occurs when there is insufficient data for new e-commerce users or new products to generate accurate recommendations. Another issue is data sparsity, which arises from the vast amounts of user and product data, making recommendation accuracy difficult. Scalability is also a problem as recommender systems must handle huge amounts of data in real-time, posing a significant technological challenge [15].

Despite these challenges and problems, the future of recommender systems in e-commerce looks promising, with the continued development of technologies such as AI, big data, and deep learning. As these technologies advance, recommender systems will become more precise, helping companies better understand their customers' needs and providing personalized shopping experiences, thereby adjusting logistics customer service to the highest standards.

Unlike recommender systems, the second cognitive technology supporting logistics customer service management in e-commerce is chatbots. These are computer programs capable of conversing with users using natural language, and they are becoming increasingly popular in logistics customer service. Thanks to advanced artificial intelligence (AI) algorithms and natural language processing (NLP), chatbots can offer fast, accurate, and personalized support for customers, significantly positively impacting service quality and operational efficiency of companies.

Chatbots in logistics customer service are used to automate responses to frequently asked questions (FAQs), which helps reduce the workload of employees and provide faster information to customers. Research shows that chatbots can effectively handle simple queries and, in the case of more complex problems, direct customers to a customer service representative [18. Chatbots operate continuously, meaning they are available 24/7, significantly increasing customer satisfaction as they can receive assistance at any time [19]. Additionally, advanced chatbots can analyze customer data, such as purchase history and preferences, to provide personalized recommendations and offers. This approach not only increases customer satisfaction but also their loyalty to the brand [20].

However, chatbots, like recommender systems, are not free from problems and challenges. Currently functioning chatbots, especially in their initial implementation phases, may require frequent monitoring and updating of response databases, which can be time-consuming and costly. Additionally, it is necessary to continuously improve algorithms so that chatbots can effectively respond to increasingly complex queries [19]. Despite technological advancements, chatbots can still struggle to understand the context of certain questions, leading to incorrect or unsatisfactory responses. This is particularly evident in cases where queries are unusual or require deeper analysis [21].

The development of AI and NLP technologies indicates a continuous increase in the importance of chatbots in managing logistics customer service. As these technologies develop, chatbots will become more intuitive and capable of conducting more natural and complex conversations with users. It is anticipated that chatbots will be increasingly integrated with other systems, such as CRM (Customer Relationship Management), allowing for even better personalization and customer service efficiency [22].

Therefore, while chatbots have the potential to significantly improve customer service quality through process automation, increased service availability, and personalized customer interactions, their effectiveness depends on continuous monitoring and improvement to meet growing customer expectations.

In conclusion, cognitive technologies in e-commerce are essential to meet increasing customer expectations, improve operational efficiency, and maintain market competitiveness. The integration of AI, big data, blockchain, and IoT in e-commerce processes brings numerous benefits, including better understanding of customer needs, increased transaction security and efficiency, and personalized shopping experiences.

3 Research Methodology

In the theoretical background, cognitive technologies were presented mainly from the perspective of enterprises that actively use them. However, the main objective of this article is to reverse the situation and examine (analyze and evaluate) how cognitive technologies used by enterprises are perceived by their customers.

To achieve the research objective and fill the research gap, which is the customer perspective in the studied area, the e-commerce industry and its users were chosen. This choice was driven by the high popularity of online shopping and the fact that online stores most frequently use recommendation systems and chatbots in their operations to support logistics customer service management.

Based on comprehensive literature studies related to cognitive technologies, especially recommendation systems and chatbots, the e-commerce sector, and logistics customer service management, a quantitative survey in the form of a questionnaire was developed. The questionnaire contained 16 main questions on a Likert-like scale regarding the topic under study, and a confidential section (questions about gender or place of residence). A pilot study was carried out on a sample of 10 e-commerce users to eliminate any ambiguities, ensuring that respondents had no doubts about the clarity of the questions.

In the second quarter of 2024, the main study was conducted among Polish e-commerce users using the CAWI method (survey questionnaire in the cloud, sent via a link). The condition for participation in the study was a declaration of online shopping.

The study was conducted on a sample of 284 Polish e-commerce customers randomly selected, assuming an error of 6% and the use of positional measures, which constitutes an appropriate sample size. Cronbach's alpha for the study was 0.77.

The Statistica 13 package was used to conduct the analyses. To elaborate the results, Spearman's correlation coefficient, significance tests for two means, and spatial simulations using the distance-weighted least squares smoothing method were employed.

4 Results

The most interesting information in the study was assumed to be the information contained in questions Z2 - Do product recommendations influence your purchasing decisions?, Z9 - Do you think chatbots are more effective at solving problems than traditional customer service?, and Z15 - Do you feel that your opinions and reviews are taken into account when improving products and services? In relation to these questions, correlations with other answers were first examined (Table 1).

Each of the three selected questions had a statistically significant impact on the issues described by Z3, Z6, Z8, and Z16. In some cases, these were not only significant but also high levels of correlation ($R_{Z2/Z3} = 0.671$; $R_{Z8/Z9} = 0.626$)). It can be said that the studied categories are strongly related to each other. The issue described by Z14 was most susceptible to the impact of the examined issues in 12 out of 15 possible cases (Table 2).

The research confirmed that the highest (statistically significant) evaluation value was indicated for the variable Z5 - Do you feel that the website remembers your previous choices and preferences on subsequent visits? This was the only question in which respondents (on average) gave answers above 4, i.e. 'yes'. After it, Z16 was indicated - Is it important to you that your opinions and reviews are analyzed and used to improve e-commerce services? and Z6 - Is it important to you that product recommendations are tailored to your individual needs? Respondents least often agreed with the statement defined by Z7, Z9, and Z8. They concerned the use and assessment of the effectiveness of chat-bots.

Due to the results obtained so far, an attempt was made to spatially illustrate - using the simulation of the least squares smoothing method weighted by distances - the relationship between the studied key variables and their arbitrarily selected determinants. Due to assumptions, the resulting graphs were limited in scale within the actual ratings (1–5) (Fig. 1).

People who believe that product recommendations help them make purchases, regardless of the recognition of their opinion, evaluate product recommendations as influencing their purchasing decisions. However, the recognition of opinions and reviews as worth analyzing and using to improve e-commerce services only beyond a certain level and a sufficiently high level of recognition for recommendations result in an increase in the frequency of purchases as a result of recommendations (Fig. 2).

People whose expectations regarding answers are met by chat-bots (Z8), regardless of the frequency of online purchases (Z7), believe that chat-bots are more effective in solving problems than traditional customer service (Fig. 3).

Table 1. Spearman's correlation coefficient values and its significance level for answers to selected questions

Variable	Z2		Z9		Z14	
	R	p	R	p	R	p
Z1. Do you often notice that the product recommendations offered by the website are accurate and match your interests?	0.343*	0.000	- 0.125	0.037	0.174	0.004
Z2. Do product recommendations influence your purchasing decisions?	-	-	- 0.105	0.083	0.020	0.738
Z3. Do you find that product recommendations help you discover new products that interest you?	0.671	0.000	- 0.104	0.082	0.217	0.000
Z4. Have you ever bought a product that you had not planned before, thanks to artificial intelligence recommendations?	0.039	0.513	0.009	0.887	0.349	0.000
Z5. Do you feel that the website remembers your previous choices and preferences on subsequent visits?	0.156	0.009	- 0.142	0.017	- 0.034	0.567
Z6. Is it important to you that product recommendations are tailored to your individual needs?	0.123	0.040	0.205	0.001	0.301	0.000
Z7. Do you often use chatbots or virtual assistants when shopping online?	- 0.062	0.299	0.515	0.000	0.494	0.000
Z8. Do the answers provided by chatbots meet your expectations?	0.140	0.020	0.626	0.000	0.501	0.000
Z9. Do you think chatbots are more effective at solving problems than traditional customer service?	- 0.105	0.083	-	-	0.482	0.000
Z10. Have you ever had to switch to human support because the chatbot couldn't help?	- 0.058	0.337	- 0.013	0.827	0.039	0.516
Z11. Are you comfortable using chatbots to obtain information about order status, product availability, etc.?	0.011	0.849	0.447	0.000	0.423	0.000
Z12. Do you have any concerns about using chatbots and virtual assistants?	0.333	0.000	0.126	0.035	0.272	0.000
Z13. Have you noticed an improvement in customer service based on feedback or reviews?	0.008	0.899	0.381	0.000	0.570	0.000
Z14, Do you rate highly the ability of AI systems to identify and solve problems based on reviews?	0.020	0.738	0.482	0.000		-
Z15. Do you feel that your opinions and reviews are taken into account when improving products and services?	0.241	0.000	0.279	0.000	0.521	0.000
Z16. Is it important to you that your opinions and reviews are analyzed and used to improve e-commerce services?	0.380	0.000	0.068	0.260	0.156	0.009

** - red color indicates statistically significant values*

The assessment of the ability of artificial intelligence systems to identify and solve problems based on reviews is based not on taking opinions into account when improving products and services, but on seeing improvements in the quality of customer service based on opinions or reviews. What matters is the clear effect, not just intentions.

Table 2. Mean significance test results for survey questions

Question	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15	Z16
Z1	←	-	←	↑	↑	←	←	←	-	←	←	←	←	←	↑
Z2		-	←	↑	↑	←	←	←	↑	←	←	-	-	←	↑
Z3			←	↑	↑	←	←	←	-	←	←	←	←	←	↑
Z4				↑	↑	←	←	←	↑	-	-	↑	↑	↑	↑
Z5					←	←	←	←	←	←	←	←	←	←	←
Z6						←	←	←	-	←	←	←	←	←	↑
Z7							↑	←	↑	↑	↑	↑	↑	↑	↑
Z8								-	↑	↑	↑	↑	↑	↑	↑
Z9									↑	↑	↑	↑	↑	↑	↑
Z10										←	←	←	←	←	↑
Z11											-	↑	↑	-	↑
Z12												↑	↑	-	↑
Z13													-	-	↑
Z14														-	↑
Z15															↑

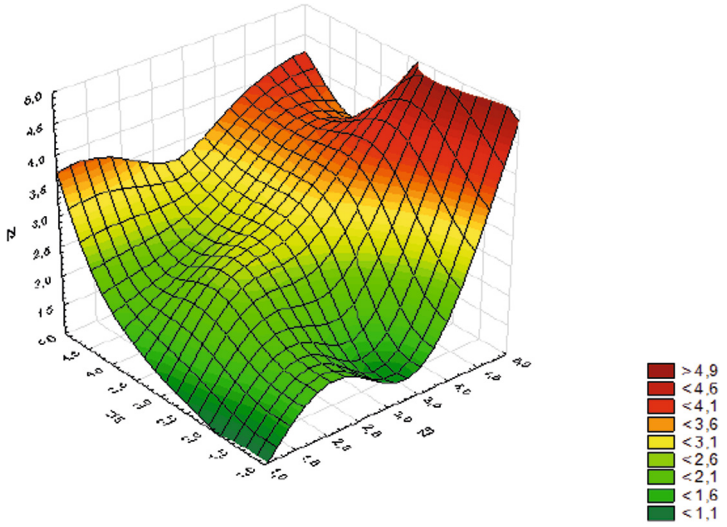

Fig. 1. Spatial simulations of the impact of product recommendations on purchasing decisions (Z2) depending on the assessment of the usefulness of recommendations in discovering new products (Z3) and the assessment of the importance of the usefulness of one's own opinions and reviews when analyzing and using them to improve e-commerce services (Z16).

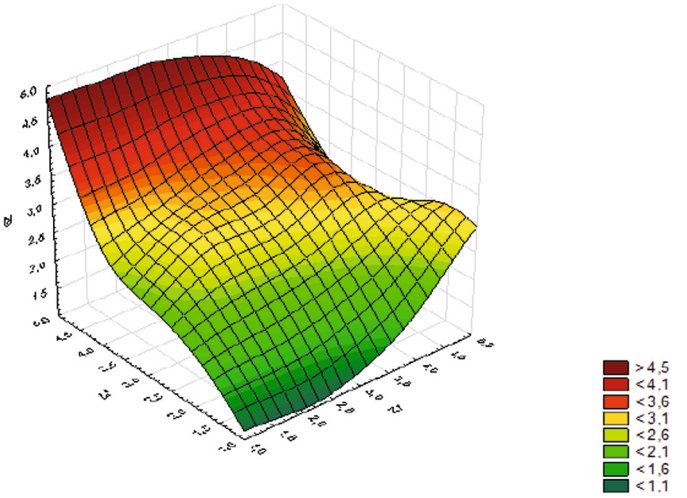

Fig. 2. Spatial simulations assess the effectiveness of chat-bots more effectively in solving problems (Z9) depending on the frequency of using chat-bots or virtual assistants when shopping online (Z7) and satisfaction with the answers provided by chat-bots (Z8).

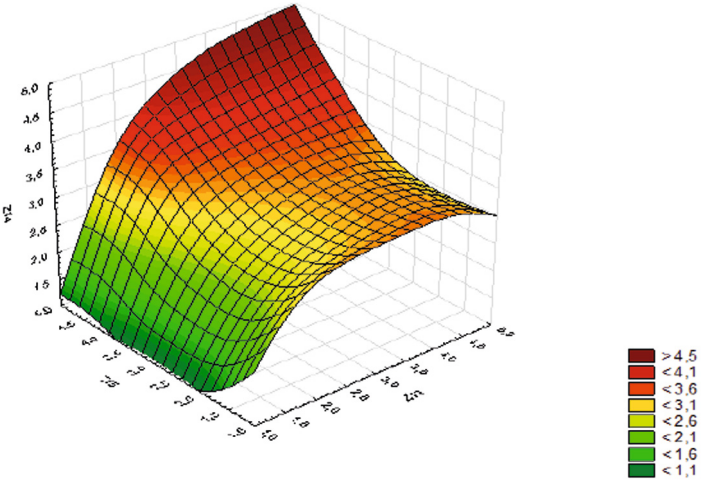

Fig. 3. Spatial simulations of the value of assessing the ability of artificial intelligence systems to identify and solve problems based on reviews (Z14) depending on the perception of improvement in the quality of customer service based on opinions or reviews (Z13) and taking opinions and reviews into account when improving products and services.

5 Discussion and Conclusion

Cognitive technologies are gaining increasing popularity in the e-commerce industry. Customers of online companies have various feelings and opinions about these advanced technologies, which are becoming increasingly integrated into their daily shopping experiences.

The above-presented research results demonstrate that the perspective of e-commerce customers on the use of cognitive technologies, particularly recommendation systems and chatbots for managing logistics customer service, is positive. This aligns with the findings of other similar studies, where users of cognitive technologies have also expressed support and satisfaction with their use in business activities [12, 23, 24].

Polish e-commerce users pointed out that AI-based recommendation systems significantly improve their shopping experience by providing personalized product suggestions. They also appreciate when recommendation systems can predict their needs and interests, which increases their engagement and satisfaction with online shopping.

Polish customers also believe that cognitive technologies help build customer trust in e-commerce platforms by improving transaction security and personalizing services. Customers feel more comfortable using platforms that offer advanced security and personalization features, positively affecting their loyalty and willingness to make repeat purchases.

And finally, according to e-commerce users, chatbots and other AI tools in customer service enable quick and efficient problem resolution, increasing their satisfaction with services. They value the ability to get quick answers to their questions without waiting for a connection to a consultant.

However, respondents were not positive about all aspects of using cognitive technologies. Negative perspectives were also confirmed in previous studies [25, 26]. Issues related to privacy and security, as well as the accuracy of chatbot responses to questions, often elicited negative feelings. Cognitive technologies, by collecting and analyzing customer data, raise concerns about potential privacy violations and data security. While chatbots effectively answer many questions, they do not always handle more complex problems. A lack of satisfactory responses from chatbots leads to customer frustration, resulting in negative shopping and customer service experiences.

In conclusion, cognitive technologies will continue to evolve, and it is expected that they will increasingly meet the needs and expectations of e-commerce customers in logistics customer service and process management. Their integration with AI and other systems will lead to even more personalized and efficient shopping experiences. However, the e-commerce industry must continue to work on building customer trust and ensuring transparency, privacy, and security in collecting and using personal data. Future research in this area should focus on these aspects.

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Conditions of Building a Career in the IT Sector from the Point of View of Students of Selected Universities in Poland

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Abstract. The purpose of the paper is to explore students' perspectives on their future careers in the IT (Information Technology) profession. Additionally, the study compares differences in the desire to pursue a career as an IT specialist between students from the two universities in Poland. The article analyzed students' perceptions of the current IT market and trends, focusing on the challenges and fears associated with working in the IT industry. The research was conducted in 2023 with the Computer Assisted Web Interview method and covered over 480 students. The analysis of the results enabled the authors to assess the level of IT career awareness among the students and understand how respondents' opinions differ in both universities. The originality of the research lies in its comprehensive approach to the topic, examining the conditions for a career in IT and highlighting differences in opinions resulting from the location of both universities and their specific circumstances.

Keywords: IT job opportunities · determinants of IT professions · IT competencies · educational programs in IT · regional comparative analysis

1 Introduction

The IT profession is approached broadly, encompassing individuals who undertake tasks related to analysing user needs, designing and programming systems, their development, implementation, maintenance, user training, etc. The article focuses on individuals potentially interested in pursuing careers in management information systems, aiming to expand the discussion beyond the scope of programming alone.

The challenge of establishing a successful IT career is complex and influenced by both substantive and non-substantive factors. Non-substantive factors include, for example, myths circulating on the Internet about this profession, which plays a crucial role in modern economic development. On the one hand, existing myths cause great interest in this career due to the possibility of quickly finding a well-paid job, often remotely [4, 5]. On the other hand, they are discouraging—the work of an IT specialist is boring and repetitive, requires constant learning, requires specific psychophysical predispositions,

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 96–107, 2024.
https://doi.org/10.1007/978-3-031-78468-2_8

and is traditionally perceived as a domain including men only [6, 7]. Such opinions prevail on social media.

There are the public media, statistics, and specialist reports that influence opinions about a career in IT. These media warn against rapid and unpredictable changes in the industry [15, 20], the effects of the emergence of artificial intelligence tools, and the realities related to wages [11, 12]. The challenges of working in IT very often stem from a lack of understanding of organizational operations, the basics of accounting, issues related to business management, teamwork skills, the basics of marketing, etc., knowledge acquired not in technical studies but in economics or management [13, 16]. Statistics also indicate that thanks to such skills, the share of women in the IT industry ranges from 15–30% [3, 28]. Graduates of technical studies often lack these competencies, which can hinder their employment prospects in the IT sector [9, 10, 18]. According to estimates provided by the Polish Software Development Association (SoDA) and the Organization of IT Service Employers, there is currently a shortage of 250–300 thousand IT employees on the market [14]. Due to their lack or incomplete soft skills related to organizational analysis, project process management, project team management, business analytics, and the use of artificial intelligence systems, it is necessary to use the resources of specialists in these fields educated at universities specializing in economics and management. However, technical universities and industry associations may not fully acknowledge this as a viable solution due to the perceived competition.

There is currently no comprehensive research that adequately addresses the challenge of resolving the employment shortages in the IT sector in Poland. There are few studies considering the issue [19, 25, 26], and they mostly refer to random or cross-sectional studies on the topic and do not point to possible solutions.

So, we are primarily dealing with two opposing positions that externally determine the willingness to build an IT career among Generation Z students who are just entering the labor market in the fields of economics and management [6]. Despite the potential opportunities offered by education and training in economics and management, they are often overlooked in discussions about addressing the shortage of IT professionals in the Polish economy. This situation raises the following research questions (RQ):

RQ1: What conditions could encourage students to start a career in IT?

RQ2: What are the differences between university programs in the field of IT and the competence requirements of IT companies?

RQ3: What are the differences between opinions about a career in IT in different academic centers?

The main aim of this paper is to examine the opinions, interests, and expectations of surveyed students from selected faculties of the Polish universities: University A (University of Warsaw) and University B (University of Economics in Katowice) about potential future employment in IT and continuing a career in this field from a practical point of view. Additionally, the entire population was divided into respondents from both academic centers, and a comparative analysis was conducted to explore the differences between them. The following structure of the article was adopted to answer these questions and achieve the goal: The second section contains a literature review related to the topic of employment. The third part presents the research methodology, including the structure of the survey questionnaire, the research procedure, and the

research sample obtained from the two analyzed universities. The next section discusses the research results, focusing on differences between academic centers. The article ends with a summary, identification of limitations, and directions for future research in this area.

2 Literature Review

The dynamic development of the digital economy, accelerated by the experience gained during the COVID-19 pandemic, requires a constant and increasing supply of IT staff every year [23]. This analysis, conducted with a focus on Poland, aims to demonstrate that by meeting certain conditions, we can expect to bridge this gap with specialists in economics and management.

Students and graduates of these studies have soft competencies that go far beyond programming skills and cover knowledge of organizations and their information needs, process, and project management methodologies, including IT, basic competencies in the use of BI systems, team cooperation skills, knowledge of sociology and consumer psychology and marketing. These competencies can be used in the company's information analysis, design, substantive testing of IT systems, implementation of IT systems, enhancing their functionality/usability, and providing training for their effective use. Therefore, their skills complement those educated in the so-called IT fields. Given that economics and management studies already encompass the abovementioned areas, their graduates do not require additional training in this regard, contrary to the opinions of some within the IT sector.

IT specialists are a heterogeneous, diverse group of professionals, ranging from hardware or standard software specialists to knowledge analysts [9]. The situation is changing very quickly [17], and keeping up with this change requires not only various skills acquired during studies or specialized IT courses but also specific personal character traits. Programming requires an understanding of algorithmizing, self-discipline, and optimal time management. The extended formula of IT employees adds, above all, the ability to communicate well and cooperate with people (both in interpersonal communication and on the Internet), the ability to use modern IT solutions in the organization (including remote work), the ability to assess the profitability of these projects as well as change management [5].

The previously mentioned stereotypes, which were not always true, also contributed to publications from the beginning of the century, when the employee market prevailed in this field [15, 24]. According to this scheme, an IT specialist is an employee who prefers working independently, primarily communicates using a computer, and focuses mainly, if not exclusively, on technical solutions. This indicated a lack of social and adaptive competencies and teamwork skills [7, 8]. Currently, competencies necessary for this profession include soft skills [5], essential job-specific skills, and emotional and social intelligence. Social competencies encompassing different perspectives are required for proper communication, teamwork, and building relationships with clients. A strong relationship was also found between modern technology and the IT-educated workforce, along with a favorable relationship between technological changes and social skills [1, 2] Also, research has shown that, in general, growing IT competencies are a

significant advantage in the labor market [17]. In this context, Generation Z, just entering the labor market, has high digital competencies, and can manage time and change, while maintaining a balance between personal and professional life [2, 6]. Therefore, their expectations towards starting their career in IT are relatively high at the beginning [21]. This fact appears to reduce their sensitivity to media opinions and myths.

The introduction highlights the wide array of professions encompassed within the broad definition of the IT profession. Each profession within the IT field demands appropriate preparation through studies, specialized courses, training, etc. This necessitates universities and specialized training companies to continually adapt educational programs and study programs to the changing requirements and expectations of the labor market and engage economic experts to conduct classes for students. Moreover, all methods of increasing IT competencies should be supported by modern teaching methods: remote learning [22] or artificial intelligence methods [27]. The scope of academic research in the field of employment includes issues such as preparing students for distinguished professions having specialist skills and soft competencies, competencies in digital areas [14], or the ability to solve business problems [17].

However, there is currently a lack of research on the conditions that would encourage students of non-IT studies to pursue careers as IT specialists, continue in this field, and prepare for emerging IT professions soon to appear on the labor market. Similarly, there are no studies on the choice of a profession outside the mainstream specialties obtained at a given university. In particular, they do not specifically examine the awareness of students of management and economics that their competencies are sufficient to pursue a career in IT. Encouraging management and economics students to start a career as an IT specialist by making them aware of the positive features of this profession could alleviate the issues related to the shortage of IT specialists in the Polish economy.

This article aims to fill this research gap in the context of the proposed research questions with the following research methodology described further.

3 Research Methodology

3.1 Research Procedure

The procedure applied to address the research problem included the following stages: (1) the literature analysis and expert consultations on working conditions in the IT sector, (2) based on literature analysis and expert opinions, the construction of a survey questionnaire and its initial verification on a pilot student group in terms of comprehensibility and relevance of questions, (3) random selection of a research sample at both universities and conducting surveys using the Computer Assisted Web Interview (CAWI) method, (4) descriptive statistical analysis of the obtained results (mean, variance, standard deviation), (5) comparative analysis of the results obtained from both universities using urban/city and Euclidean distances, (6) formulating a research hypothesis about statistically significant differences between the studied environments and checking it using the F Snedecor test, (7) describing conclusions, limitations, and recommendations for future research directions.

A survey questionnaire was created based on the literature analysis, expert opinions, and pilot verification for data collection. The survey included a data sheet on the sample

demographics and covered eight sections related to: identifying respondents who are active in the labor market; their opinions on the benefits and drawbacks of starting a career as an IT specialist their preferences for working in this field; competencies required to perform the job and how to acquire them; students' ideas regarding starting a career in IT and the scope of responsibilities of a future IT specialist; competencies acquired at the university and those that should be supplemented there; financial expectations for individual positions related to IT; social, economic, and technological reasons for career changes of an IT specialist and, finally—professional changes in IT specialist work and the extent to which current basic development trends will prevail in future enterprises.

Consultations with a pilot group of thirty randomly selected students tested the comprehensibility and relevance of most of the questions. As a result, the questionnaire was reduced by five questions, the number of answer options in four questions was expanded and several previously used terms were changed to make them more understandable to the respondents. In its revised form, the survey contained twenty-one extensive, detailed, substantive questions and a data sheet of the research sample. All questions in the survey questionnaire were closed.

The collected data were made comparable by calculating the shares of respondents from each center relative to the total number, and their variance and standard deviation of data were examined.

3.2 Sample Characteristics

The research sample characteristics from two Polish universities are presented as University A and University B. The study employed convenient sampling and focused specifically on faculties associated with management and business informatics at the university level. The survey was carried out randomly across different year-study levels by asking student groups available at the time to complete the questionnaire.

The data were collected and categorized based on the respondents' places of residence. The sample covered over 480 people, mainly aged 19–35, i.e. the most active on the Internet and the best prepared in terms of IT competencies.

In general, based on the collected data, it can be stated that:

- on average, women predominate among all respondents—56%, men constitute 44% (University A—women 75%, men—25%; University B—women 37%, men—63%),
- the majority of respondents (82% on average) were aged 19 to 24 (89% University A, 82% University B the remaining respondents were aged 25 to over 34).
- due to age—64% of respondents have secondary, vocational education (mostly 78% University A), and 27% have a Bachelor's degree, incomplete higher education (mostly University B 33%), Only 9% of respondents have higher education,
- the majority (45%) of respondents come from cities with over 500,000 inhabitants. Inhabitants (University A 60%, University B 31%), 20%—from cities with 200–500 thousand inhabitants (6% from University A, 34% from University B), and only 15% on average from rural areas,
- most respondents assess their financial situation as good (average 53%) or very good (25%). Only 22% assess their financial situation as average, satisfactory, or poor.

All collected data were subject to reliability analysis in the form of Cronbach's α coefficient. For all assessment criteria, Cronbach's α coefficient indicates the internal consistency and reliability of the sample—in this case, the coefficient was greater than 0.78.

4 Research Findings

The results were divided into two groups: the identification of factors influencing students' employment in the IT sector and the identification of differences between knowledge from university programs, and the requirements of IT companies regarding competencies in the IT profession. In each group, differences in opinions resulting from the location of both surveyed universities were highlighted.

4.1 Identification of Factors Influencing Students' Employment in IT

The survey focused on identifying the requirements for pursuing a career as an IT specialist. Respondents had varying opinions on salary levels, remote work, skill acquisition, and continuous development. The results showed a significant emphasis (averaging at 27%) on high salaries, which showed a continuous upward trend. Interestingly, the responses in this category were almost identical across the two universities analyzed, ranging from 23% at University B to 31% at University A. University A students prioritized employment security the most, while University B students did not find it as crucial. The second most important factor was the possibility of remote work with an average of 21% (20% at University B to 22% at University A). The certainty of finding employment both now and in the future, came in third place with an average of 20% (ranging from 17% at University B to 23% at University A). These were the top three categories, with other factors such as flexible working hours (9%), opportunities for continuous development (6%), or acquiring new skills (almost 6%) being of less importance during these times of economic uncertainty. Regarding job preferences, certain factors like working with a great team, accelerated promotion possibilities unless it is connected with a pay increase, and choosing between human interaction or computer work are no longer the top priorities.

The differences in each of the two populations were relatively small (variance 0.6–1.2%), and the largest absolute differences reached 7–8% (urban distance 37%), which meant that no significant statistical differences were found in this category (Fcalculated $< F_{cr}$tabulated).

Regarding factors that discourage individuals from pursuing a career as an IT specialist, the distribution of responses is more even in this case. Nevertheless, in two universities, attention is drawn to high levels of stress during the implementation of urgent and non-traditional projects (at the level of 17%), contact mainly with the computer and/or via the network (from 6% at University B to 13% in University A), high competitiveness among co-workers (15% most in University B) and burdensome contacts with the client (14%). Equally minor differences occur concerning the following categories: lack of a fixed working time and workload pileups during the implementation

of urgent projects (9% each). The variance in the data collected from each university was relatively small (0.31%), as was the standard deviation (5.51%).

In the IT profession, the key factors encouraging people to build an IT career are remuneration and job security. The level of compensation for specific positions frequently impacts employment decisions within this industry. Below respondents' expectations regarding the level of remuneration for selected positions in the IT industry in which they would like to work are presented. Respondents consider the first position "safe" because it does not require direct contact with customers. Interestingly, respondents are even willing to accept lower remuneration for working primarily with computers (programmers, technical support, back office). However, if they have the necessary qualifications, 11–12% are willing to take the highest-paid positions, e.g. project team leader or project manager. The lack of appropriate qualifications and skills, resulting from a lack of professional experience rather than management theory, also influences their willingness to choose well-paid positions. Instead, they almost as often opt for roles with specialized requirements, such as designer, modification and development specialist, tester, or implementation expert. There are noticeable differences between the choices of respondents from both universities. Most students from University B (15%) pointed to options of positions including programmer, technical support, back office, and project team manager supervising a team of 5–15 persons (12%). For University A's students, the most attractive options were business analyst, systems analyst (14%), and, similarly to the University B—programmer, technical support, and back office (12%). Urban distance is 20%, mainly due to the almost 6% difference in opinions about becoming a business analyst or systems analyst. Euclidean distance reached 0.92%. Due to the small "internal" differentiation (equal distribution of responses), the variance in the cases of both universities is similar and the F Snedecor test does not indicate significant statistical differences in the responses.

4.2 Identification of Differences Between Knowledge from University Programs and the Requirements of IT Companies Regarding Competencies in the IT Profession

When considering a career as an IT specialist, many students believe that proficiency in office software is crucial. 31% of respondents who were asked about the competencies acquired during their studies in existing IT systems and related activities during their studies indicated proficiency in software such as text editors, spreadsheets, and databases. The second most common competency was in programming languages such as C#, Java, and VBA (16%), with a higher percentage (21%) among students at University B. The third most common competency was in subsystems of integrated systems (financial accounting, HRM, warehouse, procurement, and sales) at 9%. Additionally, around 10% of respondents had competencies in network services and business intelligence systems for reporting and analysis. However, many respondents lacked competencies that are essential for IT specialists, such as system analysis and design tools, project management tools, business process optimization tools, IT service management, and database and data warehouse management. These essential competencies have either been removed from curricula due to cost efficiencies at universities and the "Gowin Act" requirements to specify the majors' programs or postponed to later years of study

or postgraduate programs. This lack of targeted competencies may hinder students' career prospects in the early years of their studies. The data show significant variations in competencies among different universities, with the highest differentiation of 10.15% observed between University A and University B (variance 1.29%, standard deviation 11.37%). This variation is mainly due to differences in attitudes toward the ability to use office software, integrated systems, and programming knowledge.

Considering all the competencies analyzed in the study, the most wanted by employers were Business Intelligence Systems 14% (with a slight advantage of University A at 19%), followed by *learning programming languages* (14%). Additionally, an average of 9% of respondents expressed interest in *modifying and developing applications* (programming) and *implementing and integrating applications in a cloud computing environment*. As a result, the question arises: if students hold a low opinion of their universities' role in acquiring IT competencies, what specific competencies do they seek, considering the differences between universities' programs and employers' preferences in the IT sector? There was a large variation in the responses of the University A students—the variance was 0.27% and the standard deviation was 5.21%. The absolute difference between the University A and University B universities was 49% for urban distance and the Euclidean distance of 1.51%. This was mainly due to differences in opinions on the implementation and integration of applications in cloud environments and comments on business process optimization tools.

Since the previous questions specified certain competency gaps, the next question provided a list of additional academic courses to choose from that, according to students, may be useful in their future work as IT specialists. Survey respondents admitted that these subjects were not adequately covered by their university. Five topics received over 10% of responses: human-computer interaction (average 14%), Business Intelligence systems—examining the value of information and its interpretation in business (11%), the use of mobile applications in society (m-commerce, m-marketing, m-location, etc.)—11%, business process modeling in IT projects (10%) and innovative IT banking systems and their use in business (10%). Surprisingly, the least expected topics were the use of games in business and teaching and coaching and communication in IT project management (3% each). There was a high differentiation in this category—urban distance 41%, Euclidean distance 0.92%, but the F Snedecor test did not show its statistical significance.

The practical skills are crucial for employment in IT but have unfortunately been neglected in some university courses in recent years. They should be reintroduced into the curricula of economic universities along with subjects in database management and design (an average of 10% and 14% at the University A). Theoretical knowledge in the field of information systems and their applications (on average almost 12%), as well as analysis and design of systems (on average almost 12% and 13% at the University A), were also important for respondents. In addition, knowledge of the latest IT products and their development was required on average at the level of 10%, and in the University B at 15%. It seems that the substantive content of lectures on the latest IT products is either outdated or insufficient. Non-specialist practical knowledge was also underestimated, such as time management of assigned and performed tasks and awareness of incomplete knowledge (3–7% on average). Respondents expressed that they had appropriate

knowledge of organizational and legal issues and the functioning of the economy. The most visible differences were observed between University A and University B, with an urban distance of 58% and an Euclidean distance of 1.71%, mainly due to a different approach to the skills of designing IT systems. In this situation, statistically significant differences were found: value FScalculated = 3.5932 > Fcrtabulated = 2.9782.

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5 Conclusion

This study examined students from Generation Z's awareness of the conditions for building and continuing a career as an IT specialist. The authors' goal was to examine the preparation of this generation to work in the IT industry. Additionally, they wanted to explore interregional differences. However, they are aware that other factors also influence the diversity of approaches to this topic. Universities in Poland have various organizational structures, which include institutes, faculties, specializations, and fields of study. They offer various types of studies - full-time, evening, and part-time studies, which can be conducted in Polish or a foreign language. Additionally, universities offer a variety of study programs featuring new specializations. Some subjects are removed from the study programs due to economic considerations if the university authorities do not consider them closely related to a given specialization. Universities' perceptions play a key role in determining which competencies are necessary for graduates to find work. Academic institutions try to analyze key trends in the labor market; they also consider and prioritize the study fields that are current, forward-looking, and critical to the country's future development. However, such perception is often burdened with a specific approach to science, in which the most important area for university authorities seems to be the area of research.

This analysis only encompasses some of the abovementioned issues because a direct, practical approach to this problem was preferred. Nevertheless, it seems that it may be interesting both for students looking for a job and a career path, for their potential employers, and for university authorities involved in updating study programs and bridging the knowledge gap essential for a career in IT. At the outset of the study, three research questions were posed. The survey content included options explaining what it is like to build a career in IT, and by choosing among them, students acquired knowledge about the wide range of job opportunities in IT, the associated benefits, and limitations.

Based on the research conducted, the answer to the first research question (RQ1) identifies the main factors encouraging people to work in IT (average 68% opinions): high wages with a rapid upward trend (27%), the possibility to work remotely (21%) and certainty of finding employment now and in the future (20%). Other factors, such as flexible working hours (9%), opportunities for continuous development (6%), and acquiring new skills (6%), are seen as much less important. At the same time, attention was paid to factors discouraging people from pursuing a career in IT, mainly: the high level of stress during the implementation of urgent and non-traditional projects (17%), inconvenience of contact with the customer (14%), and high competitiveness among colleagues (14%). Additionally, the study considered the first, most important factor encouraging a career in IT, i.e. the preferences of economics and management students regarding choosing positions and future careers that offer high salaries aligned with their competencies acquired during studies. First places in the ranking were taken by positions not directly involved in interacting with customers: programmer (average 13.5%) and those requiring knowledge in managing a small project team (average 11.5%). Further positions included business analyst, systems analyst, project manager, (team up to 50 individuals), or network security specialist. Wages for these positions are 2–4 times higher than the average wage in Poland.

The answer to RQ2 comes down to the following conclusions of the competencies. The university programs included mainly basic skills related to the use of office software. However, these are competencies currently needed to work in every sector, not only in the IT sector, broadly understood programming skills and practical skills in operating subsystems of integrated systems came in second place, and from the point of view of future employers, competencies in the field of Business Intelligence Systems, followed by learning programming languages, are currently in first place. Additionally, interest in modifying and developing applications (programming), and implementing and integrating applications in a cloud computing environment was presented slightly lower. Therefore, students aware of the shortcomings of university education to become IT workers would see university programs expanded, mainly by five types of training: human-computer interaction (average 14%), Business Intelligence systems—examining the value of information and its interpretation in business (11%), the use of mobile applications in society (m-commerce, m-marketing, m-location, etc.)—11%, business process modeling in IT projects (10%) and he practical skills crucial for employment in innovative IT banking systems and their business applications (10%).

RQ3 was answered after analyzing the results of the remaining two research areas. The basic differences between the opinions of students at University A and University B were in the following areas: factors encouraging people to work in IT, factors discouraging respondents from taking up a career as an IT specialist, respondents' expectations regarding the level of remuneration for selected positions in the IT industry, the competencies acquired during their studies, the competencies most wanted by employers, the differences in the practical skills, crucial for employment in IT, and list of academic courses useful for a career in IT.

There were some limitations in the study. First, the survey included only two universities, elsewhere they were diverse enough to draw general conclusions. Second, the survey only looked at location diversity. Third, the study did not consider the opinions

of foreign students and potential foreign partners. Fourth, the results were categorized by demographics such as gender, place of residence, employment status, etc. Lastly, the research did not determine the type and year of studies—respondents were randomly selected from the entire student population of two universities. These limitations suggest possible areas for future research. To carry out this research, data collection would need to be extended to other universities, the survey structure would need to be adjusted, and research partnerships would need to be established with universities outside of Poland. Additionally, future research plans to address cultural and organizational challenges that may address flexible software development and delivery practices (DevOps). The authors plan to pursue these avenues step-by-step, hoping to contribute to improving and developing the IT job market in Poland.

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Artificial Intelligence as a Factor in Career Development in Musical Art: Case of Students of the Academy of Art in Szczecin

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Abstract. The intersection of artificial intelligence (AI) and the arts is increasingly becoming a fertile ground for innovation and career development, particularly within the realm of musical art. This paper investigates the role of artificial intelligence as a catalyst for career advancement among students at the Academy of Art in Szczecin, exploring how emerging technologies are reshaping educational paradigms and professional trajectories in the field of music.

Keywords: Artificial Intelligence · Music Education · Career Development

1 Introduction

The integration of Artificial Intelligence (AI) into various fields has led to groundbreaking advancements, and the realm of musical art is no exception. In the context of higher education and professional development, AI presents unique opportunities and challenges, particularly for students pursuing careers in music. This paper focusses on the role of AI as a transformative factor in the career development of students at the Academy of Art in Szczecin, examining how AI technologies are reshaping educational practices and expanding career prospects in the field of musical art.

Artificial intelligence, with its capabilities in machine learning, neural networks, and data analytics, offers innovative tools for music education and performance. These technologies can create personalised learning environments, enhance the composition process, and provide sophisticated analysis of musical performances. Using AI, students can accelerate their learning, explore new creative avenues, and produce high-quality music with greater efficiency.

The application of AI in music education includes intelligent tutoring systems that adapt to individual learning styles, providing tailored feedback and practice recommendations. AI-powered composition tools assist students in generating new works, analysing existing musical patterns, and experimenting with different styles and genres. Additionally, AI's impact on performance and production allows for real-time feedback during practice sessions and streamlines the editing and mastering processes in music production.

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 108–122, 2024.
https://doi.org/10.1007/978-3-031-78468-2_9

This article will delve into the specific ways AI is being utilised by music students at the Academy of Art in Szczecin, highlighting case studies and examples of AI-enhanced learning and creativity. It will also explore the broader implications of AI proficiency for career opportunities, emphasising how familiarity with AI technologies can improve employability and open up new career paths in the evolving music industry.

However, the integration of AI in music education is not without its challenges. Concerns about the potential loss of traditional skills, ethical considerations of AI-generated art, and the necessity for comprehensive AI training are critical issues that need to be addressed. This article will discuss these challenges and offer strategies to ensure that the incorporation of AI in music education enriches rather than undermines the artistic and educational experience.

In conclusion, AI has significant potential to revolutionise the career development of music students by enhancing their educational experience and expanding their professional opportunities. As the field of musical art continues to evolve, embracing AI technologies will be essential for students to remain competitive and innovative in their careers.

2 Literature Review

Artificial intelligence (AI) has been increasingly integrated into various fields, including music education, to improve teaching methods and learning outcomes. Roll & Wylie [1] discussed the evolution and revolution of AI in education, highlighting how the scope of education has expanded to include workplace training and informal learning, indicating a shift towards more personalized and adaptive learning experiences. Wang [2] emphasised the potential of AI to transform music major teaching platforms, suggesting that AI will bring about significant changes in teaching methods and theories in music education. Miranda [3] explored the domain theories used in AI in music education, underscoring the power of AI in enhancing music learning processes through critical reviews and theoretical frameworks.

Furthermore, Tiancheng & Nazir [4] provided a comprehensive overview of AI-enabled music classification and its impact on educational practices, demonstrating how AI can effectively support music teaching and learning through advanced classification methods. Chu [5] further explored the construction of AI music teaching application models using deep learning, illustrating the growing trend of integrating AI technology into music education to develop innovative teaching approaches and tools.

Furthermore, Yang [6] highlighted the potential of AI teaching systems to engage students in classical music education through online platforms, suggesting that AI can stimulate students' interest in music studies by offering a more interactive and personalised learning experience. Zheng and Zheng & Dai [7] focused on the construction and optimisation of AI-assisted interactive college music performance teaching systems, indicating a shift toward more interactive and engaging music education practices supported by AI technologies. These studies collectively underscore the transformative role of AI in reshaping music education by offering personalised, interactive, and innovative learning experiences that meet the diverse needs of students.

Furthermore, Dai [8] emphasised the importance of AI technology in designing intelligent music teaching systems, highlighting the integration of high technology and

educational science to create more effective and efficient music education platforms. Sturm et al. [9, 10] emphasised the importance of machine learning and AI in music creation, showcasing the advanced applications of AI in the generation of music compositions and improving creative processes. The research highlighted the advanced stage of AI development in music creation, indicating a promising future for AI integration in musical art and education.

In conclusion, the integration of AI in music education represents a significant advance in improving teaching methodologies, improving learning outcomes, and fostering creativity and innovation in musical art. Using AI technologies, educators can provide personalised and interactive learning experiences that cater to the individual needs and preferences of students, ultimately transforming the landscape of music education and career development in the digital age.

3 Materials and Methods

3.1 Survey Design and Participant Selection

The study utilised a meticulously crafted questionnaire aimed at collecting data on the perspectives and attitudes of music students regarding the integration of artificial intelligence (AI) into their educational and professional spheres. The survey was specifically designed to explore various facets of AI's impact on music education and its potential to influence the career trajectories of students.

The questionnaire comprised ten multiple-choice questions that addressed different dimensions of AI's influence on the arts. The questions were structured to gather comprehensive insights into students' familiarity with AI, their evaluation of AI-based art projects, ethical considerations, and their expectations for AI's future role in the arts.

3.2 Questionnaire Structure

The ten questions included in the survey were as follows:

1. Familiarity with the possibilities of using AI for cultural and arts activities.
2. Evaluation of art projects using AI.
3. The impact of AI on the human aspect of artistic processes.
4. Aesthetic considerations of AI-created art.
5. The potential of robots to take over tasks traditionally performed by artists.
6. Exclusivity of creativity to humans.
7. The competitive potential of AI art projects compared to contemporary human art.
8. Future competition between AI and human art projects.
9. The necessity of legal control over AI in artistic activities.
10. Areas of art most likely to progress the fastest due to AI advancements.

3.3 Data Collection

Data were collected from students at the Academy of Art in Szczecin through an online survey platform. The survey link was distributed through the academy's internal communication channels to ensure broad participation. A total of 102 students completed the survey, which provided a robust dataset for analysis.

The survey was available for two weeks, during which students were periodically reminded to participate. This approach helped to achieve a high response rate, ensuring that the data collected was representative of the student body.

3.4 Methodology

Data analysis was performed using descriptive statistics to summarise the survey responses. Each response was classified and quantified to identify trends and significant patterns in students' attitudes toward AI in music education. The use of statistical software facilitated accurate data processing and visualisation, making it easier to interpret results and draw meaningful conclusions.

Statistical analysis included calculating frequencies and percentages for each response option, providing a clear and concise overview of the general sentiment toward AI integration in music education. Additionally, cross-tabulations were conducted to explore potential correlations between different variables [11, 12].

3.5 Ethical Considerations

Ethical guidelines were rigorously followed throughout the study to ensure the confidentiality and integrity of the participant data. Informed consent was obtained from all participants before they participated in the survey. They were assured that their responses would be anonymised and used exclusively for research purposes. This was crucial in fostering an environment in which students felt comfortable sharing their honest opinions without fear of repercussion.

Ethical considerations also included providing participants with a clear understanding of the objectives of the study, the voluntary nature of their participation, and the measures taken to protect their privacy. These steps were in line with standard research ethics protocols, which emphasise transparency, respect for participants, and responsible handling of data [13].

3.6 Tools and Software

To ensure the accuracy and efficiency of data analysis, statistical software such as SPSS or R was employed. These tools enabled researchers to perform comprehensive statistical analyses, including descriptive statistics, cross-tabulations, and graphical representations of the data. The use of such software ensured that data processing was robust and reliable, facilitating a detailed examination of the survey results.

This methodological approach provided a solid foundation for understanding current perceptions and potential future impacts of AI on music education among students at the Academy of Art in Szczecin. The insights derived from this survey contribute to a broader discourse on the integration of AI in creative and educational settings, highlighting both opportunities and challenges.

4 Results

The survey results provide a comprehensive overview of music students' perceptions and attitudes towards the integration of Artificial Intelligence (AI) in the arts. This section presents the findings of the survey, highlighting key trends and insights derived from the responses to each question.

Question 1: Are you familiar with the possibilities of using AI for cultural and arts activities?
This question aims to assess the level of awareness among students about the application of AI in cultural and arts activities. Understanding their familiarity with AI technologies provides insight into their exposure and readiness to integrate these tools into their artistic practices (Fig. 1).

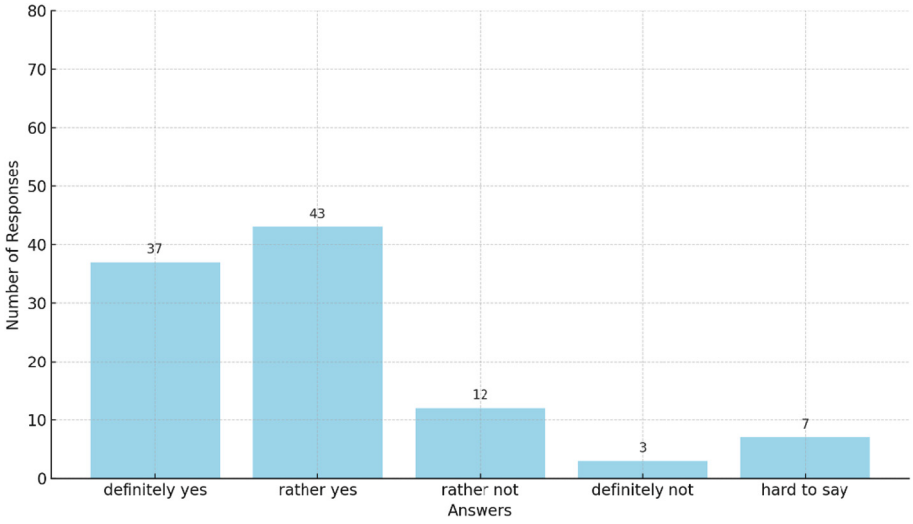


Fig. 1. Question 1: Are you familiar with the possibilities of using AI for cultural and arts activities?

The majority of students (approximately 78%) are familiar with the possibilities of using AI in cultural and arts activities, with 37 respondents indicating "definitely yes" and 43 indicating "rather yes." This suggests a high level of awareness and exposure to AI technologies among students. Only a small fraction (around 3%) are completely unfamiliar with these possibilities, indicating that AI is a well-recognised tool within this academic community.

Question 2: How do you rate art projects using artificial intelligence?
This question evaluates students' opinions on the quality and effectiveness of art projects that utilise AI. Their ratings offer valuable feedback on the current state of AI-driven art and its reception within the academic community (Fig. 2).

Art projects using AI are generally well received among the students. A significant portion (around 71%) rated these projects as either "perfect" or "reasonably good."

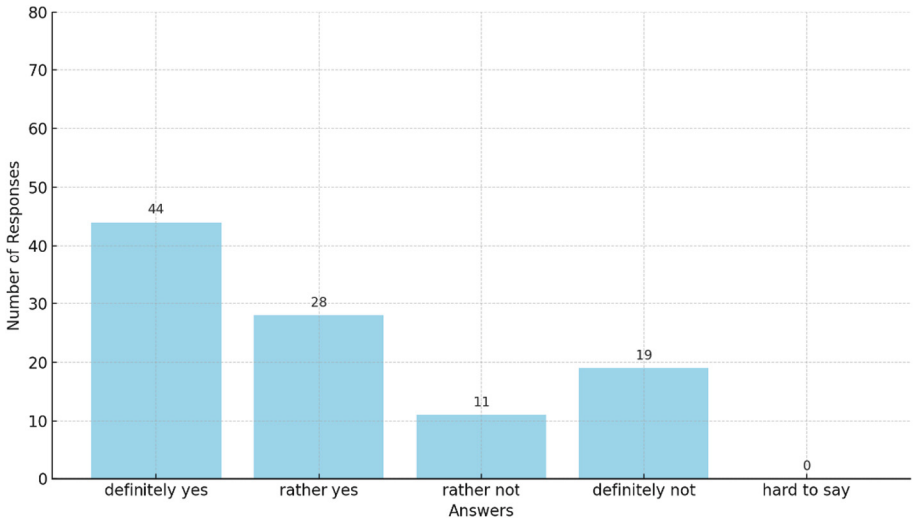


Fig. 2. Question 2: How do you rate art projects using artificial intelligence?

This positive reception indicates that students appreciate the quality and potential of AI-generated art. However, there is a notable minority (approximately 19%) that rates these projects as "rather weak," suggesting that there is still room for improvement and that some students might have reservations about the current state of AI art projects.

Question 3: Does AI replace the human subject by influencing artistic processes which problematises the issue of the possibility of development through art?
This question explores the students' views on whether AI influences and potentially replaces the human element in artistic processes. It seeks to understand their concerns about the impact of AI on human creativity and artistic development (Fig. 3).

Opinions are divided on whether AI replaces the human subject in artistic processes. While a combined total of 59 students (around 58%) believe that AI does influence and potentially replace the human element to some degree ("definitely yes" or "rather yes"), a comparable number of respondents (39, approximately 38%) think otherwise ("rather not" or "definitely not"). This division reflects ongoing debates about the role of AI in art and its implications for human creativity and development in artistic fields. There is also a small group (4%) that remains undecided, indicating the complexity and nuance of this issue.

Question 4: Can robots that become creators be considered in terms of aesthetic issues that belong to the world of art?
This question investigates the perceptions of students about whether robotic creations can be assessed through an artistic and aesthetic lens. The inquiry delves into how emerging technologies shape traditional notions of creativity and artistic standards (Fig. 4).

The majority of students (approximately 65%) do not consider robots as legitimate creators in terms of aesthetic issues in the art world, with 66 respondents indicating "rather not" and 1 indicating "definitely not." Only a small fraction (approximately

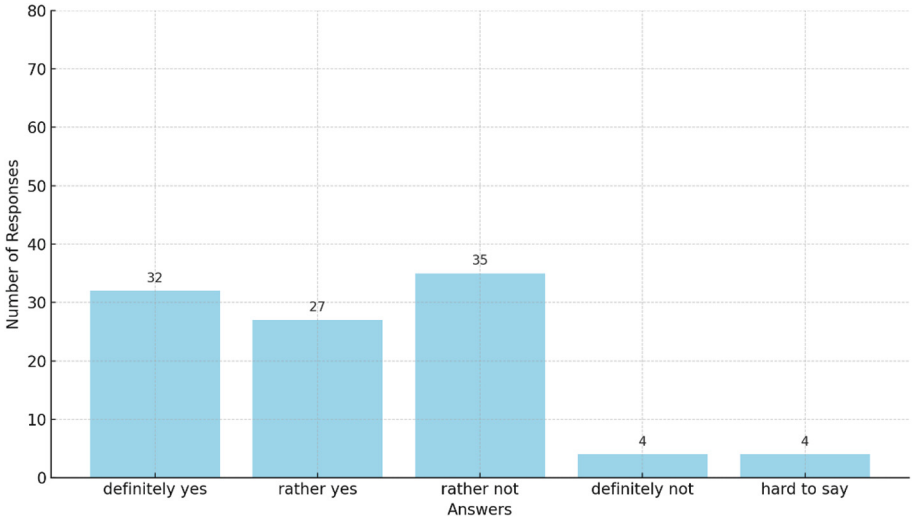


Fig. 3. Question 3: Does AI replace the human subject by influencing artistic processes which problematises the issue of the possibility of development through art?

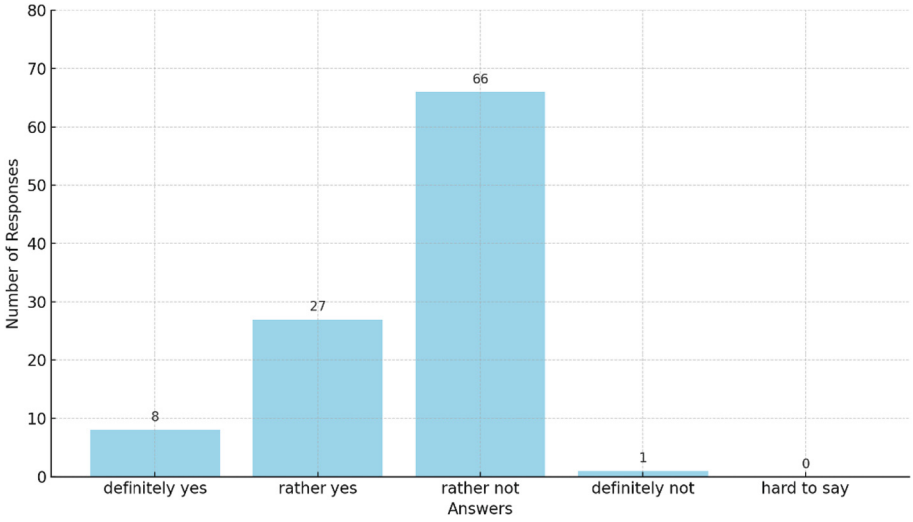


Fig. 4. Question 4: Can robots that become creators be considered in terms of aesthetic issues that belong to the world of art?

34%) believes that robots can be considered in aesthetic terms, suggesting significant scepticism about the artistic validity of robotic creations.

Question 5: Do you think robots can take on tasks that artists have performed so far?
This question addresses the potential for robots to assume roles traditionally reserved for human artists. It explores the evolving landscape of artistic production influenced by advances in artificial intelligence and robotics (Fig. 5).

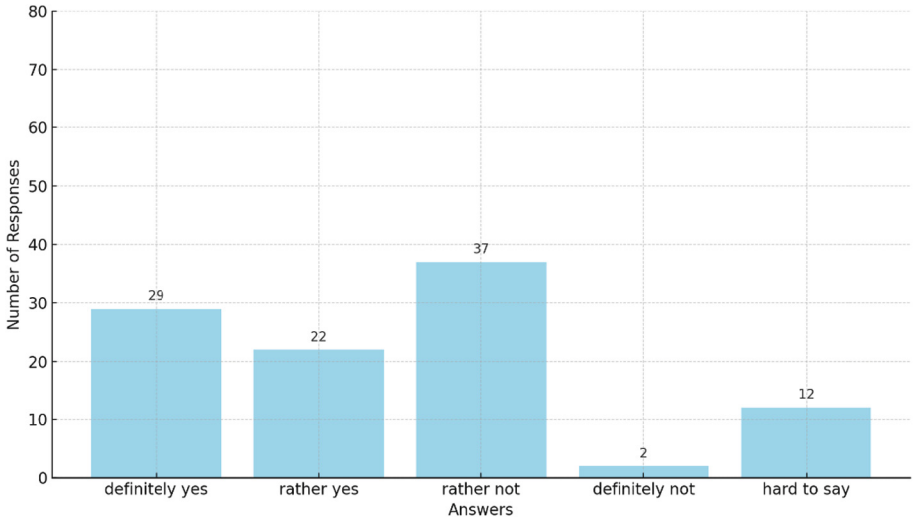


Fig. 5. Question 5: Do you think robots can take on tasks that artists have performed so far?

Opinions are varied regarding robots taking on tasks traditionally performed by artists. While 29 respondents (approximately 28%) believe robots can definitely take on these tasks, 37 respondents (approximately 36%) are sceptical ("rather not"). This distribution highlights mixed feelings among students about the capabilities of robots in artistic roles, indicating a need for further exploration and demonstration of robotic abilities in the arts.

Question 6: Are creativity and creativity features reserved exclusively for humans?
This question seeks to understand student opinions on the exclusivity of creativity to the human experience. Examines the broader implications of AI and machine learning in fields traditionally dominated by human cognitive processes (Fig. 6).

A significant majority of students (approximately 84%) believe that creativity is a feature reserved exclusively for humans, with 68 respondents indicating "definitely yes" and 18 indicating "rather yes." Only a small minority (approximately 7%) disagrees, suggesting that students largely view creativity as an inherently human trait, highlighting the perceived uniqueness of human creative processes.

Question 7: Can art projects using AI compete with contemporary artists' art projects today?
This question examines the competitive nature between AI-generated art and traditional art created by contemporary artists. Assesses student perceptions of the quality and impact of AI in the current art scene (Fig. 7).

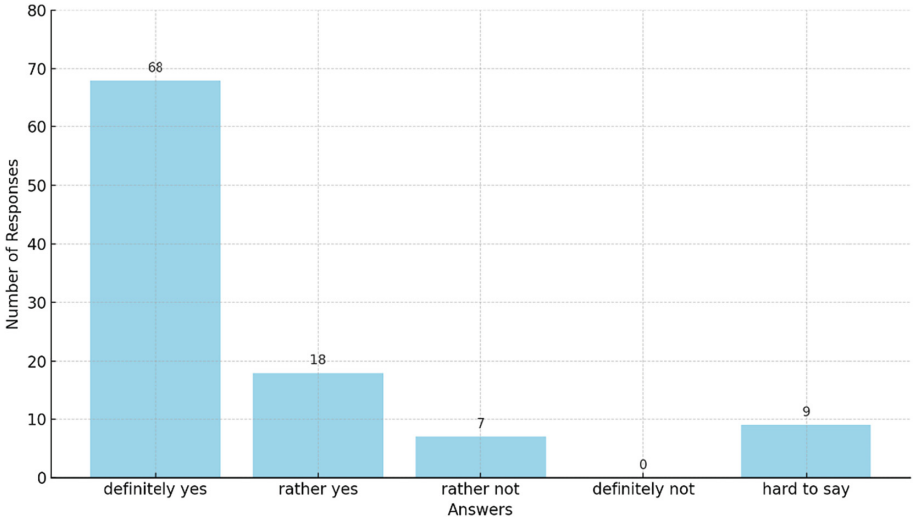


Fig. 6. Question 6: Are creativity and creativity features reserved exclusively for humans?

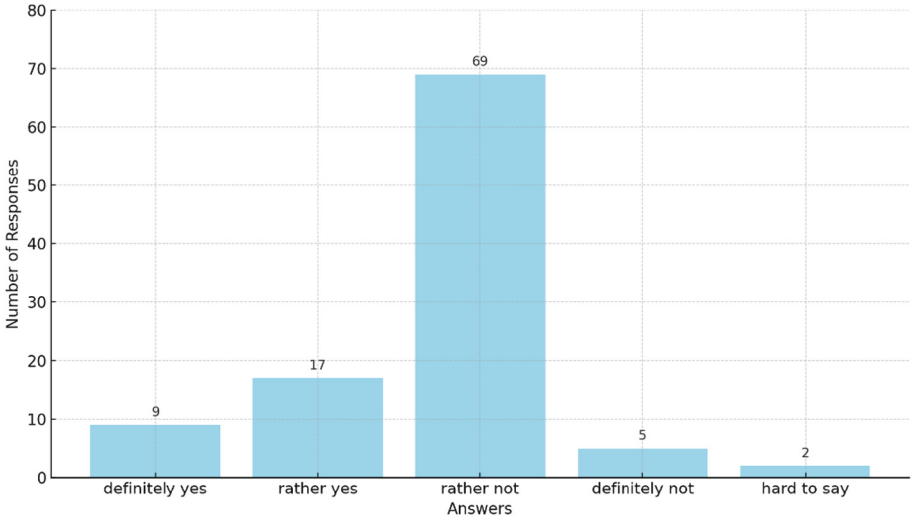


Fig. 7. Question 7: Can art projects using AI compete with contemporary artists' art projects today?

A significant majority of the students (74 responses out of 102) believe that AI art projects cannot currently compete with those created by contemporary human artists. This sentiment is strongly highlighted by the 69 responses that opt for "rather not" and 5 for "definitely not". Only a minority, 26 students combined ("definitely yes" and "rather yes"), see AI as a competitive force in the current art landscape. This reflects a cautious

or sceptical view of AI's current capabilities in matching or surpassing human artistic creativity.

Question 8: Will art projects that use AI compete with human art projects in the future?

This question explores future perspectives on the potential for AI-driven art to compete with human-created art. It looks ahead to gauge expectations about the evolution of AI in the artistic domain (Fig. 8).

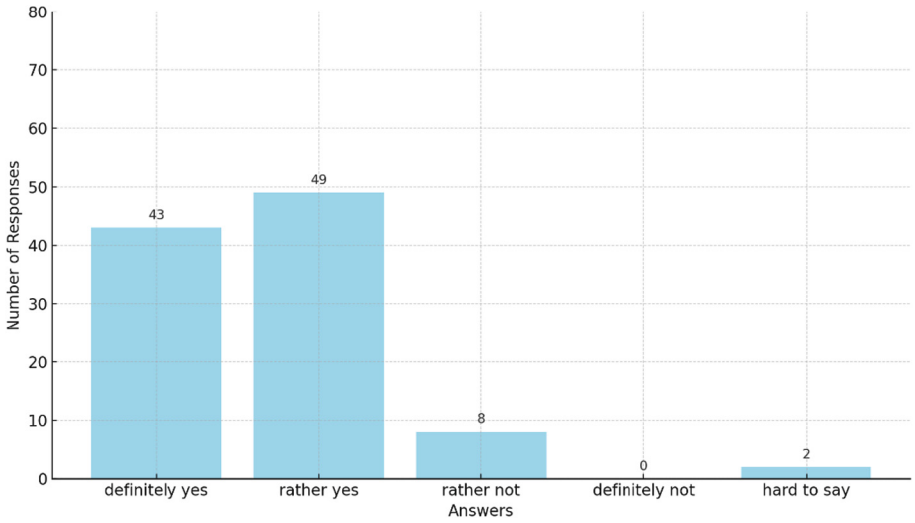


Fig. 8. Question 8: Will art projects that use AI compete with human art projects in the future?

The future seems more promising for AI in the arts, with 92 students expressing some degree of optimism ("definitely yes" and "rather yes") about AI competing with human art projects. This optimistic outlook contrasts with only 8 responses for "rather not" and none for "definitely not", suggesting that students anticipate significant advancements in AI that could level the playing field between human- and AI-generated art.

Question 9: Should the use of AI for artistic activities be limited and controlled by the legal system?

This question addresses the ethical and regulatory considerations of using AI in art. It queries whether there should be legal limitations or controls over AI's application in artistic activities (Fig. 9).

A clear majority (76 out of 102) supports the idea of legal regulations governing the use of AI in art, as shown by the responses for "definitely yes" and "rather yes". This indicates a strong concern among students about the implications of unregulated use of artificial intelligence in the arts, highlighting issues related to copyright, creativity rights, and ethical use of technology.

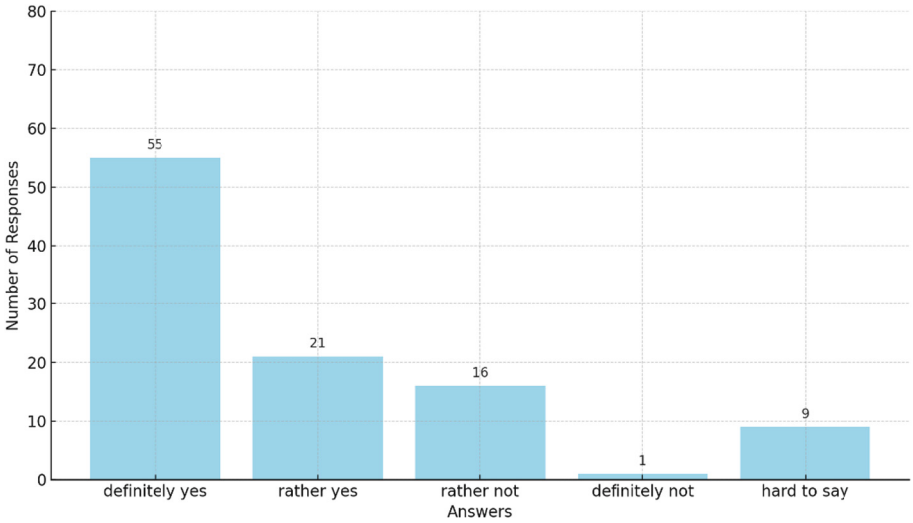


Fig. 9. Question 9: Should the use of AI for artistic activities be limited and controlled by the legal system?

Question 10: In what areas of art do you think the development of AI will progress the fastest?

This question seeks insights into which art forms students believe will be most influenced or transformed by AI technologies in the near future (Fig. 10).

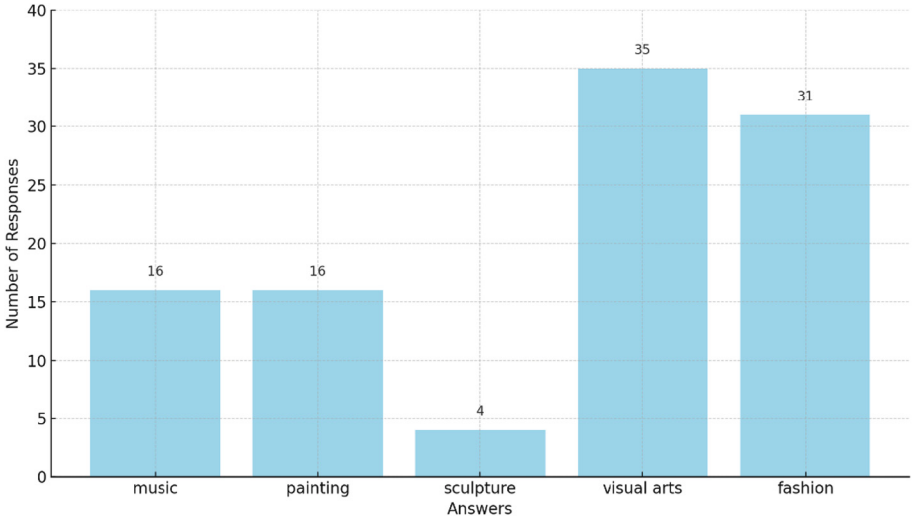


Fig. 10. Question 10: In what areas of art do you think the development of AI will progress the fastest?

Visual arts (35 responses) and fashion (31 responses) are perceived as the fields where AI will make the fastest advances, suggesting that these areas are perceived as more amenable to digital and technological integration. Music and painting also show considerable expectations for AI integration, reflecting a broader view that AI will impact various facets of artistic expression.

5 Discussion

The survey conducted at the Academy of Art in Szczecin reveals a cautious but evolving perception among students towards the integration of AI in artistic domains. This aligns with scholarly findings that suggest that AI can significantly enhance human creativity, particularly by facilitating novel and innovative artistic expressions. The research highlights how generative AI systems, like those discussed by Eric Zhou and Dokyun Lee, have begun to augment human creativity in producing digital artworks, increasing both productivity and the novelty of content produced. Such systems allow artists to explore new creative workflows, leading to a harmonious blend of human exploration and AI exploitation, which has been termed "generative synaesthesia" [14].

Furthermore, our findings that a significant portion of students support regulatory oversight on AI in the arts mirror broader academic concerns regarding the ethical and practical implications of AI in creative fields. The study by Mazzone and Elgammal underscores the necessity of a balanced approach where AI complements rather than replaces human creativity. They advocate AI as a tool that can expand creative capacities while maintaining the essential human elements of emotional and social context in art making. This perspective is vital as it emphasises the partnership between human and machine creativity, ensuring that technological advancements serve to enhance rather than undermine artistic integrity [15].

Additionally, the application of AI in music education, as discussed by Guo, Ding, and Zang, shows promising results in improving learning outcomes through innovative teaching methods such as AI-based flipped classrooms. This method not only optimises the usage of the wireless network, but also significantly improves the participation and understanding of music theory and practice of the students [16]. Such findings are crucial because they highlight the practical benefits of integrating AI into educational frameworks, providing a more personalised and efficient learning experience. This evolving landscape indicates that while AI has transformative potential, its successful integration requires careful consideration of ethical guidelines and a focus on maintaining the unique aspects of human creativity.

6 Conclusions

The integration of artificial intelligence (AI) into the field of music and arts presents a dynamic landscape filled with both promising opportunities and significant challenges. Our comprehensive survey at the Szczecin Academy of Art reveals nuanced perspectives among students, reflecting broader trends and concerns that are shaping the future of AI in creative domains.

6.1 Awareness and Familiarity

A significant majority of students at the Academy are aware of AI's potential applications in the arts. This familiarity underscores a critical shift in the educational landscape, where future artists are increasingly aware of technological advances. This awareness is essential because it prepares students to navigate and harness AI tools effectively in their creative endeavours. However, the survey also highlights the need for deeper understanding and practical exposure, suggesting that educational institutions should integrate more AI-focused modules into their curricula to bridge this knowledge gap.

6.2 Evaluation of AI Art Projects

The students' evaluation of AI-generated art projects reveals a generally positive reception, with many recognising the quality and innovation that AI can bring to artistic creation. However, there is a notable contingent that remains critical of AI art, viewing it as inferior to human-created works. This dichotomy suggests that while AI has made significant strides, it has not yet fully captured the nuances and depth of human creativity. Mixed reviews point to the importance of continued refinement of AI algorithms to enhance their creative outputs and better mimic the complexity of human artistic expression.

6.3 Ethical and Practical Concerns

One of the most compelling findings of our survey is students' concern about the ethical implications of artificial intelligence in the arts. A substantial majority supports the idea of regulatory oversight to ensure that AI's use in artistic activities remains ethical and fair. This sentiment reflects broader social concerns about the implications of AI on creativity, authorship, and intellectual property. Students' advocacy for regulations underscores the need for clear guidelines and policies that protect human creativity while fostering innovation. This balance is crucial to prevent the potential misuse of AI technologies and to ensure that they augment rather than undermine human artistic efforts.

6.4 AI in Educational Practices

The application of AI in educational settings, particularly in music education, has shown promising results. AI-driven tools, such as intelligent tutoring systems and AI-based flipped classrooms, have improved learning outcomes by providing personalised feedback and creating immersive learning environments. These advances suggest that artificial intelligence can play a pivotal role in education, offering students customised learning experiences that address their unique strengths and weaknesses. However, it is essential to maintain a balance between AI tools and traditional teaching methods to preserve fundamental skills and ensure a holistic education.

6.5 Future Prospects and Challenges

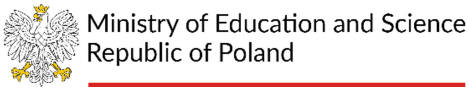
Looking ahead, the potential for AI to transform the arts is immense. Students at the Academy are optimistic about AI's future role, anticipating that AI-driven art projects will eventually compete on equal footing with human-created works. This optimism is tempered by a recognition of the challenges that lie ahead, including the need to preserve the unique qualities of human creativity and the potential for AI to saturate the market with less original content. The future of AI in the arts will likely be shaped by how effectively these challenges are addressed and how well AI technologies are integrated into creative processes.

6.6 Interdisciplinary Opportunities

The interdisciplinary nature of AI opens up new career paths for students, combining art with fields such as computer science, cognitive science, and data analytics. These interdisciplinary skills are increasingly valuable in today's job market, providing students with broader career opportunities. The ability to leverage AI for creative purposes not only enhances employability, but also positions students at the forefront of innovation in their respective fields.

In conclusion, the integration of AI into the arts is a transformative development that holds significant promise in enhancing creativity and expanding career opportunities for students. The insights from our survey highlight both the potential benefits and the challenges associated with this integration. As AI continues to evolve, it is crucial for educational institutions, policymakers, and artists to collaborate to shape an environment that fosters innovation while preserving the essential elements of human creativity. By embracing AI technologies thoughtfully and ethically, the next generation of artists can harness the power of AI to push the boundaries of artistic expression and achieve new heights in their creative pursuits.

Acknowledgments. Co-financed by the Minister of Science under the "Regional Excellence Initiative" Program RID/SP/0046/2024/01.



Disclosure of Interests The authors have no competing interests to declare that are relevant to the content of this article.

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Artificial Intelligence in Medical Field—Practical Observations from the Perspective of Medical University

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Abstract. The implementation of artificial intelligence (AI) in the medical field promises significant benefits, including increased diagnostic accuracy, better patient outcomes, and streamlined healthcare processes. The article delves into the initial stages and obstacles encountered in the practical application of AI in medicine, drawing on the experience of the Medical University of Wrocław (WMU) and the Wrocław University of Economics (WUEB). The aim of the article is to describe the main reasons determining the need to digitize information resources used by medical entities such as hospitals and academic centers in order to share knowledge and provide innovative solutions. It discusses the emergence of digital medicine centers and the methodologies used to create them, shedding light on the multifaceted nature of medical data, including electronic health records, biobank repositories, and clinical trial datasets. Against this background, the possibility of using artificial intelligence methods was shown. The article has been prepared using research methods such as literature analysis, available reports and project guidelines, and the qualitative methods like a analysis of documentation, analysis of IT solutions, interviews with project participants, participatory observations and analysis of the studied case study. This paper provides invaluable insights and recommendations for institutions starting to implement AI in a medical context, highlighting the importance of interdisciplinary collaboration, meticulous data analysis, and a comprehensive strategy.

Keywords: Artificial Intelligence (AI) · Medical data · Biobank · Electronic health records · Digital medicine

1 Introduction

The aim of this article is to delineate the foundational steps necessary for the pragmatic implementation of Artificial Intelligence (AI) in the medical domain, taking into account its inherent challenges.

The literature analysis presented in this article, as well as the authors' experience, indicate that a significant research gap are examples of integrated IT solutions using

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 123–135, 2024.
https://doi.org/10.1007/978-3-031-78468-2_10

artificial intelligence in consortia of medical entities, which include research units such as universities, medical entities such as teaching hospitals and specialist clinics, and supporting entities such as biobanks.

Commencing with an introduction, we elucidate the advantages of integrating AI into medical practice, drawing from our personal experiences garnered during interdisciplinary training in medical data science across academic institutions.

Subsequently, we delve into the establishment of digital medicine centers within the purview of university funding, outlining the strategic methodology for executing such initiatives, particularly within the context of WMU.

The article discusses the causes and difficulties that arise in the process of establishing digital medicine centers. The methodological approach used to their development will be presented, shedding light on the multifaceted nature of medical data, including electronic health records, biobank repositories and clinical trial datasets. Notable observations highlight the need to standardize, digitize, and combine these diverse data streams. The introduction of Regional Digital Medicine Centers (RDMCs) in Poland is seen as a strategic venture to accelerate the integration of artificial intelligence in healthcare. This paper provides invaluable insights and recommendations for institutions starting to implement AI in a medical context, highlighting the importance of interdisciplinary collaboration, meticulous data analysis, and a comprehensive strategy. The findings highlight both the promise and obstacles of using AI in medicine, advocating for sustained research and advancement in this dynamic field.

Our discourse then shifts towards explaining key observations about the characterization of medical data, including its diverse origins, formats, levels of digitization, and quality. These aspects are indispensable factors for planning the digitalization of medical resources, laying the foundation for the integration of AI in clinical and scientific domains. In addition, we examine strategies for organizing resources using IT infrastructure.

At the end of the article, we present a concise discussion, summarize the key conclusions and propose directions for future research and implementation projects.

This article was created as a result of the use of qualitative research methods such as: analysis of documentation, analysis of IT solutions, interviews with project participants, participatory observations and analysis of the studied case study.

2 Theoretical Background

2.1 Artificial Intelligence in Medicine—What Are the Benefits?

Artificial intelligence (AI) in medicine is advancing rapidly [1–3]. The scope of AI applications is expanding, with AI algorithms increasingly supporting diverse medical fields [4–7]. Daily, new scientific publications emerge, detailing novel AI applications, evaluating their efficacy, and underscoring the benefits for both patients and the healthcare system [11–14]. For example, AI has significantly impacted various surgical specialties, including general surgery, ophthalmology, cardiothoracic surgery, and vascular surgery [8–10]. AI enhances diagnostic processes, particularly in imaging studies, and facilitates data-driven insights, proving valuable in epidemiology and preventive medicine

[19–24]. The range of benefits is extensive, prompting a growing number of healthcare institutions to adopt AI technologies [17, 18].

2.2 The Experiences of Medical University

Between 2020 and 2022, Wroclaw Medical University (WMU) collaborated with the Wroclaw University of Economics and Business (WUEB) on a three-year training initiative focused on the integration of data science in medicine, with cardiology serving as a primary exemplar. During this program, medical scientists were introduced to the potential utility of AI algorithms in analyzing clinical data. Leveraging historical data, several experiments were conducted, notably demonstrating AI's capacity to assist in detecting the natural phenotypic heterogeneity among cardiac patients admitted for acute exacerbation of heart failure. Seasoned cardiologists have traditionally relied on their expertise and intuition to assess clinical severity and determine appropriate medical interventions, yet these insights often lacked quantifiable metrics. Our study aimed to bridge this gap by employing unsupervised machine learning techniques, specifically clustering, to analyze datasets encompassing 381 patients with acute heart failure (AHF) and 63 clinical and biochemical parameters. The resultant algorithm identified six distinct clusters characterized by significant differences in etiology, clinical presentation, comorbidities, laboratory findings, and lifestyle factors [15, 16]. These identified phenotypes hold considerable promise for informing future trial design and personalized treatment strategies.

Subsequently, our research endeavored to explore the behavioral patterns of cardiac patients, a critical aspect in enhancing patient education and fostering self-management skills in heart failure management. Utilizing the Multidimensional Health Locus of Control (MHLC) survey, administered to 758 patients across 11 Polish cardiology centers, we sought to predict patient behavior based on individual health-related beliefs. This survey assessed three dimensions of health beliefs: internal health control, external control by powerful others, and external control by chance. Analysis revealed nine distinct clusters, each representing varying combinations of these beliefs, with implications for patient engagement and adherence to medical recommendations. Additionally, our systematic review underscored the potential of predictive AI models in optimizing heart failure management, surpassing conventional risk scoring methodologies and offering promising avenues for enhancing clinical decision-making.

In summary, the burgeoning field of AI in medicine holds immense promise, as evidenced by global research endeavors and our own pioneering investigations leveraging scientific data. The challenge now lies in translating these findings into actionable strategies for AI implementation, particularly within clinical settings collaborating with academic institutions.

2.3 The Idea of Developing Regional Digital Medicine Centres

In 2023, the Medical Research Agency, a pivotal entity funding scientific endeavors in Poland, issued a call for proposals aimed at establishing Regional Digital Medicine Centers (RDMCs). These centers were conceptualized as hubs that would facilitate the integration of databases from various institutions, including universities, hospitals, and

biobanking facilities. Their primary objective is to standardize the collection and analysis of medical data while ensuring the secure sharing of this information. Tasks assigned to RDMCs encompass a wide array of responsibilities, such as the development, promotion, and implementation of intelligent AI-driven solutions. This includes the creation of digital tools such as prognostic, predictive, and therapeutic algorithms, which leverage clinical and omics datasets produced by the institution. Additionally, RDMCs are tasked with developing algorithms for drug dosage optimization and predicting the risk of adverse effects associated with drug combinations. They also support patient monitoring, treatment process management, data integration and analysis, treatment decision-making systems, and research and development endeavors in digital medicine.

An integral aspect of establishing these centers is the consideration of diverse data sources, as depicted in Fig. 1.

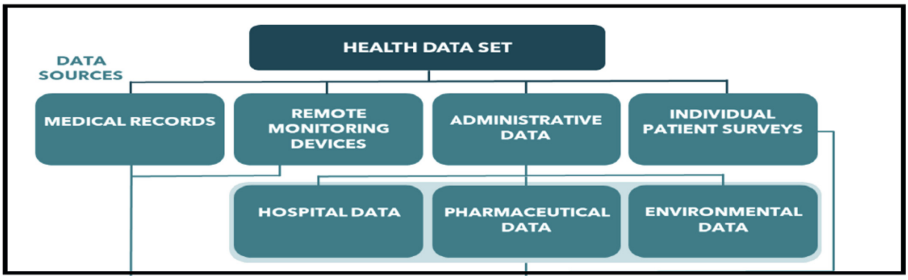

Fig. 1. Potential sources of data for the RDMC (graph copied from the official document provided by the Agency, 7) (*Source* own elaboration)

WMU spearheaded the consortium application, with WUEB joining as a pivotal partner, offering crucial expertise in consulting on the digitization process and the implementation of IT infrastructure and algorithms. Additionally, WUEB played a vital role in the recruitment and training of data science experts. The third partner in the consortium was a prominent clinical hospital with a close collaborative relationship with the University. The consortium's collective expertise and innovative proposals garnered significant recognition, resulting in the project being ranked as the top initiative in the country and securing substantial funding. Consequently, WMU and WUEB are poised to make substantial strides in the real-world implementation of AI in medical data over the next five years.

2.4 Ideas for AI Algorithms Used for Clinical Purposes as Part of RDMC Development

When strategizing the implementation of AI for medical applications, we predicated our approach on the utilization of specific algorithms. For instance, drawing from previous studies, our aim was to segment patients by considering multiple variables simultaneously, discerning clusters of patients with akin clinical attributes irrespective of the number of features analyzed concurrently. This capability is facilitated by clustering algorithms such as K-means or Gaussian Mixture Model (GMM). Additionally, we

envisaged employing neural networks to condense the data dimensionality and perform clustering based on feature maps, thereby unveiling clinical patterns to ascertain analogous patient subgroups.

Additionally, our plan involved leveraging predictive algorithms, such as logistic regression models, decision trees, neural networks, or Random Forest algorithms, to support clinical reasoning by accurately predicting the risk of complications or urgent events, such as hospitalization or patient mortality.

Moreover, we recognized the potential for algorithms to enhance diagnostics by reducing misdiagnoses. Classification and clustering methods, such as decision tree algorithms, neural networks, and Support Vector Machines (SVM), were anticipated to aid in distinguishing subpopulations of patients with similar clinical features, thereby improving diagnostic accuracy.

Furthermore, algorithms were expected to expedite the diagnostic process by analyzing previously collected medical data to suggest necessary tests for accurate diagnosis or accelerate anomaly detection, facilitating the identification of cases requiring further investigation.

Lastly, we anticipated leveraging AI for the analysis of imaging studies, particularly utilizing convolutional neural networks (CNN). This approach enables automatic feature extraction from images and the identification of abnormal structures or malignant areas in histopathological cancer images, thereby enhancing diagnostic accuracy and efficiency. An essential component of WMU's endeavors involves conducting clinical trials, where algorithms can play a pivotal role in various aspects. Firstly, algorithms can aid in the design of trials themselves by analyzing clinical datasets to identify pertinent features for specific patient groups. Additionally, they can facilitate the selection of optimal patient randomization methods, thereby enhancing the precision and effectiveness of trial outcomes. Moreover, algorithms can streamline the data collection process, leading to significant time and cost savings, while also assisting in the identification of patients most likely to respond favorably to a particular treatment regimen.

Furthermore, we recognize the indispensable role of algorithms in tasks associated with data acquisition and preparation for subsequent analysis. This includes the efficient detection of errors in medical data, such as incorrect entries or missing data, as well as the identification of outliers, which may or may not indicate errors in the dataset. Moreover, algorithms can aid in detecting duplicate data entries and support the amalgamation of records from diverse medical sources, facilitating the integration of data irrespective of variations in medical terminologies.

In summary, the preparations for implementing AI in medical tasks encompass infrastructural, financial, organizational, and conceptual aspects, underscoring the culmination of extensive collaboration between WMU and data scientists from WUEB. The forthcoming phase involves the actual implementation of the plan and its underlying assumptions.

3 Methodology

3.1 Conception of the Research Procedure

The establishment of RDMCs will entail comprehensive IT and technical assessments of resources to evaluate their integration and interoperability potential. Subsequent stages will involve the phased adoption of technology, personnel, and infrastructure necessary for the implementation of AI across all available datasets, including those obtained from clinical hospitals collaborating with the University.

The article presents the research assumptions that have been defined in the RDMC development project discussed above. The planned research process is multi-stage and includes the concept of using triangulation of research methods used in both qualitative and quantitative research. Therefore, below we will present a fragment of the synthesized research procedure that has been carried out so far.

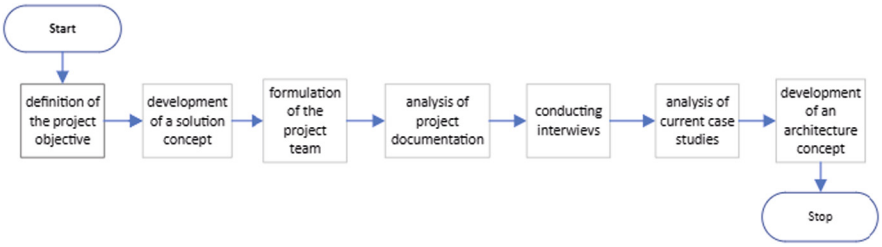

Fig. 2. Research procedure (*Source* Own elaboration)

3.2 The Research Technique Applied

The research procedure presented in Fig. 2 consisted of multi-stage research, in which the authors used a number of research tools to collect both quantitative data – which will be presented in subsequent articles, as well as qualitative – allowing for a detailed recognition of the expectations of users of the IT solution. Given that the paper focuses on detailed results obtained from the participating entities, a methodological triangulation approach was used to provide a comprehensive analysis of both qualitative and quantitative data. This approach increased the reliability of the research results, enabling cross-verification from multiple sources and perspectives. The research tools used during the RDMC project are:

- **Desk analysis:** the detailed desk analysis covered several different subject areas. The first one concerned guidelines for projects co-financed by the Medical Research Agency. The second area of analysis was aimed at a detailed recognition of the ICT solutions used so far. The third area concerned the analysis of documentation prepared under the cooperation agreement of the entities included in the consortium.
- **Participatory observations:** the members of the project team were selected from among the employees of all entities in the project consortium. This was important from the perspective of their individual experience, and knowledge of all business processes and medical procedures that should be included in the solution architecture

- **Workshops:** were conducted both with project participants as well as with direct stakeholders and future users of the solution. Their task was to identify the basic and key needs of users in terms of IT resources that should be included in the database by brainstorming as well as empathizing.
- **In-depth interviews:** were conducted with selected groups of users to verify and assess the requirements of users identified during the workshops.

4 Results

4.1 Observations (Medical Data)

A noteworthy observation and conclusion, despite the project being in its early stages, is the remarkable diversity of data, which even surprised medical personnel accustomed to operating within this data environment daily. We found it necessary to delineate general categories of data and restrict our analysis to their respective domains.

We have categorized the data as follows:

I. Patient Medical Process Data:

- Includes diagnostic information and treatment records.

II. Biobank Data:

- Data collected and stored in biobanks for research purposes.

III. Clinical Trial Data:

- Information obtained from clinical trials conducted at WMU.

IV. Scientific Data:

- Data generated through scientific activities at WMU, not directly related to patient care or clinical trials.

For a comprehensive overview of the distinctive features within each category, please refer to Table 1.

Another significant concern revolved around data formats, encompassing their standardization, intended use, and, surprisingly, the prevalent absence or limited extent of digitization in many cases.

For the first category, which pertains to data from medical processes, the majority of the data is stored within the hospital information system (HIS). However, there are additional data points that exist solely in paper documentation, such as informed consent for procedures or historical documents retained by patients at home. Electronic documentation from the HIS can be exported to formats like Microsoft Excel files, stored in databases (either locally or in the cloud), or physically transferred. The HIS serves as the primary data management system, primarily used to link medical procedures with their corresponding financial transactions to facilitate cost management for each hospitalization. Subsystems within the HIS cater to individual departments and laboratories, such as radiology.

In cases where a patient undergoes examinations using devices with digital memory, the data remains stored within those devices. Consequently, the system comprises

numerous interdependent elements, and its consolidation and integration processes are not finely tuned, resulting in various barriers. Consequently, it's common to encounter duplicate data existing in different systems and formats. Data quality assumes particular significance, especially concerning the transparency of medical service cost accounting.

While the software and interface theoretically enforce physicians to standardize data entry and utilize a unified dictionary, these protocols are easily circumvented. Consequently, data is often entered as free-text rather than structured parameters within predefined categories.

Datasets within the second category - the Biobank - exhibit distinct characteristics. While paper documentation such as informed consent forms and transport reports are common, electronic records in formats like Microsoft Excel files or databases, accessible locally or via cloud platforms, also play a significant role. Biobanks employ sophisticated data management systems known as LIMS/BIMS (Laboratory/Biobanking Management Systems) to organize biological material resources, facilitating data organization, process automation, and monitoring. Comprising interconnected elements, these systems enable comprehensive management of data across all stages of biobanking, including storage, disposal, and reporting. Local standardization within the Biobank regulates the format and quality of incoming data, ensuring consistency and facilitating collaboration with external entities. Moreover, international organizations like BBMRI-ERIC enforce global standardization, mandating specific formats and data quality criteria for biobanks seeking collaboration. This standardization effort, exemplified by the MIABIS 3.0 framework developed by BBMRI-ERIC, aims to establish a common language and harmonize data presentation worldwide, promoting interoperability and facilitating global collaboration (8–10).

In clinical trials, the study sponsor, often an external company responsible for the product under evaluation, typically provides electronic case report forms (e-CRFs) for reporting study progress. Due to the diverse nature of these forms, which directly stem from study designs, integrating their content poses significant challenges. Additionally, the clinical trials coordination unit at WMU currently lacks an IT system capable of integrating disparate projects, rendering the implementation of digital solutions in this area feasible only after several months of development.

Data within the last category exhibits distinct characteristics. It is typically highly detailed, comparable to biobank records, with electronic versions often tailored for analysis, such as statistical calculations for scientific purposes. Theoretically, this data is well-suited for adaptation to more advanced computational techniques, including AI, although the sheer volume of resources may present a limitation. Scientific research conducted by individual researchers often involves relatively small sample sizes, which may hinder broader applications. Furthermore, integrating the resources of different researchers may prove challenging due to variations in data collection methods, lacking standardization across datasets.

In all categories, a significant consideration is the prevalence of missing data, which may not solely stem from errors in data collection. Often, natural data may be inherently unavailable, expertise may prove unsuccessful due to staffing or equipment limitations, or patient conditions may preclude data acquisition. Importantly, missing data can also contain valuable information from a medical perspective, and excluding cases with missing

Table 1. Description of data categories in medical entities

Category	Data from medical process	Data from the Biobank	Data from clinical trials	Other Scientific data
Elements of the category	Minimum scope of data collected from own sources: • Hospital information systems (HISs)3 , in particular: - demographic data, - diseases (ICD10) – underlying and concomitant, - procedures performed (ICD9), - medications used (active substance, EAN code), - hospitalisations and visits (at least date of admission and discharge), - event onset times, - descriptive data – medical records unrelated to the service (e.g. discharge summaries, doctor's notes, nurse team observations, forms describing patient condition etc.),4 • Laboratory diagnostics (lab test results), • Imaging diagnostics (descriptions and images), • Pathological diagnostics (descriptions and images), • Information on the availability of biological material kept in a biobank, • Genomic analysis (whole genome sequencing, whole exome sequencing)	Data related to the study participant: • Data resulting from fulfilling the obligation to secure the rights of the research participant • Informed consent form (also as a scanned digital version) and exclusions in informed consent (if applicable, e.g. the patient does not allow genetic testing) Data from pre-analytical processes: • collection: date and time, staff, collection point, adverse events (e.g. fainting) • transport: start and end date and time, temperature log, adverse events • qualification and acceptance: quantity of material, sample codes, adverse events (e.g. hemolysis, lipemia) • processing: time, centrifugation speed, pipetting into daughter samples, materials and reagents used • storage: location, conditions (temperature + humidity) Data from scientific tests/measurements if not part of a medical procedure	Data related to the study participant: • Data resulting from fulfilling the obligation to secure the rights of the research participant • Informed consent form (also as a scanned digital version) and exclusions in informed consent (if applicable, e.g. the patient does not allow genetic testing) Data from the scientific process (defined separately for each project depending on the expectations of the study sponsor)	Data collected by the scientific staff of the University while conducting studies which are or are not related to processes conducted within the hospital eg • Omics (metabolomic, proteomic, transcriptomic) study results, • Other units/labs cooperating with the WMU, • Medical telemetry – records from medical devices and remote monitoring equipment (e.g. holter, activity trackers), • Individual well-being, lifestyle and/or quality of life patient surveys based on standardised international questionnaires such as SF-36, EQ-5D, HRQoL-14

data risks introducing bias into interpretations. Therefore, accepting and appropriately handling missing data is imperative for the realistic implementation of algorithms for medical data analysis.

4.2 Proposed Solution

The purpose of the qualitative research, in the first stage of the process, was to identify the information needs of users in relation to the following key problems:

1. What data sets should be collected in the individual modules of the proposed solution?
2. What should be the structure of the data sets so that it is possible to share these resources by all users of the entire integrated solution, depending on their information needs?
3. In which modules of the current ICT solution sufficient data resources are collected, and which modules need to be developed or developed from scratch?
4. What processes will be supported in the modeled/prototyped solution and are these processes currently formalized in their entirety or should they be improved or modeled from scratch?
5. How should processes be grouped to be available to defined user groups?
6. In the defined user groups, how will the roles be assigned with the appropriate access rights to the required information resources?
7. Which information resources will be used in the AI solution being created?
8. Which user groups will absolutely need the analyses performed by designing an AI solution, and what will be the scope of these analyses?

The qualitative research gave the authors an overview of the current situation regarding the use of ICT solutions in the processes of handling medical procedures and the scope of responsibilities and expectations of users in relation to the prototyped solution. As a result of the above research, a preliminary concept of the architecture of an integrated system using the "Physician Assistant" and a separate AI module supporting diagnostic and analytical processes were proposed. The proposed concept of architecture is presented in Fig. 3

The conducted research allowed the authors to diagnose the degree of advancement of ICT solutions used by individual consortium members. Assumptions for the planned prototype have been developed. As a result of the research, the authors diagnosed the biggest problem that the proposed task faces, namely the lack of integration and consistency of data between individual subsystems that are to create a normative database for the AI solution.

5 Discussion and Conclusions

The objective of this paper was to delineate the pathway required for the implementation of AI algorithms in medicine, transcending a purely scientific or experimental approach. While theory espouses the boundless potential of AI in the medical realm, practical implementation faces numerous barriers, many of which may not be immediately apparent to data scientists.

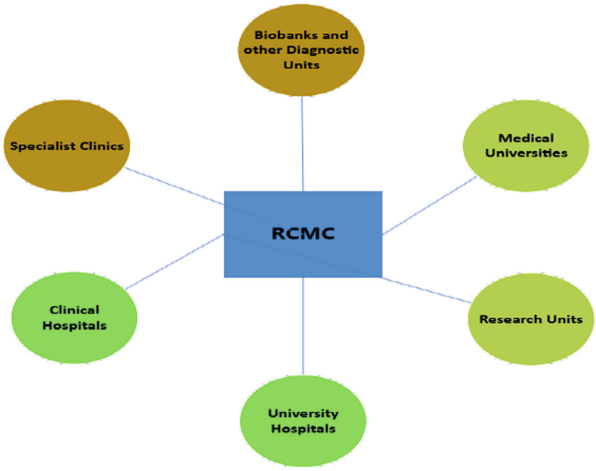

Fig. 3. Concept of the prototype architecture (*Source* Own elaboration)

Medicine, and life sciences more broadly, are characterized by a unique data landscape, marked by exceptional diversity and a distinct approach to data. Historically, the primary aim of medicine has not been centered on the collection and analysis of large datasets; however, with the increasing digitization of medical records, this has become an incidental byproduct. Consequently, many theoretical assumptions remain unattainable, necessitating the development of solutions to prepare data for the eventual stage where AI algorithms can be effectively employed.

Our proposed solutions stem from a specific initiative tied to the establishment of digital medicine centers. Similar initiatives are emerging worldwide, as the vast majority of medical data resources remain undigitized and inadequately integrated, hindering collaboration with AI algorithm developers to generate meaningful and valuable outcomes.

We posit that this article offers valuable practical insights into the process of integrating AI into medical data, a topic of increasing relevance to institutions globally amidst the dynamic evolution of AI in medicine.

5.1 Limitations

The primary limitation, yet concurrently the strength of the outlined observation, stems from the early stage of project realization, specifically the initial phase of implementing AI in medicine within WMU. Consequently, the foremost limitation arises from the uncertainty surrounding the validation of our ideas. While we endeavored to anticipate all potential complications, the inherent complexity of AI in medicine renders it an ongoing challenge.

Nevertheless, we are optimistic about continued progress, bolstered by the expertise of data science specialists from WUEB. We remain hopeful that the elucidated process can provide valuable guidance to other institutions confronting similar challenges, whether in the near or distant future.

5.2 General Recommendations

The observations presented suggest that implementing AI in medicine poses significant complexities, largely attributable to the unique nature of medical data, distinct from the datasets traditionally utilized by AI, such as those in banking systems. Institutions contemplating this process should commence with a thorough analysis of their existing data, meticulously considering factors such as digitization, granularity, and quality. Furthermore, enlisting the support of experts experienced in navigating such transformations is highly advisable.

Acknowledgments. WMU and WUEB are beneficiaries of funding under the call ABM/2023/2, related to establishment of regional digital medicine centers (RDMC), "RCMC Distruptor", 2023/ABM/02/00003–00.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Application of Machine Learning in Management Information Systems

Bitcoin Volatility Forecasting Using Statistical Analysis and AI Models - A Comparative Study

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Abstract. This work offers a comparative analysis of the effectiveness of two analytical cultures: statistical analysis and data modeling (DMC), and algorithmic AI analysis (AMC, artificial network LSTM) to forecast volatility of Bitcoin obtain by using Exponentially Weighted Moving Averages (EWMA). The analysis was based on data between March 10, 2016 and April 23, 2024, divided into two sets: a training set (1906 data points) and a test set (35 data points). Models' results of test sets' data have been compared using MSE (Mean Square Error) and MAE (Mean Absolute Error). The study has shown that on a shorter time horizon a statistical analysis resulted in a better fit than AI methods (LSTM and LSTM+x). Conversely, LSTM+x was better at a longer time period when data displays higher volatility and higher peaks. In conclusion, both methods are applicable in predicting volatility of cryptocurrencies.

Keywords: AI methods · LSTM · EWMA · Bitcoin volatility

1 Introduction

Currently, the focus on cryptocurrencies is gaining momentum. According to [8], cryptocurrencies are digital financial assets, for which records and transfers of ownership are guaranteed by a cryptographic technology rather than by bank or other trusted third party. They are created through a process called "mining" and are managed by decentralized open source code. What is more, cryptocurrencies transact on peer-to-peer (P2P) networks that enable any two parties to interact directly [11].

The first cryptocurrency – Bitcoin was proposed in 2008, when a group of computer scientist published a whitepaper introducing cryptocurrencies' revolutionary concept under the pseudonym of Satoshi Nakamoto ([13]). The number of blockchain-based digital tokens has grown to over 22,000 [12]. Cryptocurrencies can be used both as means of payment and as financial asset.

Recent years have witnessed an unprecedented rise in cryptocurrency demand resulting in significant attention from the media, regulators, entrepreneurs, institutional and

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 139–149, 2024.
https://doi.org/10.1007/978-3-031-78468-2_11

individual investors and the public, making them a current and important topic of academic discussion. A cluster-based systematic analysis by [1] revealed four literature clusters related to the main lines of research, namely, investigating investor behavior, portfolio diversification, cryptocurrency market microstructure, and risk management in cryptocurrency investment.

In general, cryptocurrencies are highly volatile, and are subject to sudden massive price swings, experience explosive and bubble behaviors in multiple periods, contain periods of very huge volatility and exhibit speculative behavior ([2, 5, 7, 9, 14]). In [7], there are listed the following factors affecting cryptocurrency price movements: lack of fundamental value, market sentiment and speculation, lack of regulation, immaturity low market capitalization and limited historical data. All these make the assessment and prediction of volatility very difficult.

The present paper aims to compare techniques for modeling cryptocurrency price/return volatility. Unlike most previous studies that focused solely on Bitcoin and ignored many other instruments already traded in the market, this research used daily quotations of Bitcoin, Ethereum, Dow Jones index, FTSE 100, FTSE China 50, GBP, Brent crude oil, Gold, S&P, 10-year bonds of Hong Kong and the USA from March 10, 2016 to April 23, 2024. Next, weekly changes were used to calculate volatility and rates of return. The data was collected by pl.investing.com platform.

2 Purpose and Scope of Work

The purpose of the work is to compare the effectiveness of two analytical cultures in the analysis and forecasting of Bitcoin volatility. The following methodologies were considered: statistical analysis and data modeling (DMC) and algorithmic modeling (AMC) (cf. [3]), using AI methods (LSTM and enriched model LSTM+x).

Empirical studies typically attempt to model realized volatility (RV) from two perspectives. The first is the historical method, which involves time series analysis used directly to model the RV series itself. Examples can be found in the literature that include the use of long run vector autoregressions (VARs) [15, 16]. The second approach, the implied method, includes RV as an explanatory variable within the variance model under study. The dynamics of the conditional variance is captured using the generalized autoregressive conditional heteroscedasticity (GARCH) model or a modification thereof [17]. Historical methods and implied methods are the two main approaches to modelling variability.

This paper uses a) the historical approach based on econometric time series analysis, fitting an autoregressive moving average (ARMAX) model to a historical series of volatility estimates, b) the implied approach was replaced by a regression model using a recursive neural network as representative of AI. In both cases, the target variable RV was estimated using a simple exponential moving average (EWMA) estimator.

EWMA generally corresponds to the use of the I-GARCH process. The formula using I-GARCH processes is a natural extension of the existing EWMA model. Comparison of volatility forecasts for time horizons expressed as a ratio of volatility calculated using single-scale EWMA and long-memory I-GARCH process. As the forecast horizons lengthen, the ratio of volatility estimates obtained from the above models decreases.

Nevertheless, in the considered range of terms it remains close to unity. This behavior is quite intuitive, a long-term forecast should use more information from the distant past (I-GARCH), while short-term forecasts are dominated by the so-called recent events (EWMA) [18]. Detailed empirical examination shows that the autoregressive mean value term must be included to construct a process that accurately captures the properties of financial time series. For this reason, external logarithmic rates of return were included in the models.

3 Data Description

The research material consists of daily data from https://pl.investing.com and covers the period: March 10, 2016 to April 23, 2024. The entire set was divided into two subsets: training part: March 10, 2016 to February 29, 2024 (1906 observations) and testing part from March 1, 2024 to April 23, 2024 (35 observations). The dependent variable Vol_EWMA (Exponentially Weighted Moving Average Volatility) was built on the basis of Bitcoin quotations (see the next section).

As potential explanatory variables, we adopted logarithmic rates of return (with increase in time = 5 days [week]) for the following quotes: ethereum cryptocurrencies (ethe), Dow Jones Index (dowj), FTSE 100 (fts1), FTSE China 50 (fts5), GBP, Brent crude oil (crude oil), Gold (zlot), S&P 500 (sp), 10-year Hong Kong bonds (oblig_hn) and 10-year US bonds (oblig_us).

4 Analytical Methods

We used two methods for the purpose of the analysis: autoregressive model from the group of statistical data modeling (DMC) and the LSTM method from the group of AI methods (AMC). In both cases, the target variable was estimated as Vol_EWMA.

EWMA is a quantitative, statistical measure used to model time series. The EWMA methodology is widely used in finance to calculate return volatility in risk management. The EWMA model strikes the perfect balance between complexity and accuracy, hence it is a very popular approach to estimating variability.

A simple mathematical formulation of EWMA may be given by [4]:

$$EWMA_t = \alpha * r_t + (1 - \alpha) * EWMA_{t-5} \tag{1}$$

where: α – the weight set by the user (researcher),

r_t – Bitcoin logarithmic returns.

ARMAX is a typical single-equation autoregressive AR(p) model. After analyzing the empirical data and logarithmic rates of return of the studied assets, we used the best-fitting ARMA (p,q) model in the following form:

$$ARMAX\,(p, q, k) = \alpha_1 AR_1 + \ldots + \alpha_p AR_p + \beta_1 MA_1 + \ldots + \beta_q MA_q + \gamma_k X_k \tag{2}$$

Single-equation autoregressive models allow for predicting short-term sequences. The main idea of these methods is that all the data necessary for the forecast are contained in the past of the financial instruments under study, and their results are easy to interpret.

5 Neural Network

5.1 Overall Dense Network

Neural networks are a series of n affine transformations. These transformations are defined by the weight matrix w_i the bias vectors b_i, and the transformations ϕ_i : called activation functions.

We can formulate the Artificial Neural Network (ANN) in the following way:

$$f_{w,b}() = \phi_n\left(Aff^{(n)}_{w_n,b_n} \cdot \phi_{n-1}\left(Aff^{(n-1)}_{w_{n-1},b_{n-1}} \cdot \phi_{n-2}\left(Aff^{(n-2)}_{w_{n-2},b_{n-2}} \cdots\right)\right)\right) \tag{3}$$

Affine transformations $Aff()$ are called neurons. The transformations create a neural network. These transformations are defined by the W and B matrices.

Function $f_{w,b}() : X \rightarrow^{net} Y$ is a model (architecture) of input–output mapping of a given neural network. The internal transformations are called hidden layers of the network. The parameters of the mapping model are estimated by minimizing a certain function $\mathcal{L}$ called the loss function.

Choosing the optimal values of the parameters $\theta \equiv \{w_i, b_i\}_{i\in\mathcal{I}}$ assumes finding the minimum of the loss function $\mathcal{L}$. If both f and $\mathcal{L}$ are differentiable, then algorithms based on the gradient $\partial\ \mathcal{L}\ /\partial\theta$ can be used to estimate the parameters. In practice, the search for θ parameters is limited to examining the training sample $\{x_i\}$. Formally, we assume that the training sample comes from the general population $\mathcal{P}$ and is described by an unknown distribution: $x_i \sim p_D$. Then, we can estimate the loss function as follows:

$$\hat{\mathcal{L}} = E_{x\sim p_D}(\mathcal{L}(\theta, x)) \tag{4}$$

Since we have a finite sample $D = \{x_i\}_{i=1}^N$, the above formula reduces to:

$$\hat{\mathcal{L}} = \frac{1}{N}\sum_{i=1}^{N}\mathcal{L}(\theta, x_i) \tag{5}$$

One of the side effects may be the problem of overtraining. This happens when the model becomes sensitive to patterns that may exist in the training set: it confuses noise with regularity. Other problems arise when modeling sequential data where the x_i probability distributions are not independent.

5.2 Recurrent Neural Net (RNN)

In order to solve the problem of sequential data, the dedicated network architectures called recurrent RNNs have been developed. RNNs enable the modeling of time-dependent sequential data. Figure 1 shows how a simple RNN model with a single hidden layer and a single output sequence looks like [19].

In a recurrent RNN network the final loss is calculated as a sum:

$$\mathcal{L} = \sum_{t=1}^{N}\mathcal{L}(\theta, x_t) \tag{6}$$

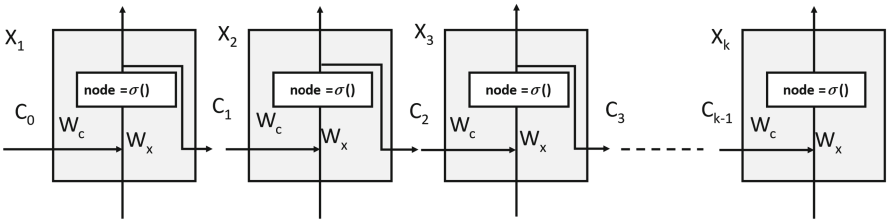

Fig. 1 RNN network model. Source: own study

the loss function is minimized at each time point.

The gradient is used to update the model parameters in the process of searching for the optimal set of parameters θ – the so-called network training process:

$$W_{i+1} \leftarrow W_i - \alpha \frac{\partial \mathcal{L}}{\partial W} \tag{7}$$

5.3 Back-Propagation Over Time in RNNs

We have a "training" task - parameter estimation, which involves T time steps. The back-propagation algorithm allows us to calculate a gradient that tends to vanish when t is large:

$$\frac{\partial \mathcal{L}}{\partial W} = \sum_{t=1}^{T} \frac{\partial \mathcal{L}_t}{\partial W} \rightarrow 0 \tag{8}$$

and finally the update of the network weights looks like:

$$W \leftarrow W - \alpha \frac{\partial E}{\partial W} \approx W \tag{9}$$

which means no significant parameter change will be made.

5.4 The Long-Run Neural Network LSTM

The solution to the problem of vanishing gradient in recurrent networks is to introduce LSTM (Long Short Term Model) cells instead of simple neurons. The LSTM cell is a specially designed logical unit that will reduce the vanishing gradient problem enough to make recurrent neural networks more useful in long-term memory tasks [20] (Fig. 2).

There are mechanisms that have been developed to replace classical activation with the so-called goals. During the appropriate update of the forget gate parameter at time $t + 1$, we obtain:

$$\frac{\partial \mathcal{L}_{t+1}}{\partial W} \nrightarrow 0 \tag{10}$$

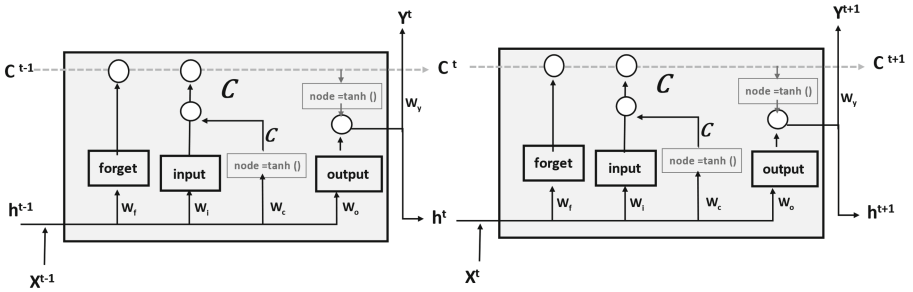

Fig. 2 LSTM network cells at time moments: (t − 1),(t),(t + 1). Source: own study

and hence:

$$\sum_{k=1}^{t+1} \frac{\partial \mathcal{L}_k}{\partial W} \nrightarrow 0 \tag{11}$$

The LSTM network updates and balances the values of the four terms during the training process, increasing the likelihood that additive terms will not vanishing.

5.5 LSTM Model with an Additional Trend Factor

An additional element is a mechanism called the transfer function in time series modeling. It means adding an external component to the model that modifies the average value of the response. The LSTM model was used to model the stochastic part. Average trend is a regression model based on rates of return [21, 22]. It allows us to enter rate of return quotes only for the global trend of the series. The stochastic component is modeled by a long-run process:

$$\text{LSTM}X_t = LSTM_t + Trend_t \tag{12}$$

which allows for the construction of medium- and long-term forecasts.

The LSTM model used in this manuscript is presented below. The scheme consisting of two layers (stacked LSTM) with 8 cells and a time horizon of H = 100 periods. Tanh() was chosen as the activation function, hence the data were scaled to the range (−1.1). Additionally, protection against overfitting was implemented using the drop-out method with a fill parameter of 0.25. The regression model was based on a linear regression scheme (activation function - linear) without scaling. Both models were combined in the last layer (Fig. 3).

The loss function is $\mathcal{L}(\theta, x) \equiv MSE$ (Mean Square Error), an ADAM optimization algorithm with standard parameters. Due to the stochastic mechanism of selecting the starting point for the optimization algorithm, the model was estimated 10 times and the result was averaged. Thus, average relative weights were obtained when combining models $w_{LSTM} = 0.965$, $w_{regression} = 0.034$.

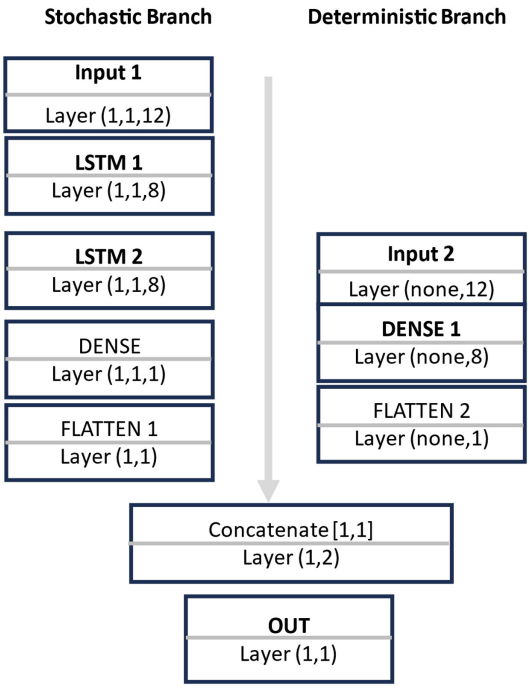

Fig. 3 Scheme of the LSTM+x neural network architecture used in the model. Source: own study

6 Discussion (Analysis of the Results of Empirical Studies)

In this paper, we compare predictions based on the ARMAX autoregressive model and long-run LSTM (Long Short Term Model) predictions derived from a neural network model for predicting volatility values.

We first estimated the correlation coefficients between the potential explanatory variables. A statistically significant correlation was found between the studied characteristics, in addition to the correlation coefficient between ethereum cryptocurrency (ethe) and US bond quotes. A stationarity analysis (ADF and KPSS test) of all the variables under study showed stationarity of their logarithmic returns [4].

Based on the statistical significance (Box-Pierce and Ljung-Box tests) and on the Akaike, Schwarz and Hannan-Quinn information criteria, the model ARMA (2, 4) estimated with the use of conditional maximum likelihood method based on the BHHH algorithm proved to be the best [10]. We extended the model to include potential macroeconomic variables. We selected these variables (a set of external logarithmic returns – Xs) using the Granger causality procedure (Pairwise Granger Causality Tests). For the further analysis, we selected those variables that Granger-caused the formation of the magnitude of logarithmic rates of return Vol_EWMA. We applied the Least Squares Method to estimate the ARMAX model. After estimating the full ARMAX model, taking into account all variables – X's, which were the cause of the formation of Bitcoin volatility,

we carried out a verification of the statistical significance of the parameters and finally adopted the following model for forecasting Bitcoin volatility (see Table 1).

Table 1 Estimates of the ARMAX model. Source: own study

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.007	0.001	6.556	0.000
SP	0.054	0.017	3.144	0.002
OBLIG_US	−0.016	0.006	−2.994	0.003
FTS1	0.052	0.019	2.711	0.007
ETHE	0.021	0.003	7.179	0.000
AR(1)	0.608	0.023	26.555	0.000
AR(2)	0.365	0.027	13.596	0.000
MA(2)	−0.333	0.028	−11.810	0.000
MA(3)	−0.327	0.024	−13.947	0.000
MA(4)	−0.217	0.023	−9.299	0.000

In Fig. 4 we show the volatility of Bitcoin over the entire study period. We observed high variability in Vol_EWMA5 with significant increases in large deviations (so-called peaks) in some periods and low variability in other periods.

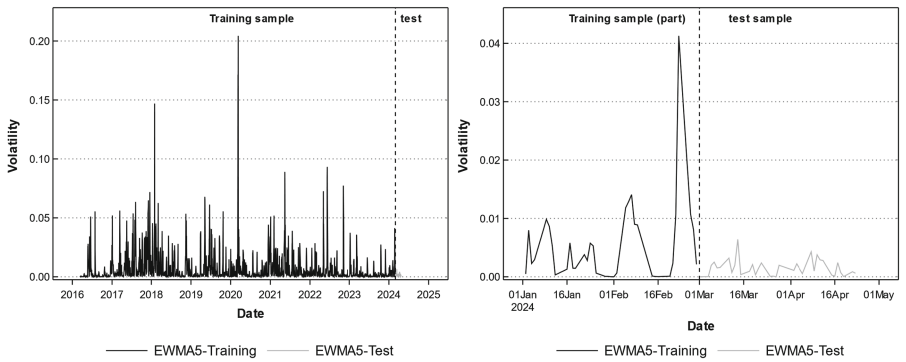

Fig. 4 Realized Volatility of Bitcoin. Source: own study

Figure 5 (below) presents the results of the forecasts obtained by different methods. Model-0 is the forecast obtained from the ARMAX model while the other models are: AI, model-1 is the LSTM forecast and model-2 is LSTM+x, a version of LSTM supplemented with an additional component depending on the returns of other instruments. The forecast can be interpreted as the expected, most likely value. The detailed analysis showed considerable differences in the results. The ARMAX method performed the

best (RMSE = 0.00163, MAE = 0.00130). The mean predictions obtained using the AI method (LSTM and LSTM+x) were slightly worse, namely for the LSTM method (RMSE = 0.00466, MAE = 0.00241) and for the LSTM+x method (RMSE = 0.00427, MAE = 0.00268).

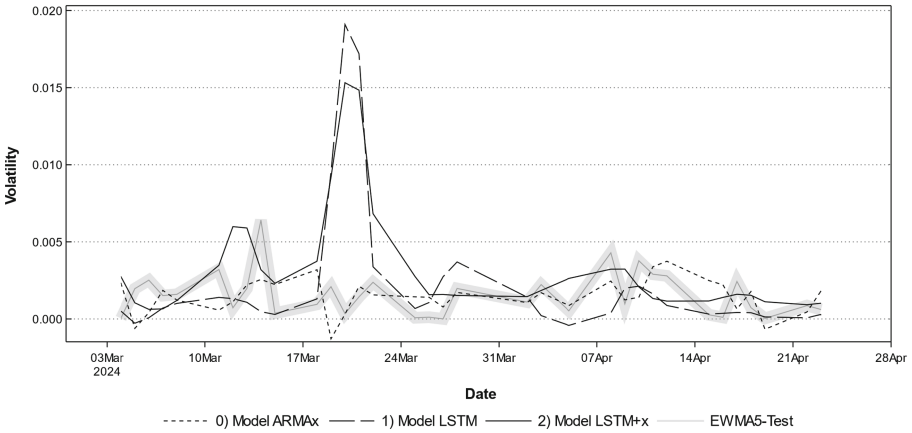

Fig. 5 Forecasts of Bitcoin Realized Volatility. Source: own study

When comparing forecasts, it should be emphasized that the auto-regression model refers to averaged values of a short horizon, while the AI models used rather a much longer period in which there are numerous deviations from the normal distribution – the so-called peaks. Nevertheless, our research has shown that methods from the DMC group as well as those from the AMC group can be successfully used to forecast the conditional volatility of financial instruments.

7 Summary

The paper compares different models employed to forecast the volatility of Bitcoin cryptocurrency. Many authors agree that exchange rate quotes are non-stationary, so simulation methods are proposed to describe them. On the other hand, the squares of the rates of return and their RV realizations exhibit stationary properties. In this paper, models for realized volatility are examined.

First, statistical theories were used to assess stationarity. Then, rates of return of other financial instruments were included to investigate the possibility of using the information contained in these time series. Of the instruments listed on the US market and the Chinese market – the Hong Kong Stock Exchange, those exhibiting statistically significant Granger causal relationships were selected. Additional data were used to model the mean forecast values.

The target variable was the EWMA estimator, which is commonly used in practice and has similar properties to advanced heteroscedastic estimators.

Within the framework described above, the estimates were obtained using statistical methods: the ARMAX model and algorithmic methods: the LSTM+x model. The calculations were based on a long training set. MSE and MAE measures obtained for the test set were used to compare the performance of the models. As expected, the statistical model fitted well the observed values on the short forecast horizon. The LSTM+x model generated a forecast with a peak characteristic for the long-term nature of the series. It can be stated that the models showed typical properties of their classes.

Calculations were performed with the use of eViews (rel 11) and Keras/Tensorflow (2.13.1) from the Python system. The detailed programs used for the calculations are available from the authors.

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Effectiveness of Automatic Data Transformation in Deep Learning Model for Leasing Decision Support Process

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Abstract. Databases used in machine learning for management decision support require, first of all, adequate preparation: transformation. This process involves determining the type of data, excluding missing data, formatting the data and preparing the text data for recoding. This stage is essential, as it significantly impacts the performance of machine learning. It is usually carried out manually or "semi-automatically", which is often time-consuming and requires advanced statistical and expert knowledge. The purpose of this article is to describe the method of automatic data transformation and to show that this method gives as good results as manual transformation, however, it allows to perform the operation without unnecessary waste of time and effort. The analysis was carried out using a dataset obtained from leasing companies, it contains a wide variety of data, many missing data and abounds in unique or categorizing text data. The results of applying the automatic transformation algorithm are based on a previously designed simulation experiment. Measurements of machine effects were made based on measures of the effectiveness of machine learning. The measurements show that the automatic transformation produces statistically indistinguishable machine-learning effects as the manual transformation.

Keywords: data transformation · deep learning · decision support · leasing decisions · repayment prediction · automatic data transformation · manual data transformation

1 Introduction

Effective statistical inference requires specific mathematical assumptions for variable distributions. The use of deep learning in the context of data analysis and further decision-making, allows to streamline processes, increase the accuracy of results and, above all, allows to take advantage of data sets of great size, variables and dynamics that do not always come out of the statistical estimation theory. Deep learning methodology requires five main steps: (1) data preparation; (2) model development; (3) model learning; (4) model generalization; (5) testing and running the model prototype in a real environment [1]. It should be noted that there is a tangential point between statistical analysis and deep learning methods: it is the preparation of data for analysis (stage 1): augmentation

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 150–165, 2024.
https://doi.org/10.1007/978-3-031-78468-2_12

and transformation. Small collections, of course, do not pose problems from a statistical point of view; they can be prepared manually. However, big data makes new demands. Already the collection preparation stage is becoming difficult and time-consuming; it therefore requires automation. We are aiming for a machine to replace humans not only in the data modeling process, but also in the process of preparing the dataset. The primary benefit would be that auto-mathematization prepares the dataset instantly, allowing new information to be inserted into the model immediately. In addition, automatization will allow standardization of augmentation and transformation methodologies, making datasets comparable and consistent. Manual augmentation and transformation methods are well described [2–4]. However, methods of automatic data preparation are lacking [4–6]. This publication therefore addresses the need to automate the data preparation process: it describes the author's methodology and algorithm for automatic database transformation. Ultimately, this method is intended to replace the commonly used manual transformations, so it should be shown that the procedure described here successfully replaces the manual transformation. We prove in the paper that the effects of machine learning in both methods turn out to be statistically identical. To make a convincing case that automating the data preparation process makes sense and produces good results, we use a simulation experiment. For its purposes, we use a database from a large international leasing company. The choice of this collection is dictated by its peculiarities: it is characterized by many missing data, the records come from different sources, so they have different formats and types of variables. In addition, this type of database abounds in textual data. Thus, it is a very demanding collection and involves considerable resources in the process of augmentation and manual transformation [7, 8]. The leasing company makes the leasing decision after a detailed analysis of the economic and financial situation of the potential lessee [9]. The greatest technical difficulty of a database-based decision is, of course, the need to validate, organize and integrate very large sets of information [10]. Obvious is the need to consider the history of decisions made so far, which are a kind of validated input to the decision-making process. Such a wide pool of information of different types therefore requires the use of different but accurate decision support methods. After all, there are risks and uncertainties associated with financial activities, which, through the proper selection of a transformation method followed by deep learning, are significantly reduced [11]. From the point of view of the designed experiment, the most important stage is the first stage: data preparation [12]. This is because we verify the research hypothesis: automatic transformation effectively replaces manual transformation. We base the remaining stages of model learning on the verified machine learning model for leasing data [13]. The data preparation stage analyzed in this paper consists of well-defined procedures: data acquisition and cleaning, data augmentation, and transformation of nonnumerical values [7, 12]. Data value transformation involves changing or transforming the original data without generating new data appropriate for the application of deep learning. This reduces the complexity of the input data, at the expense of increasing the volume of the database (which becomes a problem of computing power rather than data modeling). This is because we have additional variables to manipulate [12]. The data preparation stage lays the foundation for further steps in the process of building the deep learning model used here [8, 9]. In the dataset used for the experiment, there are numerous categorizing text variables.

Thus, the purpose of the study can be formally formulated: to develop an automatic augmentation algorithm and input data to the deep learning model. The algorithm is, of course, expected to bring tangible benefits, however, it must not be inferior to the methods used so far. Thus, the study verifies the research hypothesis: the developed method of automatic data transformation preserves the accuracy of deep learning decision support models from leasing developed on using the manual method. Thus, the study verifies the research hypothesis: the developed automatic data transformation method preserves the accuracy of deep learning models for decision support from leasing developed on using the manual method. Verification of this hypothesis was carried out by means of an experiment with controlled boundary conditions, leading to the estimation of the deep learning model separately for the automatic and manual data preparation stages. The results were compared using statistical methods.

2 Literature Review

Dataset augmentation and transformation are a set of procedures and transformations performed to better adapt data to the needs of a specific deep learning model. It refers to the first stage of building deep learning models. The transformation process usually results in better modeling results, including the ability to generalize model results [15]. In the machine learning and deep learning literature, the general term data transformation refers to a set of operations on data before it is used to teach models [16, 17]. Many times, data transformation is also referred to as a data processing process that enables machine learning and deep learning models to achieve high learning ability, generalization and better forecasting performance [18, 19]. The purpose of the study is part of the trend set by the need to construct methods for analyzing large data sets, while maximizing the effects of the methods used [20]. Positive verification of the research hypothesis set in the study will identify an effective method of data preparation for strategic decision-making in customer portfolio management that does not require human effort [20]. This is a relatively new approach, since until recently the data preparation stage was based on manual or partially automated methods (implemented under human supervision). Automatic data transformation methods and tools, such as Alteryx, Trifacta and RapidMiner, are available in the literature [21]. Another method is Transform Data by Example (TDE) [21]. Research results have shown that TDE is effective in transforming this data and can help facilitate financial analysis. It should be noted that the above methods are not fully automatic: the methods require the intervention of an expert (human) knowledge of the context and specific rules and principles of data transformation to obtain correct results. Moreover, two of the same bases can be prepared differently by different experts. This is an obvious flaw in the procedure. The various types of problems essentially boil down to the key challenges of data preparation. For example, the problem of incompatibility of data formats (Trifacta-type procedures), are unable to recognize an example belonging to a domain or convert it into another format [488]. Require the use of languages that are specifically defined for a particular type of data processing. DSL-based systems tend to have problems with "program aliasing" [22, 23]. Human effort: TDE requires significant effort in the form of manually identifying examples of input and output data [2]. In leasing decisions, the context of the data, the experience of the expert, the peculiar

flexibility and other features that should not be lost in the process of data preparation are crucial [5]. In the case of TDE, data is transformed by analyzing specific examples. The problem arises when these examples do not accurately represent the diversity of all data. Some automatic data transformation methods have fixed formats for each data domain and may not handle non-standard formats. Some tools, such as RapidMiner, offer many built-in features, but may have limitations in adapting to non-standard data formats. Some methods can get "lost" or process data in undesirable ways, which can lead to errors. TDE, based on examples, can get confused when data is ambiguous. Some automatic data transformation methods require expertise to use them properly and get the desired results. For some methods, especially those that require defining transformations in special languages (like DSL), expertise may be required. Alteryx and RapidMiner, by offering graphical interfaces, try to minimize the need for advanced knowledge, but it can still happen. The process of automated data transformation requires user interaction, leading to incomplete automation of the process. TDE, depending on the complexity of the data, may require manual definition of examples. Some obstacles are also the complexity of configuration [5]: hardware requirements, licensing, dependence on input data quality: these methods/tools may require relatively clean and well-formatted input data, which can be problematic when the data is non-standard or unformatted. In addition, the need to adapt to the business context: the methods require human understanding of the business context to effectively adapt data transformation processes, evaluation (assessment) of the deep learner model operating with post-transformation variables is generally done by an expert (human). Of course, these obstacles are not important from the point of view of a large leasing company, but the most significant one turns out to be the problem of data security: data processing with the use of tools operating in the cloud or the use of external data sources may involve security concerns, and thus practically exclude such algorithms in the activities of financial enterprises. The problem with current semi-automatic preparation methods is the desire to "get it all done." Meanwhile, current automatic data transformation methods focus on simple transformations such as scaling, normalization or dimensionality reduction [5]. There is already research into new approaches to building automatic data transformation, such as unsupervised learning on large datasets, which can help discover more complex structures in data. In addition, new technologies such as reinforcement learning can help automatically optimize data transformation for a specific problem, which can lead to even better results in machine and deep learning [3, 24]. There are also software tools and libraries that facilitate the automatic application of data transformations. Still, the process of variable type analysis and dimensionality reduction is important, as it affects the selection of appropriate transformation methods [4, 6]. In addition, the automatic application of data transformations in deep learning models requires the proper selection of hyperparameters, such as the number of features, scaling factors and transformation steps [23, 25]. As a result, although the authors use the term "automatic transformation" in existing studies, it is important to point out that the role of the user remains crucial at various stages of the process. It requires his involvement and expertise to achieve optimal results. Thus, methods described as automatic methods should properly be called semi-automatic methods. In general, these methods lead to the automation of the input of human decisions into the dataset [26]. AutoML, for example, potentially covers every

step from starting with an unprocessed dataset to building a ready-to-implement machine learning model. Libraries such as auto-sklearn, TPOT, auto_ml and H_2O are partially related to the AutoML approach, as the methods automate certain steps in the modeling process, such as hyperparameter tuning and/or model construction [27]. Thus, it can be concluded that automatic selection of data transformation based on variable type is an important and actively researched area in machine learning and deep learning. Data transformation in machine learning models has therefore been automated to some extent. However, mainly manual analysis of the data type and dimensionality reduction process is still implemented, which can be time-consuming and prone to potential implementation errors [4, 6, 23, 24, 28].

Machine learning, including deep learning is closely related to the processing of textual information, the authors place special emphasis on methods for transforming textual data using one hot encoding [29, 30] and hashing_trick [31, 32]. Both methods are commonly used in deep learning, but differ in approach and application. In practice, the choice between one hot encoding and hashing_trick methods depend on several factors: (1) the number of unique values; (2) memory and performance; (3) Model complexity [33]. Both methods have their advantages and disadvantages [29, 33], so in the planned simulation experiment we consider both methods, without deciding which one gives better results. However, the use of two decoding algorithms in simulations increases the generality of conclusions about the usefulness of automatic data preparation.

3 Methodology

3.1 Algorithm and Procedure for Automatic Data Transformation

The algorithm for preparing data for machine learning aimed at two main goals: minimizing the role of the expert in the process of data preparation (automation) and reproducing the typical actions taken by the expert (compatibility of the results of automatic and manual transformation). An expert is understood as a person with expertise in building deep learning models and domain knowledge. He understands the context of the analysis and knows the objectives of the needs of machine learning algorithms. He understands the impact of data gaps on the machine learning process, and has the skills and knowledge to mitigate input base data gaps. The expert's role in the process of automatic transformation is to determine the list of variable types and to pre-match the database to the needs of automatic transformation. Thus, he determines the basic parameters of the automatic algorithm, assigns, among other things, the appropriate roles to the various variables: first indicating the explanatory and explanatory variables. The task of the automatic transformation algorithm is to systematically review the types of variables, automatically assign specific characteristics to them from the expert's input list, automatically select transformation methods depending on the type of variable, automatically fill in data gaps according to the expert pattern, automatically prepare text data for the process of encoding them into numerical form. Thus, the algorithm is autonomous under the boundary conditions specified by the expert. Basic features of the algorithm:

1. Way of describing the method: formal language (Python).
2. Types of variables supported by the method of automatic transformation: numeric binary, numeric continuous, numeric discrete, text categorization, text in the form of numeric code.

3. The developed method allows selective selection of transformation methods and introduction of additional advanced procedures in the programming code.
4. Scope of application: data processing in the process of decision support from the field of management. The method can also be used in the process of decision support from the areas of economics and finance, among others.
5. Limitations of the method: the method includes methods of transformation of data from a predetermined set of features, does not include methods from automatic selection of variables. The method does not process graphical variables. It does not work well in processing text data other than categorization (unique database entries). Before applying automation, it is necessary to recognize its applicability, it does not work autonomously to its full extent. In practice, this means that the role of the expert is crucial to a successful automatic transformation procedure.

The automatic transformation algorithm was developed based on observation of typical activities performed in manual transformation. Thus, the first step was to (commercially) involve several experts in leasing data transformation and observe the procedures, the experts use. The group of experts included an employee of the company that provided the database for testing. In his work, the expert is responsible for analyzing the reliability of applicants. The experts, using their own transformation methodology, revealed typical repetitive activities that were written into the automation algorithm. It should be noted that the biggest differences in the processed databases concerned the filling of data gaps, which in several cases had to be considered incompatible with the statistical analysis methodology. Therefore, in the automatic transformation algorithm, data gaps are a separate and strictly expert-dependent module. Experts, however, agreed on key aspects: determining the type of variables, making data types consistent, grouping variables, the method of selecting a learning and validation set, and creating categories for text variables. Therefore, these aspects were subjected to automation. The algorithm, therefore, can be described as follows:

3.2 Dataset

Extensive data from authentic leasing contracts were used for the simulation experiment. The dataset was obtained from a leasing company with international operations. It works with numerous subsidiaries and affiliates. The dataset reflects actual *post choc* decision cases related to the granting of leasing contracts. The dataset was pre-processed by experts to identify incomplete data, identify types and identify the dependent variable (see Fig. 1. Section 1.a). Two sets of learning and validation databases were developed for the experiment. The first was manually transformed bases. The base in this case was a set-in which data preparation was carried out using formal statistical analysis and manual transformation methods accepted by all experts. The development of the automatic transformation method involved analyzing the individual needs of each expert and coding these needs into an algorithm. Thus, the second base is the result of the automatic transformation. Both bases were independently decoded.

Table 1. Automatic data transformation algorithm.

1. Expert analysis	a. Developing a pattern for automation transformation (in the publication called as EX_template: boundary conditions of transformation) i. List of variables for the model (total N) ii. List of permissible variable types iii. Method for filling missing data for variables iv. Method for unifying formats of categorizing text data v. Indication of the explained variable in the model b. Analysis of machine learning effects
2. Automation of variable review (loop)	c. Loading the database into the algorithm d. Entering the column, recognizing and saving the name e. Reviewing the contents of the column records and classifying the type based on (EX_template) (function vartype was used) f. Exiting the column and assigning it a type from the list of predefined types (EX_template) g. Moving to the next column
3. Memorizing variable types and their properties (using shape and iloc methods)	h. The result of the loop is a 2xN dimensional vector $\overrightarrow{v}$ describing the types and properties of variables i. Dividing the vector $\overrightarrow{v}$ into four classes of subvectors: i. Continuous numerical, $\overrightarrow{v}_{int}$ ii. Binary numerical, $\overrightarrow{v}_{bin}$ iii. Discrete numerical, $\overrightarrow{v}_{disc}$ iv. Categorizing text, $\overrightarrow{v}_{txt}$

(*continued*)

Table 1. (*continued*)

4. Selection of subsequent vectors $\overrightarrow{v}_n$, conversion of the corresponding records according to the pattern	j. For a variable where there are missing data, automatic filling according to *EX_template* k. b. For selected variables (*EX_template*), for which there is no possibility of filling data, the missing data is replaced with NULL. This is necessary from the point of view of distinguishing between the states of the variable's value - lack of variable content (in the database it was the variable capital: key in the leasing decision process. It cannot be replaced by statistical methods)
5. Automation of transformation	l. The procedure for cleaning and unifying text data described by the vector $\overrightarrow{v}_{txt}$ (according to *EX_template*) m. Trimming the character length to the relevant ones $\overrightarrow{v}_{txt}$ (*EX_template*) n. Converting text data $\overrightarrow{v}_{txt}$ of an undefined type to type str o. For $\overrightarrow{v}_{txt}$ removing spaces, white characters, hyphens, special characters (*EX_template*) p. Numerical data types $\overrightarrow{v}_{int}$ and $\overrightarrow{v}_{disc}$ are unified to the float type q. h. Binary data $\overrightarrow{v}_{bin}$ without changes r. Unifying variable values while maintaining the distinction between discrete and continuous: i. Discrete numerical data $\overrightarrow{v}_{disc}$ are unified by the min-max method ii. Continuous numerical $\overrightarrow{v}_{int}$ data are subject to standardization s. Exporting the database for the process of decoding text variables $\overrightarrow{v}_{txt}$

3.3 Encoding

After the transformation stage of the text data contained in the two sets of databases, the classic one hot encoding and hashing_trick methods were applied. The methods are successfully used in deep learning models. Transformation of text data with the help of these methods makes it possible to create a set of binary variables while preserving the original categorization of the set. Let us emphasize that the two methods used in the study differ in the way the methods are encoded [34]. In the study, the performance parameters of the deep learning methods were used after applying the manual transformation and, in parallel, the author's automatic transformation [33]. This is how two sets were created, which were decoded separately using one-hot encoding (O-H) and hashing_trick (H-T) methods. One-hot encoding is a method of converting textual data to numeric form. Each unique observation is converted into a binary vector of new variables. This technique is used for data where categories have no natural order or hierarchy [25, 33, 35]. The method is used when the lack of a sequence criterion should be transferred to numerically encoded data. This method works well for a small number of unique categories [25, 33, 35]. Hashing-trick, on the other hand, is a method of converting qualitative variables into numerical form using an appropriate function. It assigns a specific index to a category. It is used when the number of unique categories is large, or the categorization variables take up a lot of memory. This technique aims to reduce the dimensionality of the data, where full coding using a single hot one would be inefficient [29, 32, 33].

3.4 Simulation Experiment Procedure

Thus, four databases are formed: automatic H-T, automatic O-H, manual H-T and manual O-H. In the simulation experiment procedure, the methods constitute four dependent samples, derived from the same source. A deep learning model was then developed for each of them. In this model, the key variable was the value of the leasing decision made: the leasing decision was coded as follows: 0- customers who have paid off all lease payments; 1: customers who have not paid off all lease payments. Thus, the task of the deep learning model was to correctly classify customers as "paying off" or "not paying off." Minimized in the algorithm was the number of "non-paying" customers. The data set for learning the model contains 29 variables and 13436 records. For each of the four bases transformed in the study, 90 computer simulations of the model were made with different but pre-planned input parameters. The deep learning model therefore consists of an input layer, three hidden layers with a reLu activation function, and an output layer with a sigmoidal activation function. Adam optimizer was used. The parameters of the experiment were the epochs and the number of units (neurons) in the hidden layers. The experiment designed in this way was aimed at verifying the hypothesis that two methods of transforming the same dataset produce systematically equal machine learning. The methods were compared by measuring measures of the quality of the resulting deep learning model (performance). The study used standard measures of model evaluation at the validation stage (val_loss, val_accuracy, val_precision, val_recall and val_roc_auc) [28–30].

The experimental result presented in the paper allowed the creation of 5 variables with $n = 90$, for each transformation method and each method of decoding text sentences.

The statistical material required pairwise comparison of parameter distributions. The procedure of the experiment is shown in the figure below.

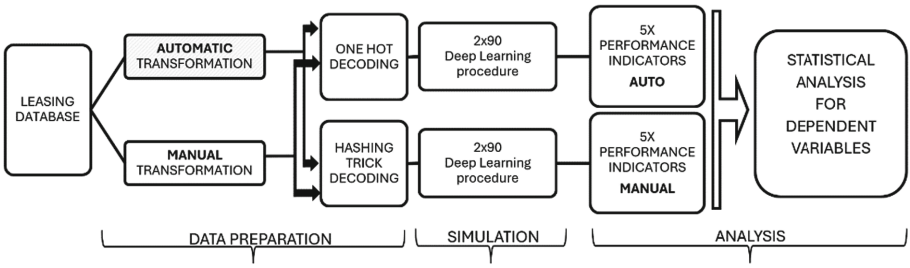

Fig. 1. Simulation experiment procedure.

4 Results

4.1 Analysis of Variable Distributions

Statistical analysis requires determining the normality of variable distributions and testing the homogeneity of variances. This helps determine an acceptable set of statistical tools for comparing variables. The results of the analysis are shown in Table 1. Normality of the distributions was found for the variables val_precision and val roc auc in the hashing-trick decoding method, and for the variables val recall and val roc auc in the one-hot decoding method It should be noted that the input base transformation procedure (auto v. manual) has no effect on the variance value of the distributions. This is indicated by the statistically insignificant result of the Leaven test. This result is important from the point of view of further comparative analysis: there is reason to believe that the automatic transformation preserves the spread of the variables at the level of the manual transformation. In such a situation, the normality of the distributions makes it possible to use the Student's t-test for the dependent variables. When normality of distributions was not found, the results were based on the non-parametric Wilcoxon test. All comparisons, regardless of distribution, were further supported by the Kolmogorov-Smirnov test for two samples (see Table 2).

4.2 Results of the Benchmarking Analysis

The results of comparisons of automatic transformation and manual methods are shown in Table 2. The analysis of normality of distributions allowed to select the method of comparison of simulated data. The test results clearly show that the model performance measures for the transformed tables do not differ significantly at the level of significance $\alpha = 0{,}05$. This is the case both in the sets for which decoding was based on O-H and for decoding by the H-T method. Additional analysis of the datasets by the Kolmogorov-Smirnov test confirms that the distributions of the variables generated by the automatic

Table 2. Normality test homogeneity of variances in samples*.

SAMPLE n = 90		Shapiro-Wilk normality test				Leven homogenity of variances test			
Parameter		manual		automatic		manual	automatic	F	P
		W	p	W	p	std. Dev			
Hashing trick	val loss	0,664	0,000	0,725	0,000	0,0968	0,0882	0,099	0,753
	val accuracy	0,959	0,007	0,957	0,005	0,0110	0,0103	0,170	0,681
	val precision	0,978	0,128	0,980	0,171	0,0485	0,0491	0,053	0,818
	val recall	0,950	0,002	0,947	0,001	0,1047	0,1164	1,016	0,315
	val roc auc	0,979	0,144	0,988	0,570	0,0104	0,0108	0,306	0,581
onehot	val loss	0,698	0,000	0,831	0,000	0,2512	0,1885	1,860	0,174
	val accuracy	0,982	0,246	0,902	0,000	0,0219	0,0220	0,283	0,595
	val precision	0,920	0,000	0,963	0,011	0,0503	0,0477	0,086	0,770
	val recall	0,984	0,335	0,984	0,316	0,0900	0,0895	0,048	0,826
	val roc auc	0,988	0,587	0,984	0,360	0,0196	0,0197	0,007	0,933

*statistically significant results noted red ($\alpha = 0{,}05$)

transformation and the manual transformation do not show statistically significant differences. Considering the results of the Leaven test (Table 3), it can be concluded that the automatic transformation produces statistically indistinguishable machine learning effects as the manual transformation of the database.

The behavior of the distributions of the machine learning accuracy measures is presented in Fig. 1. The figure is based on the median measure and highlights the scatter in the values of the measures as well as the asymmetry of the distributions (pronounced in the case of val_loss). As can be seen, the differences in the distributions in the sample are minimal and mainly relate to the few cases of extreme observations, in which the deep learning model had a specific instability. It is an inherent component of machine learning and is often due to the specifics of hardware and computing power (Fig. 2).

5 Conclusions

Data transformation is a key and so far, time-consuming step in analyzing the learning and validation set for deep learning methods. It usually relies on manual or semi-automatic methods that require interaction with an expert. While manual transformation methods involve systematic ordering, completion, step-by-step integration of databases. The authors of this paper propose an approach to automation in line with manual methods: unlike in semi-automatic methods, automation does not rely on the establishment of a specific schema, a pattern for the database transformed. The automation method presented here involves mapping the manual method, based on elementary steps that are as uncomplicated as possible. Optional selection of individual components used in the algorithm allows to have more user control over the transformation process. It should be borne in mind that in practice, manual transformation methods are time-consuming and require

Table 3. Method selection and test results for two dependent samples.

SAMPLE n = 90		TEST FOR TWO DEPENDENT SAMPLES manual versus automatic transformation	RESULT			
Parameter			Z		p-value	
Hashing trick	val loss	Wilcoxon test	0,0968	0,0882	0,099	0,753
	val accuracy	Wilcoxon test	0,0110	0,0103	0,170	0,681
	val precision	t-test for dependent variables	0,0485	0,0491	0,053	0,818
	val recall	Wilcoxon test	0,1047	0,1164	1,016	0,315
	val roc auc	t-test for dependent variables	0,0104	0,0108	0,306	0,581
onehot	val loss	Wilcoxon test	0,2512	0,1885	1,860	0,174
	val accuracy	Wilcoxon test	0,0219	0,0220	0,283	0,595
	val precision	Wilcoxon test	0,0503	0,0477	0,086	0,770
	val recall	t-test for dependent variables	0,0900	0,0895	0,048	0,826
	val roc auc	t-test for dependent variables	0,0196	0,0197	0,007	0,933

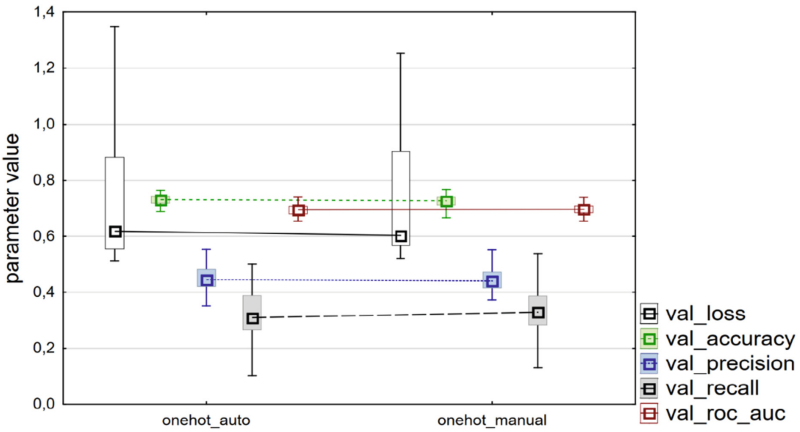

Fig. 2. Visualization of distributions in the automatic and manual transformation for the one-hot decoding method and the hashing trick method.

a certain amount of human labor. Depending on the type and complexity of the database, this manual transformation process can take from several hours to even several days. This is an obvious drawback in an environment where speed of big-data-based decision-making is key to success. In contrast, the duration of the automatic transformation in the presented experiment lasted several seconds. The question is whether it is at least as efficient as the manual transformation. The primary purpose of developing an automatic transformation procedure is to assist the expert in his work, by automating some elements of his procedure. Therefore, the author's algorithm proposed in the paper is not intended to "improve" the expert's work, but to reproduce as faithfully as possible the procedures he undertakes. As this study shows, the results of the automatic transformation, are highly consistent with the results of the manual transformation. In quantitative terms, the automated transformation produces statistically indistinguishable machine learning results from the manual transformation. Therefore, it can be concluded that transformation automation can successfully replace manual procedures. The automatic transformation algorithm presented in the publication is a relatively new development, having been developed in 2023. It therefore requires verification and review. At the current stage of research, it is known that in the case of financial data, containing numerous textual data, inconsistent and without specific formats and types, the algorithm behaves very well. It retains the accuracy of machine learning algorithms. However, so far it has been tested on a single database. It is large, difficult to transform manually, and contains a lot of text variables. Although the results are promising, it should be remembered that this is the initial phase of testing the algorithm. This is because we do not know the stability and effects on other bases, which should be a prelude to further research. The systematization of knowledge about the algorithm will certainly be helped by planning further experiments, which are currently entering the operational phase. Disturbances are introduced into the base in a controlled manner, and the algorithm's threshold of resistance to an increasingly unformed output base is investigated by simulation. This procedure allows identifying the properties of the algorithm and its impact on machine

learning. Completion of this stage will make it possible to test the algorithm on other bases: it will be possible to interpret the results, knowing its stability and resistance to base perturbation. It should also be emphasized that a limitation of the presented inference is the lack of knowledge of how the proposed automatic transformation method affects the learning effects of models other than the one used in the publication. Although the applied deep learning algorithm has been positively verified and is used in practice by leasing companies [13], it will be necessary to study the transformation automation on other machine learning algorithms.

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Clustering Customers' Behavior of an Online Store Offering e-learning Courses Using Machine Learning

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Abstract. Clustering customer behavior is very important issue for improving customer relation-ship management, including online store offering e-learning courses. The aim of the paper is to develop a method for clustering customers' behavior of an online store offering e-learning courses using machine learning. The main contribution of the research is performing the clustering in the context of retention of customers' behavior of an online store offering e-learning courses. The K-Means, self-organizing map (SOM) and Decision tree methods have been used in this research. The research results demonstrated that the primary factors influencing customer segment membership are the recency and monetary score columns, suggesting these should be examined in promotion profiling. Another key finding is that the maximum amount of money spent does not increase indefinitely with the number of purchases. It stays the same after 2 purchases. Conversely, the minimum amount spent rises with the number of purchases, indicating that customers are inclined to buy more courses at discounted prices and are less interested in paying full price after their initial purchase. Each of the conducted analyses suggests that the most important discriminating factor is the type of sales channel. Therefore, as the implication for practice, it seems reasonable to suggest that the price proposition algorithm should take it into account as one of the most important factors.

Keywords: Clustering · customer behavior · online store · e-learning courses · machine learning

1 Introduction

Clustering customer behavior is very important issue for improving customer relation-ship management, including online store offering e-learning courses. Increasingly, customer clustering is being done on the basis of customer retention. Therefore there is no no need to obtain additional data characterizing the user, such as demographics (gender, age, etc.), and the ability to operate in the absence of the availability of additional data

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 166–182, 2024.
https://doi.org/10.1007/978-3-031-78468-2_13

(this is a key benefit for new customers who are not registered in the CRM system, but use it anonymously through the website). However there is also a lack of research on the use of machine learning methods (including deep learning) to clustering the customer behavior of an online store offering e-learning courses on the basis of customers' retention. It should be noted that e-learning courses, have characteristics that distinguish them from products and services in other market sectors. These features include, among others: availability regardless of place and time, ease of personalization, a certain level of information coverage, a specific user interface. These features mean that for the computer application market, particularly e-learning courses, the application of a general approach to retention analysis, or approaches used for other market sectors, may not be sufficient. At the same time, it should be noted that since machine learning methods, including deep learning, are used for other market segments, it is highly likely that they will allow to improve the retention analysis process and obtain the features of innovative technologies, also with regard to the computer applications segment, including e-learning courses. Their advantage over other methods used in retention analysis is, among other things, their ability to, classify, recognize, detect, describe data and automatically analyze cause-and-effect relationships between data.

The aim of the paper is to develop method for clustering customer's behavior of an online store offering e-learning courses using machine learning. The main contribution of research is performing the clustering in the context of retention of customers' behavior of an online store offering e-learning courses. The remaining part of the paper is structured as follows: Sect. 2 presents the background. The data description is presented in Sect. 3. Section 4 presents methods used in the research. In Sect. 5, the results are presented and discussed. Section 6 summarizes the paper's findings and indicates the future research directions.

2 Background

Much research considering e-learning courses and machine learning concentrates on effective recommendation systems for new learners based on customers' behavior or course information. Abhirami et al. [1] analyzed online learners' behavioral characteristics and motivation factors towards the learning process and presented an intelligent model for an e-learning system with a supervised machine learning algorithm to offer personalized learning courses and to improve the learner's performance. Other researchers proposed a novel algorithm named MK-means by exploiting the cluster-wise weighing co-association matrix mechanism and improving the K-means algorithm based on the mean shift theory [2] to recommend high-quality online education services. The results showed that this model may support personalized e-learning in a wide range. Cansiz et al. [3] employed Complex Event Processing (CEP), Association Rule Mining (ARM), and Clustering methods based on distributed software architecture to model student activities on e-learning platforms. Different modules that work in real time were developed. An admin panel was also created to control all modules and track student actions. Another research [4] focused on an effective online course recommendation system with sentiment analysis using hybrid similarity-based approaches. The input text online course information was pre-processed with different combinations of approaches. Afterward,

effective feature extraction was performed, and courses were categorized. Then, the course was recommended to users based on their interests. A similar system is proposed in [5], where a procedure for finding the best e-learning course is designed. First, the course description was analyzed, and after that, their keywords were used to identify a particular subject of the user's interest. The second phase was the prediction of queries of specific links to e-learning websites. The proposed procedure used content mining, lexical analysis, classification, and machine learning-based prediction as its key features. Another research [6] used multicriteria ratings extracted from users' online reviews to propose course recommendations according to the users' preferences and behavior. Latent Dirichlet Allocation (LDA) for text mining, Decision Trees for decision rule generation, Self-Organizing Map (SOM) for users' reviews on courses, and the fuzzy rule-based system for users' preferences prediction were used. The results showed that the method accurately provides relevant courses tailored to users' preferences. Dahdouh et al. [7] developed a distributed courses recommender system for the e-learning platform for new students at a university who need a system to help them take the relevant courses that consider each learner's requirements and needs. The system is to discover relationships between students' activities using the association rules method to help choose the most appropriate learning materials. Also, past historical data on course enrollments or log data is analyzed. The experimental results show the effectiveness and scalability of the proposed system. Bhaskaran et al. [8] designed and analyzed an efficient machine learning-based hybrid recommendation system with enhanced density-based spatial clustering for digital e-learning applications. The authors indicate that the limitations in well-known recommender systems are variations in the expected absolute error, consuming more query processing time, and providing less accuracy in the final recommendation. In their research, new strategies were experimented with to improve the performance of a hybrid recommender. They analyze the confidential rate of learners and provide the best recommendations. The proposed model is simulated on public datasets for machine learning. The experimental analysis concludes that the enhanced clustering strategy discovers clusters that are based on random size. The proposed recommendation strategies achieve better performance than other methods. Rahman et al. [9] show how data mining techniques such as clustering and association rule algorithms can be used on historical data to develop a unique recommendation system module for online courses. The methods can be used to unearth hidden relationships between topics and trends in student performance. K-means clustering was used to provide instructors with visual representations of the generated associations, which helps organize the data and supports the verification of the relationship between topics. Another study on students' results was conducted by Rao and Kumar [10]. They applied existing models, such as a student performance prediction model based on a supervised learning decision tree classifier, to predict students' final grades using a Recurrent Neural Network (RNN) from the log data stored in the educational systems. The experimental results, compared with multiple regression analysis, confirmed that an RNN is effective in the early prediction of a final and suitable job for the student based on their academic performance and knowledge of skill set. E-learning studying often requires group formation to improve the learning outcomes. This is mainly done randomly since university

courses are attended by different students. It saves time and resources, but student heterogeneity in terms of learning capabilities is not guaranteed. Nalli et al. [11] proposed an intelligent application that allows the creation of heterogeneous groups by using machine learning. First, it uses clustering algorithms to identify homogeneous groups that are composed of students having similar behavior. Then, heterogeneous groups are created by combining students selected from different homogeneous groups. The application was implemented in real e-learning courses. An increasing offer of online courses to students makes it difficult to locate specific information. Recommendation systems based on machine learning techniques and algorithms are used to reduce this complexity. However, such systems face data scarcity, cold-start, scalability, time consumption, and accuracy challenges. An overview of recommendation systems in the e-learning context following four strands: Content-Based, Collaborative Filtering, Knowledge-Based, and Hybrid Systems was performed [12]. The authors developed a taxonomy based on the components required to develop an effective recommendation system. They indicate that machine learning techniques, algorithms, datasets, evaluation, valuation, and output are the necessary components. A systematic review of deep learning-based recommendation systems in e-learning environments is presented in [13]. The authors introduced a classification of deep learning techniques for course recommendation. A detailed analysis of the existing recommendation systems is conducted based on the collected literature. A summary of the existing research on the use of multilayer perceptual machines, recurrent neural networks, convolutional neural networks, neural attention mechanisms, and deep reinforcement learning-based recommendations in e-learning environments was presented. Also, the flaws in the current recommendation systems are discussed, and opportunities for future research are identified. Much less research is done to help the sellers deal with sales or customer retention. Improving e-commerce sales performance on the social web is the subject of another research [14]. The authors describe different machine-learning algorithms that may be used for data analysis to help identify patterns in the data to strengthen the enterprise to lead the market more effectively with timely product marketing, timely introducing product promotions, and providing a better quality of services. Customer retention prevention using machine learning was researched by Shobana et al. [15]. Companies in the e-commerce sector compete for survival by trying to get other companies' client databases while keeping their current customers. As the cost of acquiring new customers rises, detection and prevention of churning customers are important, as well as understanding why the customer decided to go away to apply suitable strategies. Machine learning and data mining were used to analyze each customer's information kept by the e-commerce company, including searches made, purchases made, frequency of purchases, reviews left, and feedback given. The process for forecasting e-commerce customer attrition based on support vector machines and a hybrid recommendation strategy for targeted retention initiatives was presented. The results show that suggesting reasonable offers or services can prevent future customer churn. To effectively create a customer churn retention strategy, categorization of the various lost customer types is essential.

3 Data Description

The purpose of this stage was to prepare a training set, as well as a preliminary analysis of historical data, which will allow finding statistically significant dependencies affecting the sale of educational courses offered by a CRP company. The following actions were performed:

1. Data acquisition - customer data was collected from the existing CRM system and from the www.synerise.com system. The obtained data was saved in the form of a set of user data and markers describing their retention.
2. Selection of data features - a selection of data features that can be used to build a data model in machine learning methods was carried out.
3. Value transformation - it consisted in replacing the values of source variables with values that can be processed by machine learning methods. In this task, activities aimed at standardization and normalization of the obtained data were also carried out.

The "raw" data in the sales.csv database contained 55443 records described by 49 columns. The data were merged with collections exported from the configuration and expansion database tables, as shown in Table 1.

Table 1. Method of linking data for analysis

Source set	A field in the source file	Attached set	A field in an appended set	Binding type	Target set
sales.csv	channel_id	channels.csv	channel_id	inner	sales_df
sales_df	discount_code	kody.csv	code	left	sales_df
sales_df	course_id	courses.csv	corse_id	inner	sales_df
sales_df	name	kurs.csv	nazwa	inner	sales_df
sales_df	id_kurs	kurs_kategorie.csv	id_kurs	inner	sales_df
sales_df	id_kategoria	kategorie.scv	id_kategoria	inner	sales_df

After adding the configuration and extension data, the set contained 50,327 records described by 107 fields (variables). The fields sale_id, email, date and price were highlighted in the result set. The email field has been anonymized - replaced by numeric tokens (ids). For these data, an RFM (Recency, Frequency, Monetization) analysis was performed. The result set was connected with the processed set (sales_df) via the email field. The fields selected for the final analysis are presented in Table 2.

Null values (NA) were removed from the dataset. In the end, after initial preparation, the dataset had 31,667 records and 10 fields defined. The next step was data transformation. When starting the data transformation process, the sales.csv input file had to be adequately prepared. In several places, the data contained gaps or notes left by the administrator. It gave the impression that the dumps from the database were combined into one CSV file. Fortunately, this was not a recurring problem, so it was easy to correct

Table 2. Fields selected for analysis

Field (variable) name	Type	Meaning
nazwa_kategoria	Nominal	Course category name
name_channel	Nominal	Sales channel name
cena	Metric	Course price
czas_trwania	Nominal	Course duration (as a text string)
type_course	Nominal (binary)	Online or on-site course
discount_used	Nominal (binary)	Whether a discount was applied
Sex	Nominal (binary)	Sex
Recency	Metric	R - Relevance - time elapsed since the last purchase (destimulant)
Frequency	Metric	F - Purchase frequency (stimulant)
Monetization	Metric	M - Monetization (stimulant)

it manually and then save the file. Thus, the data set was brought to the appropriate table. The next step was to convert sales data to RFM (described in more detail at: https://how-many-steps-inc.webflow.io/rfm-segmentation-overview, March 29, 2023). In this way, a table with recency, frequency, and monetary values for each client was obtained, where:

- Recency is a value describing how long ago the customer made a purchase.
- Frequency describes how often the customer makes a purchase in a given period. Due to the fact that we are examining historical data for the analyzed period, all the time covering all observations was adopted, bringing the frequency to the number of customer transactions.
- Monetary is the total value of money spent by the customer in the system.

The data was calculated based on the price and date columns from the sales.csv file, with the email column used as the user's index. The resulting RFM data set is presented in Figs. 1 and 2, where frequency values are in four groups. Figure 2 shows, among other things, a distribution chart of customer monetary values versus frequency values, revealing that higher purchase frequencies are associated with higher transaction amounts. Conversely, customers with lower purchase frequencies tend to spend less money per transaction.

4 Methods

The following methods have been used in this research:

1. K-Means algorithm is one of the most popular data mining algorithms. It is an unsupervised algorithm and is used for data clustering. Its applicability in many areas comes from its implementation simplicity and low computational complexity. Clustering algorithms exploit the underlying structure of the data distribution and define

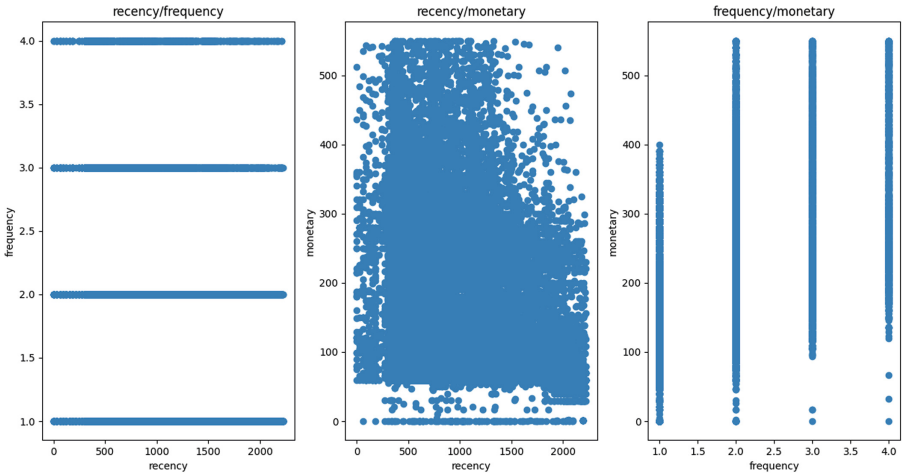

Fig. 1. RFM structure of sales data.

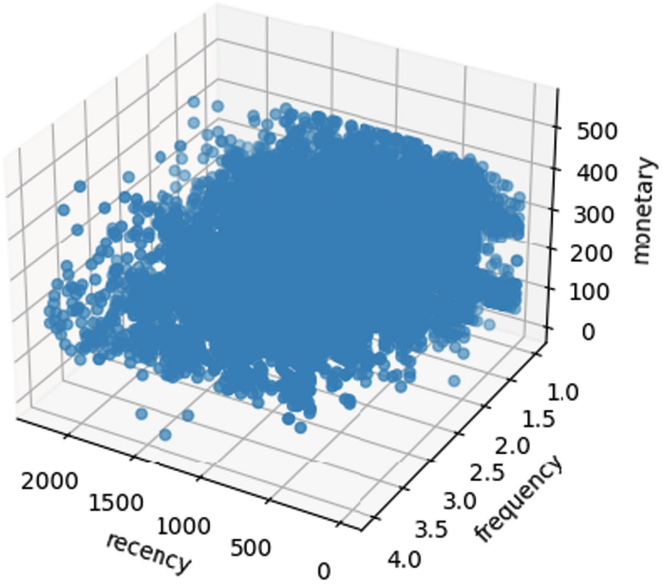

Fig. 2. Views of RFM structure.

rules for grouping the data with similar characteristics. The main disadvantage of using this method is that users must specify apriori the number of clusters in a dataset while the initial cluster centers are randomly selected. Moreover, the algorithm's performance is susceptible to the selection of the initial cluster, which may make determining the optimal number of clusters for large datasets complex. The issues mentioned above and other issues regarding the operation of the algorithm indicate

that the k-means is not exactly an unsupervised clustering method. Much research has been conducted on improving the K-means algorithm's performance and robustness, but there is no universal solution for these problems; each of the existing variants of the algorithm is either application-specific or data-specific [16–18].

2. The self-organizing map (SOM) is based on an unsupervised learning algorithm. It has visualization capabilities to give an informative picture of the data. It is an artificial neural network technology that is used to conduct dimensionality reduction, mining, and rule summarization of data. SOM is suitable for dealing with complex discrimination and classification problems and is applied mainly in research for hydrology, the environment, and other related fields [19–22], but also for customer segmentation[23–25].
3. Decision tree (DT) is a basic supervised algorithm in machine learning and is mainly used to solve classification problems. Supervised algorithms get labeled sample data for training, based on which they predict outputs. After training, the model is tested for correct and exact outputs with random data. DT consists of two types of nodes. The first one is the decision node, which represents the structures of the branches of a tree; it is a decision node. The second is the leaf node, which is the output of decision nodes and has no further branches. The algorithm's name comes from its structure, as it is similar to a tree. The decision tree divides data into sub-trees based on the answer to a question, e.g., specific value, i.e., whether a value is below or over the borderline. This algorithm has two variants: the classifying one and the regression one. The classifying tree has a categorical variable as the target, and the regression one may have a constant variable as the target. The main advantage of using this algorithm is its simplicity and ease of interpretation of results. It also has no data type constraints, as it may handle numerical and categorical variables. The main problem may be overfitting. However, pruning and setting model parameters may limit or eliminate it [26].

5 Results

The K-Means, Self-Organizing Map (SOM) - Kohenen network, and decision trees algorithms, all implemented in the sci-kit learn package, were used for clustering. The comparison was conducted on the RFM data described in Sect. 3. The first analysis was done with the use of the K-means algorithm for 10 clusters. The results are shown in Figs. 3 and 4.

As shown in Figs. 3 and 4, the main data defining the segments are the recency and monetary score columns. To confirm this thesis, the clustering process was repeated on 2 clusters. The results are presented below in Figs. 5 and 6.

The results presented in Fig. 6 confirm that the main factors belonging to a specific segment are recency and monetary score columns. This data is the most dispersed, allowing for the best differentiation between segments. The threshold value for recency, determining the membership between these clusters, was around 1100.

Another approach involved using the SOM algorithm on the same dataset and conducting the same research, first for 10 clusters and then for 2. The results of the analysis with 10 clusters are presented in Figs. 7 and 8.

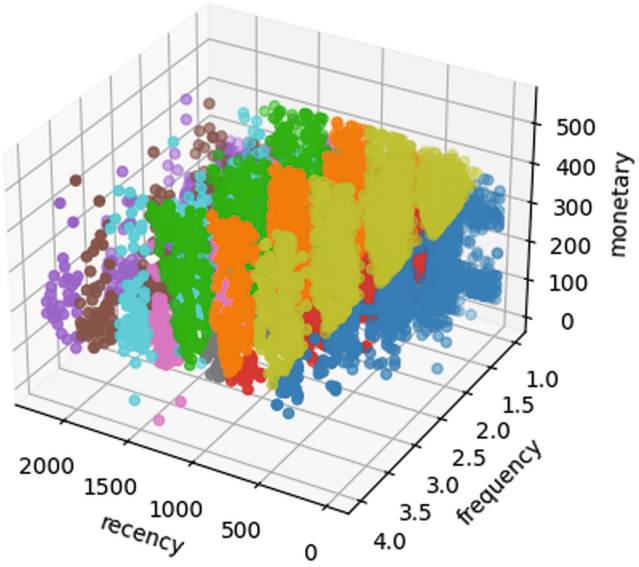

Fig. 3. RFM structure with superimposed clusters (number of clusters: 10; algorithm: K-Means).

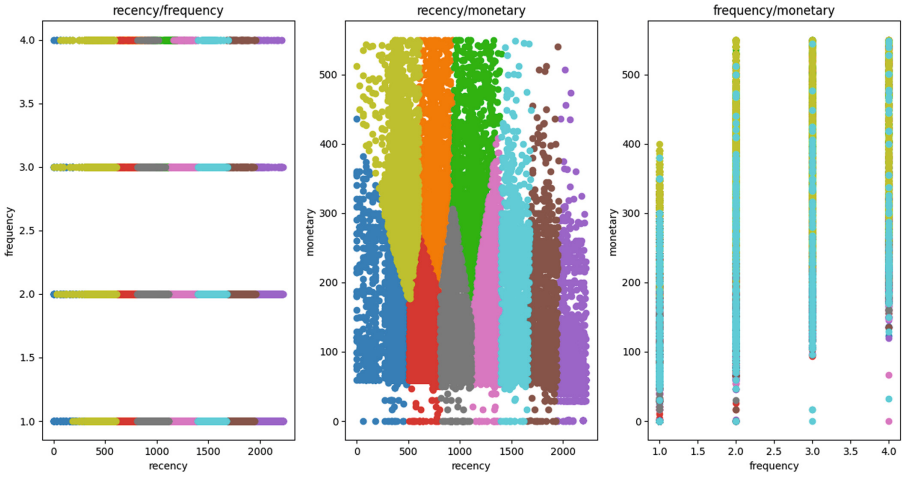

Fig. 4. Views of RFM structure with superimposed clusters (number of clusters: 10; algorithm: K-Means).

As with the K-Means algorithm, the recency and monetary score columns had the greatest impact on the segmentation, which was confirmed by the analysis with 2 clusters (Figs. 9 and 10). However, in the case of the SOM algorithm, the threshold recency value was slightly below 1000.

The results of the segment analysis with the SOM algorithm for 2 clusters (Fig. 10) corroborate those obtained with the K-Means (Fig. 6). Based on the structure of the

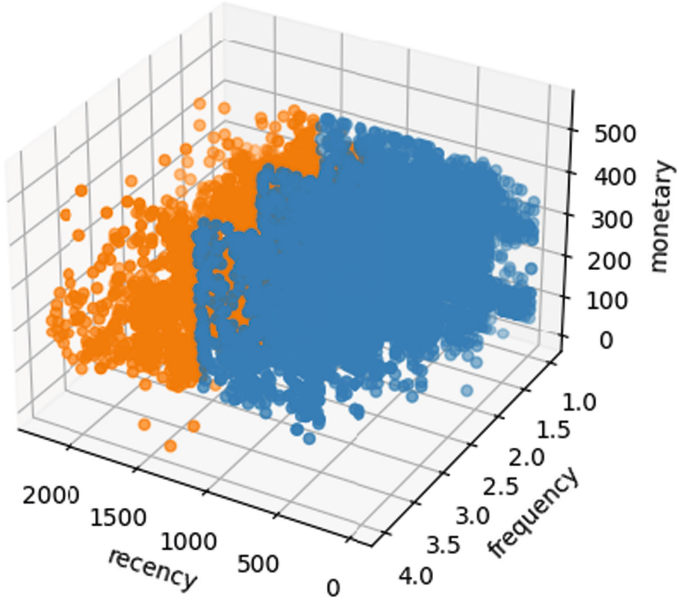

Fig. 5. RFM structure with superimposed clusters (number of clusters: 2; algorithm: K-Means).

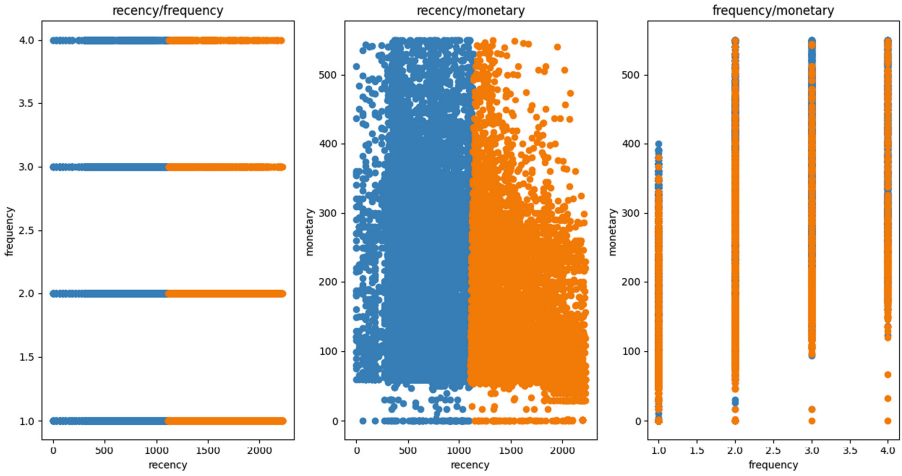

Fig. 6. Views of RFM structure with superimposed clusters (number of clusters: 2; algorithm: K-Means).

RFM, user behavior can be described, and assisted by one of the clustering algorithms, user segmentation can be performed.

The next part of the research focused on factors influencing relevance (Recency), using a classification tree for the analysis. Figure 11 presents the classification tree model explaining the variable R (Recency) and its descriptive summary.

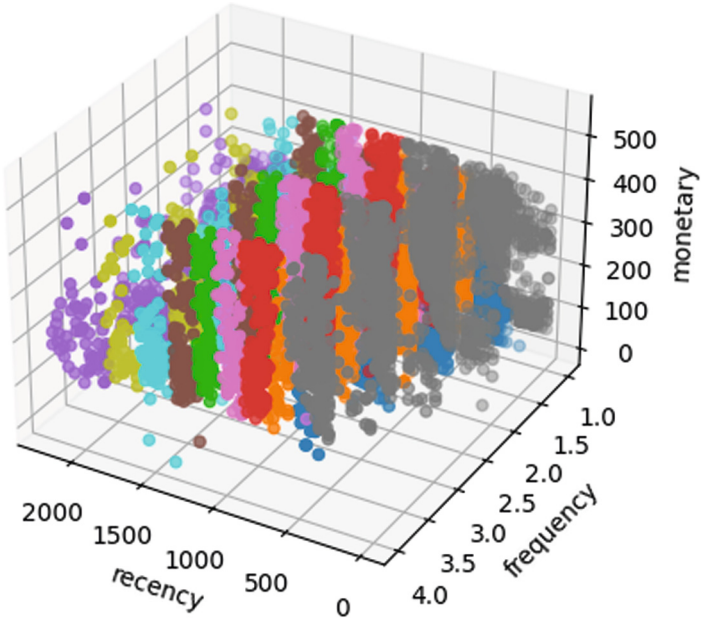

Fig. 7. RFM structure with superimposed clusters (number of clusters: 10; algorithm: SOM).

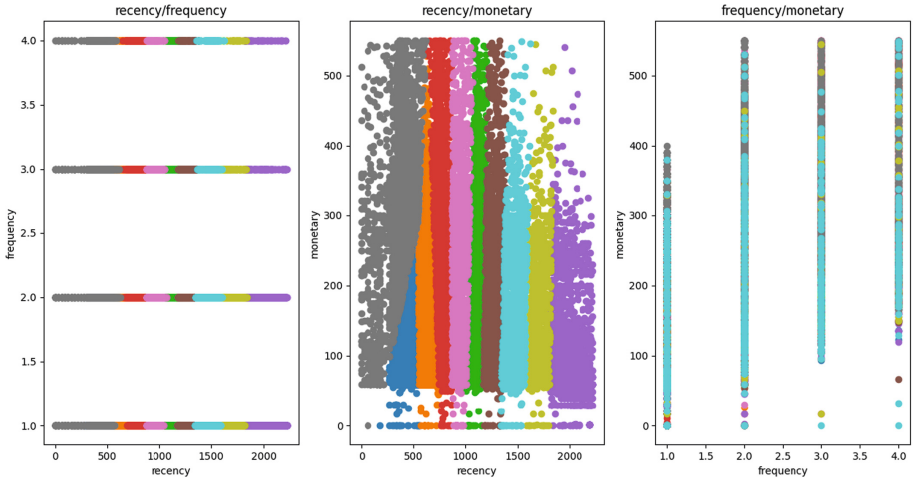

Fig. 8. Views of RFM structure with superimposed clusters (number of clusters: 10; algorithm: SOM).

The most differentiating factor in terms of variable R was the type of sales channel. For the channels: *Caritas, Firma/Instytucja, WWW,* and *Wyjatkowy prezent*, the average value of the R variable was 863.6028. In this group, for courses priced at 325 or higher, the average R value was 641.2411, while for other courses, it was 904.7086. For the

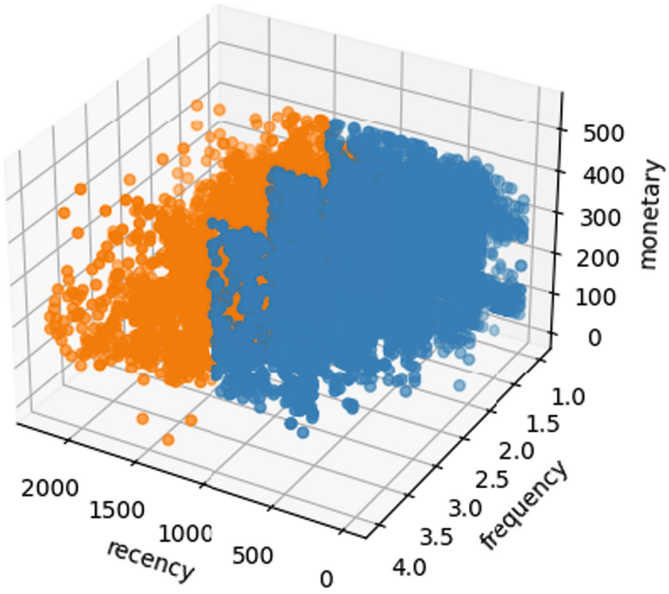

Fig. 9. RFM structure with superimposed clusters (number of clusters: 2; algorithm: SOM).

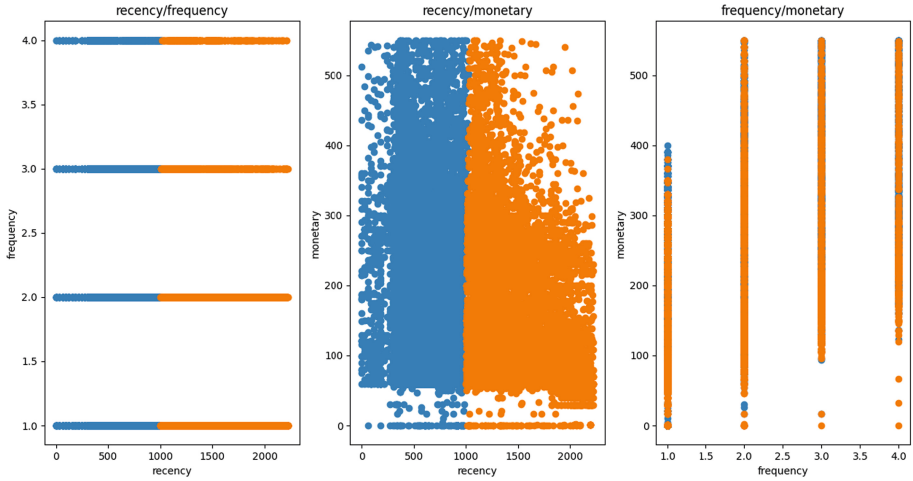

Fig. 10. Views of RFM structure with superimposed clusters (number of clusters: 2; algorithm: SOM).

channels: *Akcje Specjalne, Cross-Selling, Fast Deal, Groupon, Inne, Okazik*, the average R value was 1215.980. In this group, for courses priced at 305 or higher, the average R value was 877.6539; whereas for courses, it was 1313.3460. At further levels of the tree, the variable: *nazwa_kategorii* also demonstrated discriminatory ability.

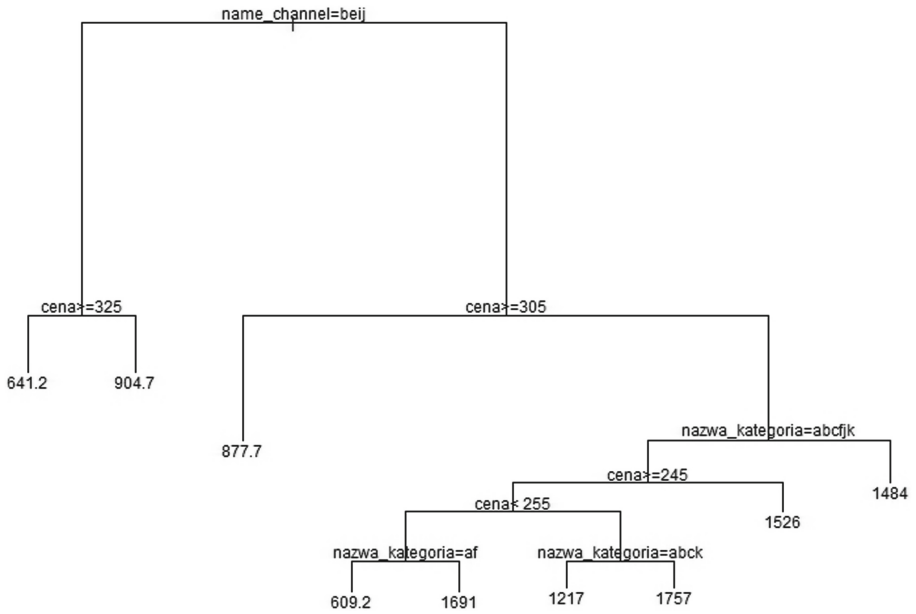

Fig. 11. Classification tree model for variable R.

Another analysis was conducted to identify factors affecting purchase frequency (Frequency) using a classification tree. Figure 12 presents the classification tree model explaining the variable F (frequency) and its descriptive summary.

The most differentiating factor in terms of variable F was the type of sales channel. For the channels: *Caritas, Cross-Selling, Firma/Instytucja, Groupon, Inne,* and *Wyjatkowy prezent*, the average value of variable F was 1.472634. In this group, for courses with an unused discount, the average F value was 1.424258, while for courses with a discount, it was 1.95586. For the channels: *Akcje specjalne, Fast Deal, Okazik,* and *WWW*, the average F value was 1.757308. In this group, for courses with an unused discount, the average F value was 1.730266, while for courses with a discount, it was 2.238614. At further levels of the tree, the variable *nazwa_kategorii* also demonstrated discriminatory ability.

The factors influencing monetization were also analysed using a classification tree. Figure 13 shows the classification tree model explaining variable M (monetization) and its descriptive summary.

The most differentiating factor in terms of variable M was the type of sales channel. For the channels: *Akcje specjalne, Caritas, Cross-Selling, Fast Deal, Groupon, Inne,* and *Okazik*, the average value of variable M was 111.5801. For the channels: *Firma/Instytucja, WWW,* and *Wyjatkowy prezent*, the average value of variable M was 286.7237. In this group, for courses priced lower than 255, the average M value was 238.0672, while for other courses, it was 302.1743. The remaining variables do not show discriminatory capacity in terms of variable M.

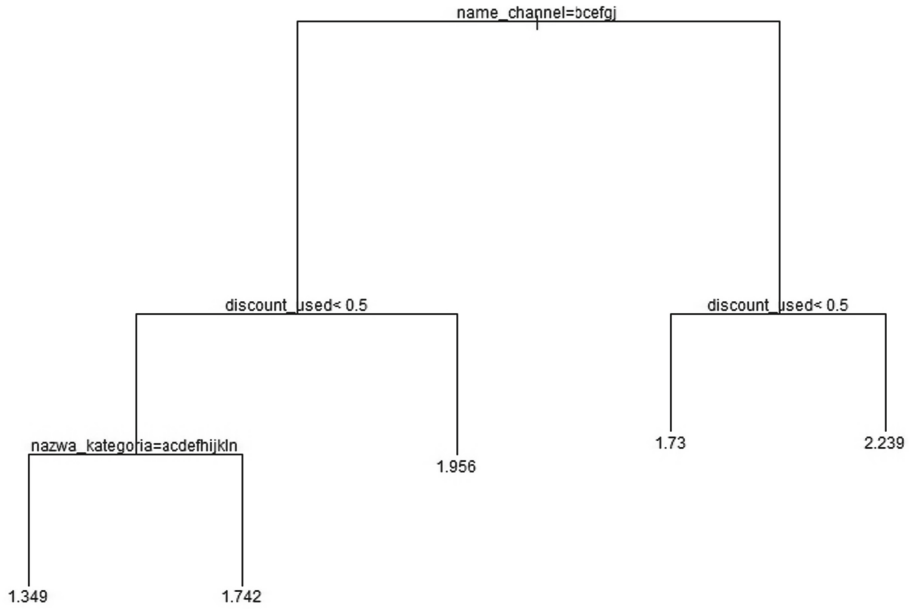

Fig. 12. Classification tree model for variable F.

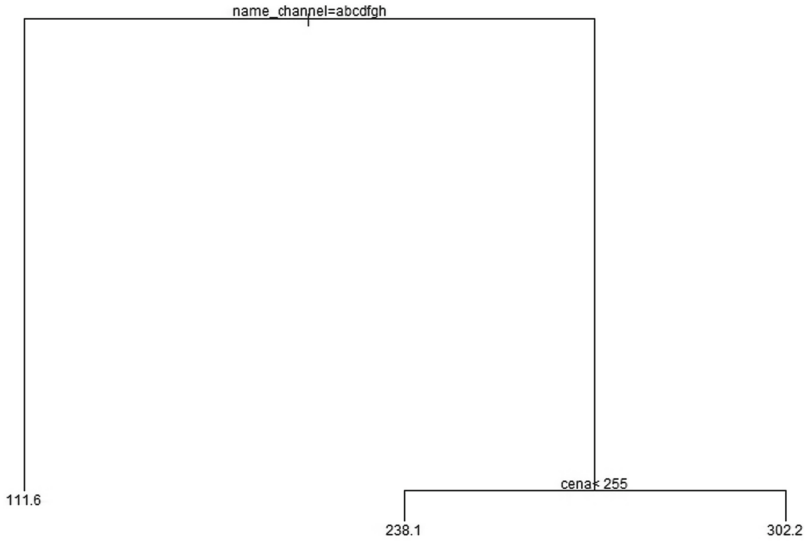

Fig. 13. Classification tree model for variable M.

6 Conclusions

The method for clustering customers' behavior of an online store offering e-learning courses has been developed in this research. A feature that distinguishes the developed approach from existing approaches is the use of customer retention data to build machine learning models. The K-Means, self-organizing map (SOM) and Decision tree methods has been used in this research. The research results demonstrated that the primary factors influencing customer segment membership are the recency and monetary score columns, suggesting these should be examined in promotion profiling. Another key finding is that the maximum amount of money spent does not increase indefinitely with the number of purchases. It stays the same after 2 purchases. Conversely, the minimum amount spent rises with the number of purchases, indicating that customers are inclined to buy more courses at discounted prices and are less interested in paying full price after their initial purchase. Each of the conducted analyses suggests that the most important discriminating factor is the type of sales channel. Therefore, as the implication for practice, it seems reasonable to suggest that the price proposition algorithm should take it into account as one of the most important factors. The main limitation of research is using only one dataset for performing three experiments. Another limitation is using three methods for clustering. Also other clustering methods, such as DBSCAN or OPTICS should be used in further research. A In the future research it also seems advisable to propose a method of price differentiation for different groups of courses and for the original price level. Factors that are irrelevant to the RFM analysis and the final pricing algorithm include the type of course, the gender of the buyer, and the duration of the course.

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Prediction of the Importance of Factors Influencing Co-sharing Attitudes Using Machine Learning

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Abstract. The sharing economy concept has been gaining importance in recent years. It promotes environmentally friendly practices. A growing group of consumers values access to goods or services more than ownership, leading to better use of resources. Getting information on factors influencing co-sharing attitudes is essential for market competition. As the most common marketing research method is a survey and the survey response rate is lowering, machine learning methods may be employed to predict factors importance based on a sample of previous research results. The aim of the research was to determine the possibility of classifying co-sharing survey respondents depending on their method of assessing each decision-making factor separately using selected machine learning methods. XGBoost, decision trees, and LightGBM models were used. The input data were the respondents' characteristics, and the output data was the importance of eight factors in the co-sharing decision-making process. The accuracy of built models was the highest for sharing preference using all three methods: LightGBM (0.715), decision trees (0.704), and XGBoost (0.660). Considering the accuracy for all the factors, the most suitable method was decision trees (mean 0.551) and the worst XGBoost (mean 0.484). The presented research shows that there is a possibility of predicting the importance of decision-making factors based on respondents' characteristics. The research results may be essential for smaller companies that do not have the funds or time to take extensive market surveys.

Keywords: neural networks · prediction · machine learning · sharing economy · decision-making process

1 Introduction

Sharing goods and services has been practiced for ages. Recently, it has gained much more attention and popularity because of technological advancements, the use of information and communication technologies (ICT), and unlimited access to the Internet, allowing people who do not know each other to communicate and share resources that

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 183–195, 2024.
https://doi.org/10.1007/978-3-031-78468-2_14

previously were out of their range [1]. The concept known as the sharing economy promotes environmentally friendly practices. A growing group of consumers value access to goods or services more than ownership, leading to better use of resources [2]. The provider, who is the owner of goods, is connected online through a commercial networking system with a customer, who acquires temporary ownership of offered goods for a fee. Such a business model causes market globalization, enables easy interaction and dialogue, and allows the possibility to read others' reviews and opinions, supporting the selling process [3].

The market is constantly researched to get information about customers, their needs, and the factors influencing their decisions. The main research method in marketing is a survey. The response rate in marketing surveys is essential for the quality of survey results. When it is low, the analysis of the results is also low quality, and it is impossible to generalize the results. The high response rate is important because companies need to evaluate customers' attitudes toward services or products. These attitudes indicate long-term customer behavior and may influence the success of companies in terms of customer retention and market share [4].

New technologies come with some solutions. One of them might be to predict survey responses based on respondents' characteristics to get missing responses. Companies usually have large databases of selected customer characteristics. They also sometimes have survey results conducted on the part of the clients. Based on real survey results, it is possible to predict the responses of the rest. Machine learning techniques give such opportunities.

The aim of the research was to determine the possibility of classifying respondents of a survey considering co-sharing attitudes, depending on their method of assessing each decision-making factor separately using selected machine learning methods. Separate estimation of each model for each factor corresponds to how the factors were created: they are assumed to be independent and unrelated to each other (orthogonal rotation). The model's input data were the respondents' characteristics, and the output (classifying variable) was the respondent's assessment of a given factor of co-sharing.

To achieve the aim of the study, two hypotheses were posed. The methodological hypothesis assumes that the machine learning model effectively assigns qualitative and quantitative respondents' characteristics to how individual factors are assessed. The hypothesis will be verified positively if the model parameters are satisfactory. The second hypothesis is the cognitive hypothesis, which assumes that how a respondent evaluates individual decision-making factors depends on their individual characteristics. This hypothesis will be verified based on the interpretation of the model.

The structure of the paper is as follows. Section 2 presents the related works. Section 3 indicates materials and methods, including data source, data preparation, and modeling. In Sect. 4, the results are presented and discussed. Section 5, the conclusion, summarizes the paper's findings and indicates the future research directions.

2 Related Works

Recent studies have examined the components of the decision-making process for sharing goods and services. In the context of the sharing economy, various literature reviews have been conducted focusing on different industries and sectors [1]. Only a few selected

works have attempted to provide a critical perspective on the sharing economy by exploring all its key aspects across different industries and sectors [5–7]. Kong et al. [3] investigated how social and technical factors affect consumer trust in sharing goods and services and how this trust subsequently influences continued usage and positive word-of-mouth recommendations. Mitake et al. [8] identified key motivations for asset providers in the sharing economy, including economic, environmental, social, and altruistic reasons, as well as the perceived usefulness of sharing. For service or goods receivers, the study highlighted six motivating factors: economic, environmental, and social motivations, enjoyment, familiarity, and usefulness. Additionally, a survey confirmed the significance of social motivation, familiarity, self-actualization, economic motivation, and enjoyment in the context of sharing services. Pelgander et al. [9] also investigated trust in sharing transactions, focusing on how trust constructs from relational interactions manifest in the sharing economy. They found that users' trust in providers is based on emotional traits, while trust in the platform relies on functional components, with the platform and providers complementing each other in building trust.

Grybaitė et al. [10] identified several technological factors influencing the sharing economy in European countries, such as the level of interest access, technological literacy, and the smartness of technology. Additionally, social-demographic factors like population structure, including population density and the number of women per 100 men, a sustainability mindset (including the generational shift in consumption habits, value-driven minimalism), trust factors, entrepreneurial spirit and aspiration, and dependency on technology (including knowledge level, participation in social networks) also significantly influenced sharing economy practices in Europe.

Alraeeini et al. [11] identified several influential drivers of sharing services in accommodation areas, including lower costs, ease of use, contribution to the development of the local economy and residents, innovative technologies, social media, and the ability to increase the usage of existing products and reduce the use of raw materials. Economic factors such as the uncertainty of a country's economic performance (including 'GDP per capita' and 'total unemployment rate') and 'new opportunities' (including 'lower transaction costs', 'investment into SE business/R&D,' and 'economic benefits') were highlighted as well. Veith et al. [12] pointed out that factors such as 'openness to the IT industry,' a 'legal and regulated framework' for the sharing economy, and 'new technologies' enhance the acceptance of the sharing economy. Moreover, Nastase et al. [13] observed that economic, social, environmental, technological, and cost factors facilitate the development of sharing economy businesses.

Although there is growing enthusiasm for the sharing economy concept, there is a lack of studies focusing on the application of machine technologies to assess the factors influencing sharing economy decisions, which are crucial for understanding its key aspects. Therefore, this article tries to fill this research gap.

3 Materials and Methods

3.1 Data Source

The data used in the research were taken from a survey conducted on a group of 1623 respondents [14], which was a representative group of the population of Poland. The questionnaire consisted of questions about their characteristics and the selected aspects of their attitudes connected to co-sharing goods and services. The answers to respondents' characteristic questions were single-choice descriptive answers, and the answers to the questions about co-sharing were given on a 7-point Likert scale from 0 to 6.

Based on the answers obtained, the dimensions of the research area were reduced by using EFA with varimax rotation. The method allowed authors to isolate key factors in respondents' assessments. These factors were subjected to further statistical analysis. As a result, the key decision-making factors of the prosumer attitudes were identified and indicated with the use of EFA. These factors were: sharing preference, trust, realized benefits, propensity to propagate, risk awareness, aversion to sharing, willingness to share, and the limits of anonymity [14]. The factor loadings were expressed as numbers from 1 to 6 in increments of 0.2.

3.2 Data Preparation

The dataset taken to modeling consisted of five respondents' characteristics (sex, age, education level, place of residence, subjective income satisfaction) and values of eight factors influencing co-sharing. The factors of co-sharing indicated above were used as classification (target) variables in the models built.

The database needed filling in and transformations. Missing data (relatively few) were filled with the average; the distribution of the variable with missing data was symmetric and close to normal. The answers to respondents' characteristic questions (models' input data) were transformed into numbers:

- quantitative interval data were recoded into an ordinal numerical variable of the mean value from the interval;
- ordinal text data was recoded into an ordinal numerical variable;
- categorizing text data was recoded into consecutive integers.

Factor values (models' output data) were recoded with three levels:

- level 0 was defined when a factor value had a mean value within its confidence interval. This level should be defined as an indeterminate assessment; the respondent cannot decide whether a given factor is important to him or not in relation to the population;
- level -1 when values were below the confidence interval. This means that the respondent assesses a given factor as insignificant in relation to the population;
- level +1 when values are above the confidence interval. The respondent assesses the impact of a given factor relatively highly.

Factor coding favors the minimization of unmarked states in favor of states that discriminate between respondents. The sample of the dataset is presented in Fig. 1.

	ID	sex	age	education level	place of residence	income satisfaction	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity
0	215266460	0	35	1	150000	2	1	-1	-1	1	-1	-1	1	0
1	645962108	0	21	2	500	2	-1	1	-1	1	1	-1	1	0
2	486093889	0	65	2	10000	2	-1	1	1	1	1	1	1	-1
3	482427625	1	45	1	500	2	-1	1	-1	-1	1	-1	-1	1
4	687279783	0	65	1	75000	1	-1	-1	1	-1	1	-1	1	-1
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1618	697324067	0	55	3	350000	2	1	1	1	1	1	-1	1	1
1619	715169535	0	21	2	350000	2	-1	1	-1	1	1	1	1	1
1620	723367197	1	45	2	350000	4	1	-1	1	1	1	1	1	1
1621	644210568	0	45	2	150000	2	-1	-1	1	-1	-1	-1	1	-1
1622	711343588	0	21	2	650000	2	-1	1	1	1	-1	-1	-1	-1

1623 rows × 14 columns

Fig. 1. The sample of the dataset.

3.3 Modeling

The dataset consisted of 1623 records and was divided into two sets. The split of the dataset for training and testing was done in the first stage of the research, which is described at the beginning of Sect. 4. Finally, 80% of the dataset (1298 records) was used to train and validate the model, and 20% (325 records) for testing the prediction capabilities of the trees. The set for training and validation was divided into two parts: 80% was used for training (1038 records), and 20% was used for validation of the model (260 records).

In order to predict the importance of factors, three different models were created: a decision tree, a LightGBM, and an XGBoost. The XGBoost model was the main model; the results of the remaining two models were compared to it. Accuracy was the measure that indicated the best model settings, and it was calculated for all the models. For decision trees and LightGBM models, feature importance was measured. Moreover, precision and recall were calculated for decision trees and XGBoost models.

4 Results and Discussion

The first step of the research was to determine the best split of the dataset for training and testing. The stage was realized with XGBoost models. The tested variants of the test set size were: 10%, 20%, 30%, and 40%. In each case, the fixed hyperparameters were used: the *number of jobs* was set at 16, the *maximum depth* of a single tree was 8, and the *learning rate* was 0.2. As the measure that defined the best solution, the accuracy of the model validation was calculated. Table 1 presents the results of this phase of research. The accuracy was measured for each factor separately, and the mean value was calculated. The best results were achieved using test datasets in proportions of 20% and 40%. Based on this, the split at the level of 20% was decided to be used in further experiments in all the models. The choice was motivated by the fact that this way, more data would be assigned to the fitting process and potentially increase the performance of the final model.

Then, the XGBoost models for tested co-sharing factors were built. Among many hyperparameters, the *number of estimators* and the *learning rate* were changed in order to get the best results. The *number of estimators* was changed from 32 to 256, and the *learning rate* from 0.1 to 1.

Table 1. The accuracy of models of dataset split testing stage.

Set size	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity	mean
10%	0.59	0.42	0.37	0.50	0.39	0.43	0.39	0.43	0.44
20%	0.61	0.47	0.38	0.52	0.39	0.44	0.38	0.44	0.45
30%	0.58	0.44	0.40	0.50	0.39	0.42	0.38	0.45	0.44
40%	0.62	0.45	0.40	0.50	0.46	0.39	0.40	0.42	0.45

In all built models, the hyperparameter *number of estimators* influenced the values of the measured parameters significantly, and the *learning rate* had a much smaller impact. Figure 2 shows the measured parameters response surface for the factor with the highest values of the model parameters, *sharing preference*, depending on hyperparameter changes. In this case, it can be noticed that, in general, the more estimators, the lower the value of parameters. The *learning rate* did not have a noticeable impact on measured model parameters. In the case of all the remaining factors, the influence of the *number of estimators* was diverse but always much stronger than the influence of the *learning rate*.

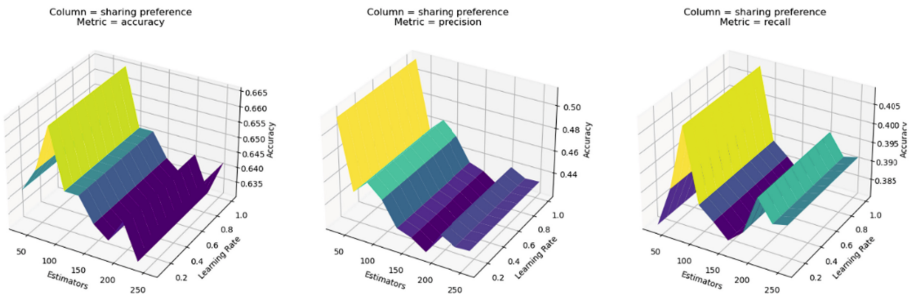

Fig. 2. Parameters' surfaces for factor *sharing preference*.

The best solution was indicated by the accuracy of the model validation. Table 2 summarizes the results of this research phase, presenting the values of the measured parameters of built models: accuracy, precision, and recall for each factor.

Table 2. The parameters of XGBoost models.

Parameter	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity
Accuracy	0.66	0.48	0.36	0.54	0.47	0.48	0.38	0.50
Precision	0.46	0.34	0.38	0.36	0.34	0.35	0.33	0.36
Recall	0.41	0.34	0.32	0.36	0.33	0.33	0.31	0.34

As seen in Table 2, the accuracy of the models is not high. The highest value was obtained for the factor *sharing preference*, 0.66. For most of the remaining factors, these parameter values were in the range between 0.47 and 0.54. The lowest values, 0.36–0.38, were obtained for *realized benefits* and *willingness to share*. The precision and recall of the model for *sharing preference* were also the highest among all the factors and equaled 0.46 and 0.41, respectively. In all the other models, these parameters' values were between 0.31 and 0.38.

In the next phase, decision trees for each factor were built. Among many hyperparameters of decision trees, the *criterion*, which measures the quality of a split, and the *maximum depth* of the tree, which is the number of split levels, were changed in order to get the best results. The *criterion* hyperparameter was changed between gini and entropy, and the *maximum depth* of trees was tested from 2 to 5. As the measure that defined the best solution, the accuracy of the model validation was calculated. Table 3 presents the values of the hyperparameters and results of the decision trees for which the accuracy of model validation was the highest among tested variants, and other selected measures of trees, i.e., the accuracy of validation, precision, recall, and finally, the accuracy of prediction of the values on new data.

As seen in Table 3, the accuracy of the models' validation was, in most cases, between 0.5 and 0.6, except for the model for *sharing preferences*, where the value was the highest, over 0.7. The precision and recall of all trees were low; the highest values were determined for *propensity to propagate*, 0.4 and 0.37, respectively. In other models, the parameters were slightly lower. In most cases, the accuracy of factors' values prediction on new data was lower than the accuracy of model validation. Only for the *realized benefits* tree was it higher. For half of the models, the better hyperparameter *criterion* was *gini,* and for the other half, it was *entropy*. In most models, the best *maximum depth* of a tree was 3.

Among respondents' characteristics, age seems to be the most important feature influencing decision tree models (Fig. 3). It was the most important for five out of eight factors. For two of the remaining factors, the place of residence was the most significant. Income satisfaction seems to be the least relevant for all tested factors.

The last phase included the building of LightGBM-boosted trees. As for decision trees, other models were built for each factor. Among hyperparameters for LightGMB trees, the *learning rate* and *maximum depth* were changed to get the best accuracy. *The learning rate* tested values were: 0.1, 0.5, and 1.0; *maximum depth* was changed between 2 and 5, as in decision trees. Table 4 summarises the models' hyperparameters that obtained the highest accuracy.

The highest accuracy, 0.715, was achieved for the *sharing preference* factor. The value of this measure for other trees was lower, between 0.508 and 0.573. A little lower accuracy was measured for stimulants. In half of the models, the best *learning rate* was 0.1, and in most cases, the best *maximum depth* of a tree was 2. Only for the *aversion to sharing* factor, the best depth was 3 levels.

The feature importance for LightGBM boosted decision trees is presented in Fig. 4. Age is the most important respondents' characteristic for *sharing preference* and *propensity to propagate*. For four of the remaining factors, place of residence is the most significant. The least important feature for all factors is sex.

Table 3. Values of hyperparameters and measured parameters of decision trees.

Parameter	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity
Criterion	Gini	Entropy	Gini	Gini	Gini	Entropy	Entropy	Entropy
Max_depth	3	3	2	3	5	3	5	3
Accuracy of validation	0.704	0.538	0.515	0.585	0.519	0.508	0.515	0.523
Precision	0.230	0.350	0.380	0.400	0.350	0.340	0.340	0.360
Recall	0.330	0.350	0.360	0.370	0.360	0.350	0.380	0.360
Accuracy of precision	0.662	0.511	0.548	0.572	0.483	0.480	0.511	0.511

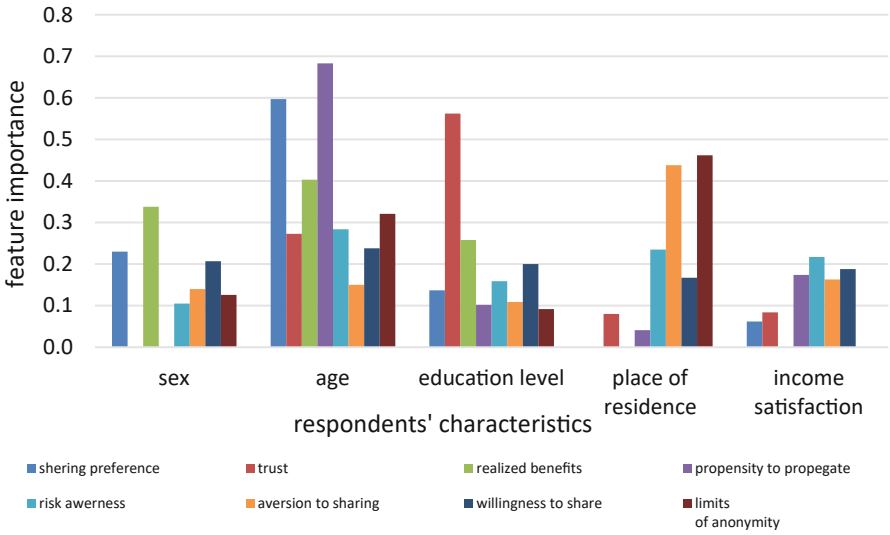

Fig. 3. The feature importance for decision trees.

Table 4. Hyperparameters and accuracy of LightGBM boosted decision trees.

Parameter	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity
Learning rate	0.5	1	0.1	0.1	0.1	0.5	0.5	0.1
Max_depth	2	2	2	2	2	3	2	2
Accuracy	0.715	0.531	0.515	0.573	0.512	0.508	0.504	0.515

After building all the models, the accuracy of the models' validation was compared to asses which method is the best for the prediction of factors' importance in the co-sharing decision-making process. Table 5 summarizes the accuracy of XGBoost, decision trees, and LightGBM models.

Based on the information provided in Table 5, the highest accuracy was achieved for *sharing preference* using all three methods: LightGBM (0.715), decision trees (0.704), and XGBoost (0.660). Considering the accuracy for all the factors, the most suitable method was decision trees (mean 0.551) and the worst XGBoost (mean 0.484). The accuracy of prediction is similar to those presented in other research [4, 15, 16]. It is not very high, but predicting human behavior or social preferences is more complicated than predicting economic or financial data [17].

Conducted research allows the authors to verify the hypotheses posed in the Introduction. The first was methodological and assumed that the machine learning models effectively assign qualitative and quantitative respondents' characteristics to how individual factors are assessed in the co-sharing decision-making process. The verification of this hypothesis is based on the models' parameters. In most cases, the accuracy of the

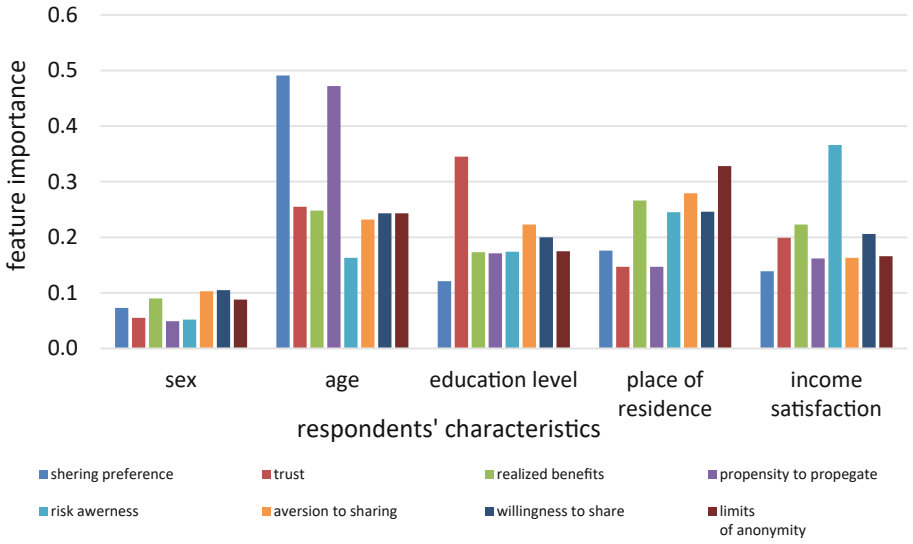

Fig. 4. The feature importance for LightGBM boosted decision trees.

models was above 0.5, and for *sharing preference* factor, even over 0.7, so the hypothesis may be verified positively, as the models' measures are quite satisfactory. More research is necessary to check if other parameters of built models may influence their accuracy. The second hypothesis was cognitive and assumed that how a respondent evaluates individual decision-making factors depends on their individual characteristics. This hypothesis may be verified positively because the results showed that a respondent's age and place of residence were the most important features influencing the models. Other characteristics did not show such a clear impact on the results.

Positive verification of the posed hypotheses implies that the aim of the research was achieved. Determination of the possibility of classifying co-sharing survey respondents depending on their method of assessing each decision-making factor separately using selected machine learning methods, including XGBoost, decision trees, and LightGBM, is possible. Still, the model parameters are not as high as expected when predicting hard financial or economic data. However, the prediction of human behavior or preferences is always more complicated [17]. Taking into account the nature of output data, the parameters of the models are quite satisfactory, as they are similar to other studies presenting the prediction of survey answers [4, 15, 16]. More research is needed to improve models or test other machine-learning methods. As many authors study the factors that favor co-sharing attitudes [3, 8–11, 13], there is a lack of studies focusing on applying machine learning technologies to assess the factors' importance in co-sharing.

Table 5. The accuracy of built models.

Model	sharing preference	trust	realized benefits	propensity to propagate	risk awareness	aversion to sharing	willingness to share	limits of anonymity	Mean
XGBoost	0.660	0.480	0.360	0.540	0.470	0.480	0.380	0.500	0.484
Decision tree	0.704	0.538	0.515	0.585	0.519	0.508	0.515	0.523	0.551
LightGBM	0.715	0.531	0.515	0.573	0.512	0.508	0.504	0.515	0.547

5 Conclusion

The conducted research showed that it is possible to predict the importance of factors in the decision-making process of co-sharing based on respondents' characteristics. The output data are of a subjective nature, so the model measures are not as high as when predicting hard data, but they are quite satisfactory. This is the main contribution of the research, as it opens the way to building models that would predict the survey answers when the response rate is low or the respondents are unwilling to share knowledge and experience.

There are practical implications for survey conductors. The results show that there is a possibility to build a model that would predict the survey answers based on a sample of collected data when the cost of conducting research is high, there are time limits, or there is a problem with getting the survey answers. Such a solution may be helpful, especially for smaller companies that do not have funds or time to conduct extensive market surveys.

The main limitation of the research was the dimensions of the used dataset, as it was not large enough, and the data was not diverse enough. The augmentation of data will be performed in further research. Another limitation is using the three chosen machine learning methods. The neural networks can be employed in future research. Future research will also cover improving already built models, mainly changing different hyperparameters to obtain higher accuracy. Other techniques will also be used to predict factors that are important in the decision-making process. Finally, the authors would like to try to build models that would directly connect respondents' answers with factors' importance, simplifying the statistical analysis of the results of such surveys.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Multiple Criteria Decision Analysis and Computational Methods for Management Information Systems

Exploring the Mechanism of Compromise in Novel ICRA Method: An In-depth Analysis

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Abstract. Multi-criteria decision analysis (MCDA) has become increasingly significant due to its impact on various domains. This rapid development has led to the creation of numerous MCDA methods, each enhancing specific aspects of decision-making. This study investigates the Iterative Compromise Ranking Analysis (ICRA) procedure, which aims to compromise solutions provided by multiple MCDA methods. In this study, we conduct a simulation to examine the ICRA compromise mechanism across different similarity of initial rankings, considering both preference values and ranking-based compromise seeking. Additionally, we analyze the impact of the ICRA weighting mechanism on the final compromise ranking. A detailed theoretical example is provided to enhance comprehension of the research. The primary contributions of this article include an in-depth analysis of the compromise shaping in the ICRA method concerning the similarity of decision-maker rankings, the comparison of using preference values versus rankings in achieving a final compromise, and an analysis of the ICRA decision-maker weighting mechanism. Our findings demonstrate the ICRA procedure's significant potential, allowing the compromise process to be tailored to the decision-maker's expectations. Preference values are identified as the preferred initial assessment method in the compromise process, as rankings can lead to a partial loss of information.

Keywords: Compromise · Multi-criteria decision analysis · ICDA

1 Introduction

Multi-criteria decision analysis (MCDA) is a rapidly growing field due to the increasing importance of informed decision-making and its significant impact on various areas of everyday life and specialized domains. The decision-making process is particularly critical in sectors such as business [6], medicine [3], and supply chains [12], which are prominent topics in MCDA research. The rapid development of this field reflects its efforts to meet the evolving expectations of decision-makers by providing robust and well-informed decisions [22].

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 199–211, 2024.
https://doi.org/10.1007/978-3-031-78468-2_15

This dynamic development has led to the creation of numerous new multi-criteria decision-making (MCDA) methods. Each method aims to enhance specific aspects of the decision-making process; however, no single method is perfect. Many attempts have been made to compare methods to aid the decision-making process. Wątróbski et al. presented a generalized framework for selecting MCDA methods, highlighting that the selection process itself can become problematic [21]. Similarly, Sałabun explored the potential for benchmarking MCDA methods [18]. Nevertheless, selecting a single method is not always the only solution. In situations where decision-makers believe multiple methods can yield satisfactory results, a compromise approach may be more appropriate.

Given the multitude of potential solutions and the necessity to account for the judgments of multiple decision-makers, compromise becomes an essential process in such scenarios. Certain multi-criteria decision-making methods incorporate a form of compromise mechanism. For instance, VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [20] involves a simplistic compromise between two rankings computed differently, while A Combined Compromise Solution (CoCoSo) [25] integrates the Weighted Product Method (WPM) and Weighted Sum Method (WSM) for compromise purposes.

In such cases, specialized methods and procedures are commonly employed to obtain a compromise between the assessments of different decision-makers or between multiple rankings. One widely used approach involves voting methods, which utilize simple ranking-based techniques to reconcile all ratings. The literature highlights the application of methods such as Borda [16] and Copeland [7]. Additionally, there are methods for deriving compromise based on multiple rankings, including the rank position method [2] and the dominance-directed graph [24].

In addition to these methods, the literature provides examples of approaches that achieve compromise using preference values. Notable among these are the improved Borda rule, developed for the MCDA method known as multiplicative multi-objective optimization by ratio analysis (MULTIMOORA) [23], and the half-quadratic compromise, which uses linear programming to achieve compromise [13]. The most recent approach proposed for obtaining a compromise ranking is Iterative Compromise Ranking Analysis (ICRA) [14]. Although ICRA, with its numerous parameter settings, remains underexplored, it shows significant potential for use in decision support processes as it directly integrates with MCDA methods.

This study will investigate the compromise mechanism of the ICRA procedure. The examination will begin with a simulation study covering various ranges of similarity in the initial rankings considering two distinct cases: one where the ICRA matrix is created based on preference values and another where rankings are used. Additionally, the impact of the ICRA weighting mechanism on the final compromise ranking will be analyzed. Furthermore, a detailed theoretical step-by-step example will be provided to enhance the comprehension of the conducted research. In summary, the primary contributions of this article are:

- In-depth analysis of shaping of compromise in ICRA method in regard to similarity of rankings provided by decision-makers
- The difference in the usage of alternative preference values and ranking in the final compromise
- ICRA decision-maker weighting mechanism analysis

The remainder of this paper is organized as follows: Section 2 introduces the foundational concepts, including the Iterative Compromise Ranking Analysis (ICRA) procedure, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, and the similarity coefficient employed. Section 3 details the simulation studies conducted, providing additional insights into the obtained results. Section 4 offers a theoretical example, illustrating a step-by-step problem to enhance understanding of the research. Finally, Section 5 presents the conclusions drawn from the study and suggests avenues for future research.

2 Preliminaries

This section will present the approaches used in this paper, first introducing the Iterative Compromise Ranking Analysis (ICRA) method, which later will be tested to demonstrate the characteristics of the compromise mechanism. This will be followed by a detailed description of the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), one of the most widely used methods in multi-criteria decision analysis. Finally, the similarity coefficient used for comparing rankings will be described. Two libraries were used to conduct research for the present study, namely PySensMCDA [15] and PyMCDM [10].

2.1 ICRA

The primary objective of the Iterative Compromise Ranking Analysis (ICRA) is to compromise rankings derived from different multi-criteria decision-making (MCDA) methods [14]. This need arises from the continuous development of new MCDA methods, each providing distinct approaches for evaluating alternatives. The challenge lies in selecting the optimal method for the final evaluation, which can be complex in certain situations. Therefore, a compromise approach such as ICRA may be more appropriate, where multiple methods can be used directly in the compromise process. The following steps outline the ICRA process:

Step 1. Identify the set of methods or experts to be used. Evaluate the initial decision problem matrix using these n methods or experts, and define the influence of each expert on the compromise ranking.

Step 2. Construct an ICRA decision matrix from the acquired preference values. The criteria types are determined based on the ranking type of the method: an ascending order indicates a cost type, while a descending order indicates a profit type.

Step 3. Calculate preferences using each MCDM method based on the ICRA decision matrix.

Step 4. Repeat steps 1 to 3 until the rankings provided by all selected methods are identical. In the process of achieving the compromise, the usage of a ranking correlation coefficient is advised; in this study, the weighted Spearman's correlation coefficient was employed to ensure that all methods produced the same ranking.

The detailed flowchart of the ICRA procedure is presented in Figure 1.

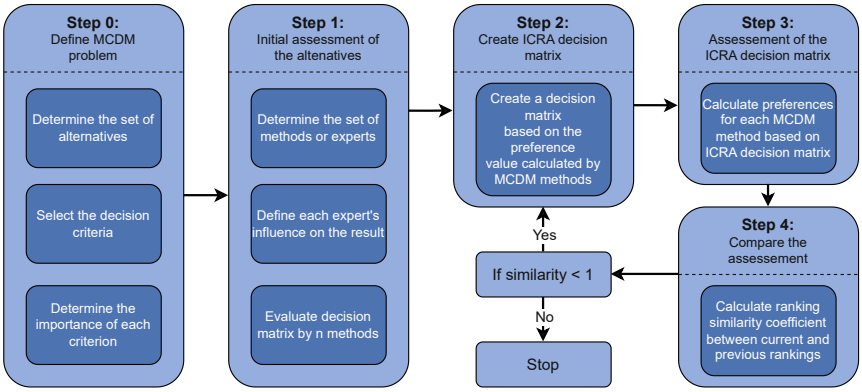


Fig. 1. Iterative Compromise Ranking Analysis (ICRA) procedure flowchart.

2.2 TOPSIS

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), despite its limitations [11], remains one of the widely adopted approaches in addressing multi-criteria problems [19]. Over time, researchers have refined or extended this method [1, 9], demonstrating its applicability across various domains [4]. The steps below outline the classical version of this technique.

Step 1. Establish the decision matrix and choose the criteria's type and weight. The type of criterion can be either profit (more is better) or cost (less is better).

$$F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{bmatrix}, \tag{1}$$

where f_m - Alternative m

Step 2. Calculate the normalized decision matrix. The decision-maker can choose the normalization. In this study, a min-max normalization was used for profit-type criteria using Equation (2) and cost-type criteria using Equation (3).

$$r_{mn} = \frac{f_{mn} - \min(f_n)}{\max(f_n) - \min(f_n)} \tag{2}$$

$$r_{mn} = \frac{\max(f_n) - f_{mn}}{\max(f_n) - \min(f_n)} \tag{3}$$

Step 3. Determine the weighted normalized decision matrix. The weighted normalized value is calculated in the following way (4):

$$V = \begin{bmatrix} r_{11} \cdot w_1 & r_{12} \cdot w_2 & \cdots & r_{1n} \cdot w_n \\ r_{21} \cdot w_1 & r_{22} \cdot w_2 & \cdots & r_{2n} \cdot w_n \\ \vdots & \vdots & \cdots & \vdots \\ r_{m1} \cdot w_1 & r_{m2} \cdot w_2 & \cdots & r_{mn} \cdot w_n \end{bmatrix}, \tag{4}$$

where r_m - normalized alternative m, w - weight corresponding to criteria

Step 4. Calculate positive and negative ideal solutions. Calculate the separation measures using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as (5):

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2}, \quad j = 1, \ldots, J, \tag{5}$$

where $v_{ij} = r_{ij} \cdot w_j$, v_i^* - positive ideal solution

Similarly, the separation from the negative ideal solution is given as (6):

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2}, \quad j = 1, \ldots, J, \tag{6}$$

where $v_{ij} = r_{ij} \cdot w_j$, v_i^- - negative ideal solution

Step 5. Calculate the relative closeness to the ideal solution. The relative closeness of the alternative f_m is defined as follows (7):

$$C_j^* = \frac{D_j^-}{\left(D_j^* + D_j^-\right)}, \quad j = 1, \ldots, J \tag{7}$$

Step 6. Rank the preferences in descending order.

2.3 Spearman's Weighted Similarity Coefficient

One method for comparing the results of different MCDA approaches is the ranking similarity coefficients. A particularly popular measure is the Spearman similarity coefficient, which is widely used in studies requiring comparative analysis of results [8, 17]. The weighted variant, introduced by Pinto da Costa and Soares [5], has become a standard benchmark owing to its robustness and applicability in various decision-making scenarios. This coefficient is calculated using Equation (8).

$$r_w = 1 - \frac{6 \sum_{i=1}^{n} (R_i - Q_i)^2 ((n - R_i + 1) + (n - Q_i + 1))}{n^4 + n^3 - n^2 - n} \tag{8}$$

where R_i - position in the reference ranking, Q_i - position in the second ranking, n - number of alternatives

3 Simulation Study

This section presents simulations to investigate the impact of the similarity of initial rankings, obtained through MCDA methods or derived from expert knowledge, on the compromise process. Additionally, the relevance of individual initial rankings in ICRA, introduced through a weighting mechanism, will be examined for its impact on the compromise ranking. The simulations were conducted as follows:

- Specified correlation ranges between initial rankings.
- Generated 100 decision matrices with 8 alternatives and 5 criteria for each correlation range, ensuring they met the specified correlation values.
- Values for matrices were generated from a continuous uniform distribution over the half-open interval [0.0, 1.0).
- Calculated assessment and ranking using the VIKOR and TOPSIS methods for the first and second rankings, respectively.
- Compromise ranking was achieved using TOPSIS for both initial assessments. Meaning that only TOPSIS was used in the ICRA procedure.
- Calculated the correlation between initial rankings and the compromise ranking.

It is important to note that VIKOR and TOPSIS were used only to obtain initial assessments. Different methods or experts could also be used for this purpose. This information is provided for clarity and to facilitate the replication of this study's results.

3.1 Correlation Between Initial Rankings

Firstly, simulations were conducted to highlight the differences between the initial rankings used in the compromise process and the resulting compromise ranking. This analysis spanned ten ranges of correlation between the initial rankings. In the case of ICRA, its use has been presented based on preference values obtained from different multi-criteria decision-making methods. Initial simulations were carried out to observe the behavior of the compromise mechanism under these conditions. Figure 2 presents aggregated results showing the correlations between the initial and compromise rankings for varying levels of similarity among the initial rankings. When preferences are utilized and both initial assessments are equally weighted, the correlation values of the initial rankings to the compromise ranking exhibit similar distributions for the first (R_1) and second (R_2) initial rankings. The spread of these values decreases as the similarity of the initial rankings increases, which aligns with expected behavior.

In the case of ICRA, it is also possible to use the rankings alone to achieve a compromise. In this case, in contrast to the use of preferences, the results of similarity to compromise ranking for the individual initial rankings differ. This is illustrated in Figure 3, where it can be observed that the resulting compromise ranking exhibits a higher correlation with R_2 in half of the cases. This is intriguing, as the simulation approach would typically suggest similar distributions for rankings one and two. This discrepancy might be attributed to the method by which the expert assessments were generated, necessitating further research to provide a more insightful explanation for this anomaly. Nevertheless, this finding underscores the importance of using preference values when available. Utilizing preferences tends to yield more consistent and predictable results in the compromise mechanism.

3.2 Compromise Weights

Next, as ICRA offers a possibility it is worth taking a closer look at the impact of weighting the initial assessments on the compromise ranking. To this end, two scenarios will be analyzed, each involving five pairs of weights. These scenarios represent cases with

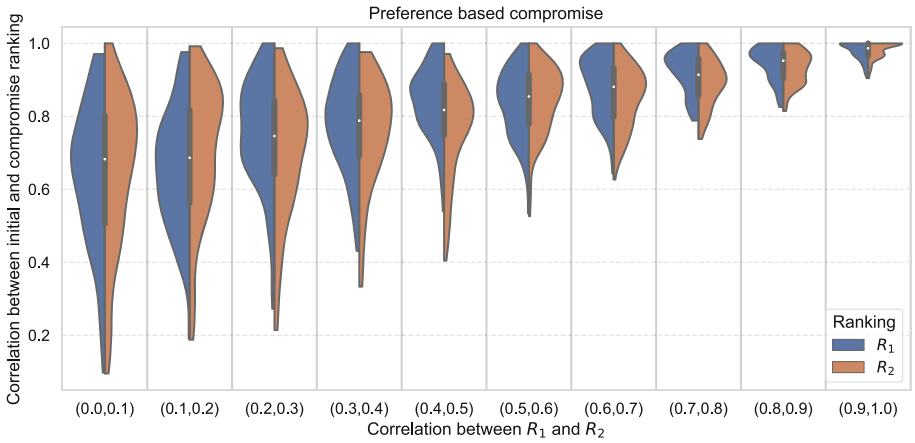


Fig. 2. Correlation between initial rankings and compromise ranking based on preferences in specified ranges of similarity of initial rankings.

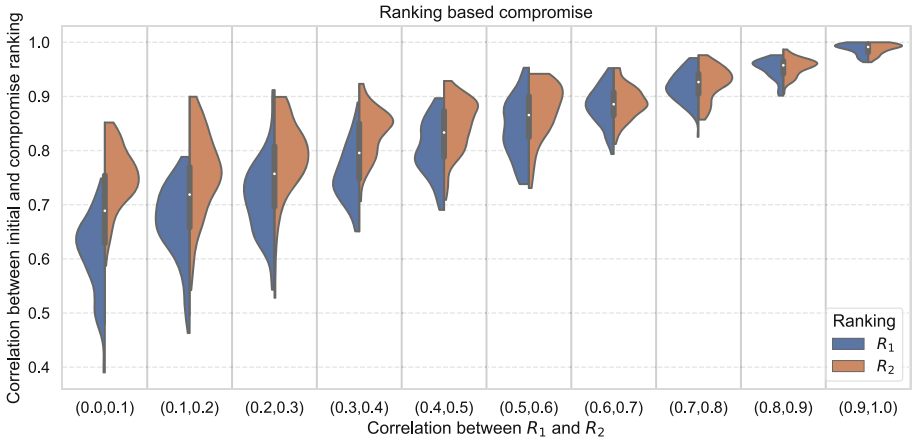


Fig. 3. Correlation between initial rankings and compromise ranking based on rankings in specified ranges of similarity of initial rankings.

low correlation (values between 0 and 0.1) and high correlation (values between 0.9 and 1.0) between the generated initial ratings. A scenario with an average correlation range of [0.45, 0.55] will not be presented, as it yielded similar results to the low correlation scenario, albeit with greater sensitivity to changes in weight values.

Low Correlation Figure 4a illustrates the aggregated results of the correlation between the initial assessments and the compromise ranking as the weights in the ICRA approach vary. In this case, the compromise was derived from the preference values, meaning the initial ICRA matrix was created using these values. The initial ratings were generated with a Spearman's weighted coefficient between 0.0 and 0.1. The graph shows that when equal weights are used, the compromise ranking is similarly close to both R_1 and R_2,

with a slight advantage for R_1. When the weights are adjusted to 0.25 and 0.75, there is a noticeable shift in the distribution in both cases. It is important to note that using weights can result in a compromise ranking that is entirely consistent with the ranking having the higher weight, in this case, the assessment having an importance of 0.75. Conversely, setting the weights to 0.1 and 0.9 demonstrates that in most of the 100 initial ratings generated, one of the initial rankings achieves a correlation of 1.0 with the compromise ranking.

Figure 4a presents a similar scenario to the previous one but with rankings used to create the initial ICRA matrix instead of preference values. In this case, it is evident that with equal weights, there is a greater similarity between the compromise ranking and the initial R_2 ranking. This observation might be influenced by the method of generating the initial rankings. Additionally, it is noteworthy that when rankings are used for constructing the ICRA matrix, the correlation coefficient values exhibit a narrower distribution. This could be attributed to the loss of information about the assessment of individual alternatives when converting preference values into rankings. Furthermore, changing the weights to 0.25 and 0.75, or to 0.1 and 0.9, resulted in significant changes in the distributions, indicating that the ranking-composition process is more sensitive to the significance of the individual initial rankings when using rankings in the initial ICRA matrix.

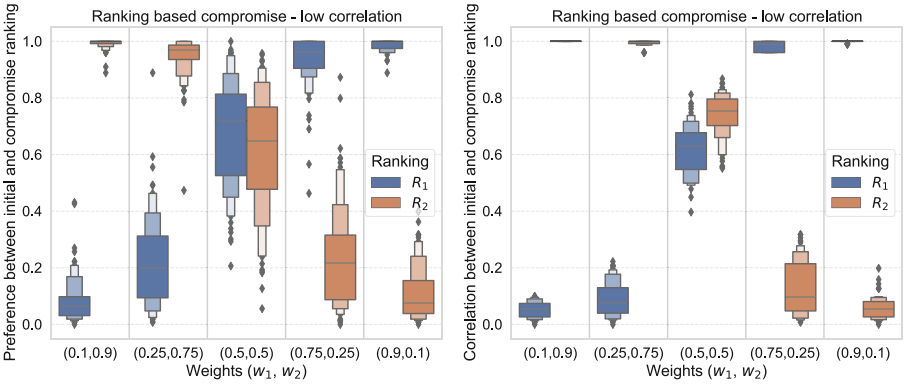


Fig. 4. Weighted Spearman's correlation of initial and compromise rankings in the case of low correlation between initial rankings.

High Correlation Subsequently, an exploration into modeling the compromise in scenarios with high correlation among the initial rankings. Figure 5a illustrates the case where preferences were utilized in constructing the initial ICRA matrix. Despite the inherent high correlation in such instances, we can influence the compromise by adjusting the weights assigned to individual rankings. Notably, even with weights set at 0.25 and 0.75, instances may arise where the correlation with the chosen initial ranking does not reach 1.0.

Figure 5b presents the results for the compromise obtained using rankings. The sensitivity of the compromise process to the assigned weights for each initial ranking

is significantly higher in this scenario. With weights set at 0.25 and 0.75, there are no instances where the correlation of the more heavily weighted initial rankings falls below 1.0. These findings highlight the need for further research on weight setting in the ICRA procedure to better understand how the compromise ranking changes.

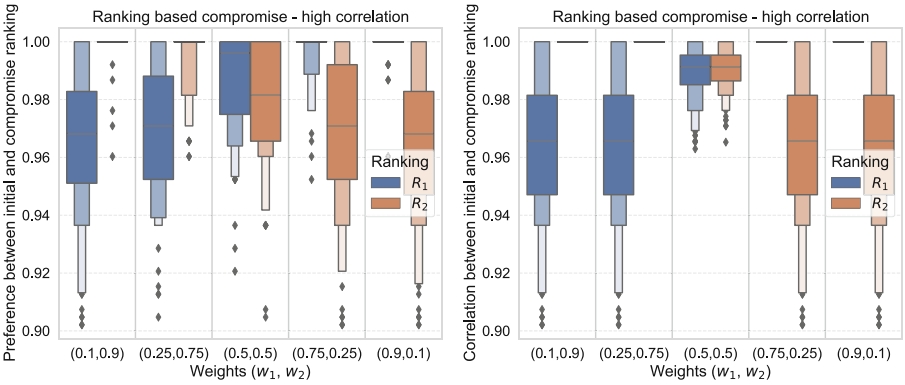


Fig. 5. Weighted Spearman's correlation of initial and compromise rankings in the case of high correlation between initial rankings

4 Example case

This section presents a theoretical decision problem example to demonstrate the impact of modeling compromise using available parameters. The decision matrix was generated under the same assumptions as in the simulation scenario, where values were drawn from a continuous uniform distribution over the half-open interval [0.0, 1.0). The resulting decision matrix is depicted in Table 1.

Table 1. Decision matrix of theoretical decision-making problem.

A_i	C_1	C_2	C_3	C_4	C_5
A_1	0.6322	0.6646	0.3959	0.9404	0.2191
A_2	0.5426	0.3620	0.1500	0.7222	0.9471
A_3	0.1373	0.7191	0.8568	0.6348	0.2746
A_4	0.4710	0.3940	0.2716	0.0064	0.3040
A_5	0.3464	0.9202	0.0607	0.4106	0.8678
A_6	0.3627	0.3983	0.2875	0.8550	0.5069
A_7	0.2154	0.1249	0.9783	0.3677	0.9961
A_8	0.3185	0.6579	0.4875	0.4429	0.4487

Next, preferences were calculated similarly to the simulation scenarios, employing the VIKOR (p_1) and TOPSIS (p_2) methods. The outcomes computed using the VIKOR method were transformed to reflect a profit-type criterion by performing a $(1 - p_1)$ operation on the obtained values. The resulting values were utilized to construct an initial ICRA matrix. These preference values are illustrated in Table 2.

Table 2. Preference-based initial ICRA decision matrix.

A_i	$1 - p_1$	p_2
A_1	0.5000	0.5675
A_2	0.6273	0.5583
A_3	0.2976	0.4815
A_4	0.0000	0.3175
A_5	0.3954	0.5254
A_6	0.7059	0.4713
A_7	0.3524	0.5052
A_8	0.7696	0.4557

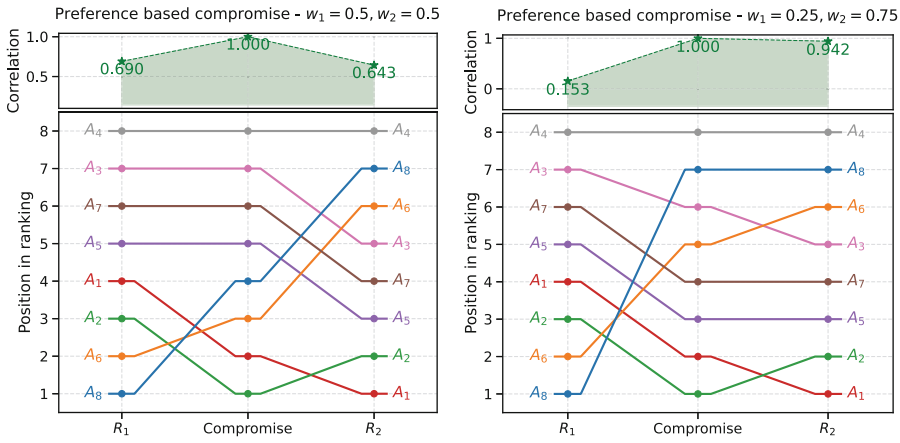
Figure 6a shows the initial and compromise rankings, along with their correlations. With equal weights, correlations of 0.69 and 0.643 were obtained, indicating both initial rankings were nearly equally impacted. The most notable change was alternative A_8, which moved up three positions relative to both initial rankings.

When the weights were adjusted to 0.25 for R_1 and 0.75 for R_2, the correlations changed to 0.153 and 0.942, respectively. Despite the higher weight for R_2, it did not entirely dominate the compromise ranking, as four alternatives had slight positional changes, as shown in Figure 6b.

As in the simulation scenario, let's explore the compromise in this example using rankings instead of preference values in the initial ICRA matrix, as depicted in Table 3. The values of rankings have been adjusted to reflect a profit-type criterion.

Figure 7a presents the use case of rankings in the initial ICRA matrix with equal weights. Despite equal importance assigned to each ranking, R_2 shows more similarity to the compromise ranking due to minor changes in its top positions. In contrast, R_1 has lower similarity, with its top two alternatives moving down four and two places, respectively.

The final case, shown in Figure 7b, examines distinct weights allocated to the initial rankings. Unlike using preferences in the initial ICRA matrix, here the R_2 ranking with a weight of 0.75 dominated, resulting in a compromise ranking with a correlation of 1.0. When preferences are used, this dominance effect is less pronounced, especially as seen by the R_1 ranking's correlation of only 0.013 in the case of using rankings and 0.153 in the case of using preferences. Further investigation into various weight combinations is needed to better understand the characteristics of achieving a compromise in such scenarios.



(a) Equal weights. (b) 0.25 and 0.75 weights.

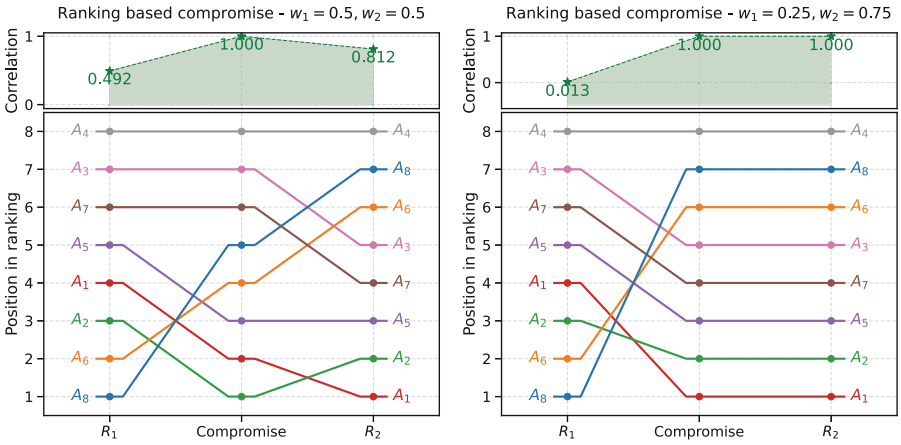
Fig. 6. Example theoretical case compromise based on preferences.

Table 3. Ranking-based initial ICRA decision matrix.

A_i	$8 - R_1$	$8 - R_2$
A_1	4	7
A_2	5	6
A_3	1	3
A_4	0	0
A_5	3	5
A_6	6	2
A_7	2	4
A_8	7	1

5 Conclusions and Future Works

This study demonstrates how the Iterative Compromise Ranking Analysis (ICRA) procedure varies with the discrepancies between decision-makers' assessments. The differences were ensured by generating problems in which evaluations produced a correlation coefficient within a specified range. Additionally, the study analyzed the mechanism of weighting the individual decision-makers' evaluations and the potential of using rankings instead of preference values to construct the initial ICRA matrix. The findings highlight the significant potential of the ICRA procedure, as it allows the compromise process to be tailored to the decision-maker's expectations. The research indicates that preference values are the preferred initial assessment, as opposed to rankings, which can lead to a partial loss of information regarding the relative superiority of alternatives.



(a) Equal weights. (b) 0.25 and 0.75 weights.

Fig. 7. Example theoretical case compromise based on ranking.

Future research should explore different methods for generating initial rankings and assess their impact on compromise. Additionally, examining the influence of various multi-criteria decision-making methods, beyond TOPSIS, on the ICRA procedure would be insightful. Involving real experts to gather their perspectives on the compromise process could also provide practical insights and enhance understanding of the mechanism.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Grass Cutter Heuristics for Knapsack-Like Problems of Resource Allocation

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Abstract. Resource allocation emerges as a multifaceted challenge spanning various disciplines, each with its own unique considerations and requirements. This study presents innovative grass-cutter heuristics devised to address knapsack-like resource allocation problems incorporating product categorization. These heuristics are designed to streamline the solution process, enhancing efficiency and profitability. We implemented a set of twelve parameters strategically aimed at narrowing down the solution space. By doing so, we aim to craft solutions that are relatively profitable while avoiding random element generation and avoiding exhaustive exploration of the entire solution space. We give examples of the application of the proposed approach to two problems: (1) the shelf space allocation in retail and (2) the commercial to TV break placement in media planning.

Keywords: resource allocation problem · shelf space allocation problem · media planning knapsack · heuristics

1 Introduction

Allocating resources is a ubiquitous challenge across various domains, ranging from management and economics to engineering and operations research. It stands as a cornerstone issue, impacting the efficiency and success of endeavours in these fields.

In the realms of management and economics, resources encompass a spectrum of assets, including savings, investments, and expenses, collectively influencing the overall cost of production or service provision. Within manufacturing contexts, resources manifest as essential components of the production process, encompassing materials, tools, machinery, labour, and financial capital. Each element plays a vital role in shaping the outcome of goods or services.

Thus, the challenge of resource allocation permeates various disciplines, each demanding nuanced approaches to optimize resource utilization and drive desired outcomes. Through strategic allocation and management, organizations can navigate complex environments, enhance productivity, and foster sustainable growth.

The study makes the following contributions highlighting innovative approaches to improving solutions to resource allocation problems across different disciplines, with practical examples showcasing the real-world applicability of the proposed heuristics in retail and TV media planning:

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 212–223, 2024.
https://doi.org/10.1007/978-3-031-78468-2_16

- The study introduces novel grass-cutter heuristics specifically designed to tackle knapsack-like resource allocation problems.
- The heuristics consider product categorization, adding a layer of complexity and specificity to the resource allocation problem.
- The proposed heuristics aim to streamline the solution process, making it more efficient and enhancing profitability.
- A set of twelve parameters is implemented strategically to narrow down the solution space, making the problem-solving process more manageable.
- The proposed heuristic approach helps in creating solutions that are relatively profitable without relying on random element generation or exhaustive exploration.

The rest of this paper is organized as follows. In Sect. 2, we position this work in the literature. The knapsack, shelf space allocation and media planning problems are defined in Sect. 3. In Sect. 4, we describe the new grass-cutter heuristics for knapsack-like problems. In Sect. 5, we explain how knapsack-like resource allocation problems, such as shelf space allocation and media planning, can be solved using the proposed approach. The research concludes in Sect. 6.

2 Related Literature

2.1 Shelf Space Allocation

Shelf space stands as a paramount resource within the realm of retail management, requiring accurate handling. Retailers face the rigorous task of defining which products warrant inclusion in their assortment, determining the allocated shelf space for each product to optimize customer-facing visibility, and establishing the appropriate shelf space for these items [1–6]. Consequently, clear-headed management of the finite shelf space available and profound merchandising choices emerge as pivotal considerations.

The effective management of limited shelf space necessitates strategic decision-making to ensure optimal utilization of this valuable resource. Moreover, judicious merchandising decisions are vital for enhancing product visibility, stimulating customer engagement, and ultimately driving sales [7–9]. By employing different strategies in shelf space management and merchandising, retailers can enhance the overall shopping experience, cultivate customer loyalty, and maintain profitability.

In modern retail stores, products that are exposited on the shelves are a result of careful planning. Recent research has placed significant emphasis on the integration of planograms into the operational workflows of retail establishments [10–15]. Planograms, which represent detailed schematics outlining the arrangement of products on shelves, have garnered attention due to their pivotal role in optimizing retail space allocation. The intricate design of shelf space allocation strategies necessitates a delicate balance between the store's merchandise strategy and the behaviour patterns of its customers. Furthermore, these strategies aim to present visually appealing product arrangements that entice both retailers and shoppers alike [11–15].

There are a lot of known mathematical models for shelf space allocation problems and solution methods known from the literature [16–20]. Moreover, the implementation of such solutions has been shown to enhance overall store performance. By facilitating

fast generation, management, printing, and dissemination of customized planograms across multiple store locations, these solutions streamline operational processes. This enables retailers to adapt quickly to changing market demands and consumer preferences, ultimately contributing to improved efficiency and profitability across the retail network.

2.2 Media Planning

Television networks and advertisers strive to establish commercial agreements aimed at fostering successful partnerships. For television networks, the primary source of revenue lies in selling access to their target viewership to advertisers, who then place commercials during TV program breaks. These agreements typically outline specific terms, including the delivery of a predetermined target viewership or number of impressions within a specified demographic over the course of the advertising campaign. Additionally, the contract specifies the number of advertising spots required to achieve the desired number of impressions [21–24].

The process of media planning entails careful balancing actions, considering various factors such as audience demographics, programs' schedules, advertising rates, and budget limitations. By constructing efficient media plans, advertisers aim to enhance brand visibility, drive consumer engagement, and ultimately increase sales or revenue [25–27].

3 Problem Definition

3.1 Knapsack Problem

The knapsack problem (KP) stands as a quintessential example within the realm of combinatorial optimization problems. Its essence lies in the quest to optimize the selection of items destined for a knapsack, all while abiding by the constraints of weight capacity. This could be explained as a collection of items, each item tagged with a specific weight and a corresponding value. Concurrently, there's a knapsack waiting to be loaded with a predefined maximum weight it can bear.

Here's how it's set up: there is an array of items N $(i = 1, ..., N)$, each with its own weight w_i and value v_i, and there's this knapsack just waiting to be filled, but with a strict weight limit W. The objective is twofold. Firstly, to determine the items to be placed into the knapsack so that their cumulative weight doesn't surpass the knapsack's limit. Secondly, the total value must be as large as possible. The knapsack problem could be interpreted as a sort of strategic packing task, where each item choice represents a complex trade-off between its value contribution and the space it occupies in the knapsack [28–32].

Maximize

$$\max \sum_{i=1}^{N} v_i x_i \tag{1}$$

subject to the constraint:

$$\sum_{i=1}^{N} w_i x_i \leq W, \tag{2}$$

where

$$x_i \in \{0, 1\} \tag{3}$$

3.2 Shelf Space Allocation

In retail, there is a problem of placing products on shelves in retail stores to maximize the profit from selling the products. Often, to achieve this goal, retailers use planograms. The planogram consists of shelves. A set of products must be placed on shelves, so the shelf for each product must be specified. After that, the number of items of each product which lies in a range of earlier defined possible values, must be found. The ultimate goal is to maximize the total profit from selling products on the planogram.

Under consideration of the retailer is not just the task of filling the shelves but optimizing the planogram layout to ensure that every inch of retail space works in harmony to drive revenue. The arrangement of products isn't arbitrary; it's a carefully calculated strategy aimed at maximizing the return on investment. In this dynamic retail environment, factors like product placement, visibility, and consumer behaviour all come into play. From eye-catching displays to strategic bundling, every decision is made with the ultimate goal of boosting sales and increasing profitability. Additional retail constraints may be imposed, but at this point, we do not focus on them.

3.3 Media Planning

In media planning, there is a problem of decisive placing commercials within TV breaks to maximize viewership. Across this variety of channels, the breaks for TV commercials serve as essential helpers of connection between advertisers and viewers.

Generally, a TV break is segmented into a set number of spots; each is sold at varying prices and has its own viewership. The goal is to orchestrate the placement of these ads in a way that maximizes viewership while adhering to a strict budget for advertisers. Different constraints may be imposed, but now we do not focus on them.

The magnitude of the advertising campaign is quantified through factors including budget, spot viewership, and viewing frequency within a specified timeframe (e.g. 2 weeks, 1 month). The budget specifically refers to the portion of the advertising budget allocated solely to spot purchases, excluding expenses related to market research, pre-testing, post-testing, and specialist fees.

The effectiveness of the advertising campaign can be evaluated through the following parameters: gross rating point (GRP), reach, frequency [33–35]. These parameters are delineated on a daily, weekly, monthly basis, which depends on the scale of experiments.

The goal of the advertiser in solving the commercial placement problem is the maximization of the viewership. In this context, the viewership may be expressed in GRP, reach, frequency or any kind of rating.

4 Grass-Cutter Heuristics Description

In this research, we introduce novel grass-cutter heuristics for solving knapsack-like resource allocation problems with product categorization. Our approach entails the development of several distinct variants, each characterized by a different sorting order for forming solution parts within. The core methodology of our heuristics involves several key steps (see Fig. 1):

1. **Laying the lawn**: Imagine a lush lawn with grass growing at varying heights and densities across different areas. This serves as our solution space, providing a dynamic landscape for exploration.
2. **Identifying cuttable areas**: Determine which sections of the lawn will be subject to cutting. These designated areas represent the solutions that will undergo comparison and evaluation.
3. **Utilizing the grass cutter**: Employ a grass cutter equipped with specific parameters tailored for this task. These parameters include:
   - **Blade movement length**: Control the distance covered by the grass cutter in each movement, regulating the granularity of the cutting process.
   - **Target grass height**: Specifies the height at which the grass should be cut, guiding the cutter's actions to achieve uniformity.
   - **Grass box size**: Determines the capacity of the grass box, which affects the amount of grass that can be collected during cutting operations.

Adjusting these parameters allows for the generation of a diverse array of solutions, thus facilitating a comprehensive exploration of the solution space. Opposite to the real grass cutter, in this method, we are interested not in the evenly cut grass but in the blades that the grass cutter cuts and collects into the grass box. The goal is to find the highest blade without cutting the whole lawn.

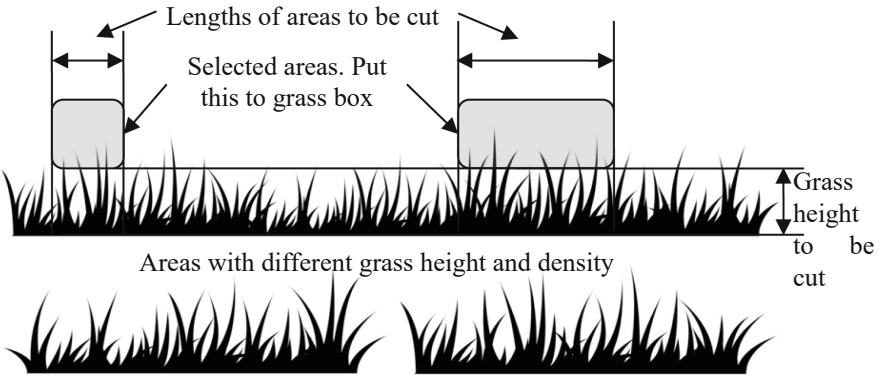

Fig.1. Looking for areas to be cut

By integrating these steps, our approach develops a systematic framework for addressing the knapsack-like resource allocation problems, leveraging the metaphor

of grass-cutting to efficiently navigate the problem landscape and identify optimal or near-optimal solutions.

Let's explain how the proposed heuristics could be applied in practice. We need to iterate through the process of identifying areas on the lawn to be cut and fine-tuning the grass cutter's parameters to ensure that the overall cutting time remains manageable while also ensuring that the volume of cut grass doesn't exceed the capacity of the grass cutter's box. As we remember, our ultimate objective is to pinpoint the highest blade of grass amidst the lawn.

Figure 2 explains the grass cutter heuristics notation applicably to real problems. Firstly, we need to estimate how many solutions exist and generate all possible solutions or some samples of them. When the problem size is large, it is not possible to generate all solutions, i.e. all variants of item selection.

Secondly, we need to scan the lawn to determine which regions require cutting. This involves a careful assessment of the grass height across the lawn, identifying patches where the grass has grown beyond the desired length. By pinpointing these areas, we can focus our cutting efforts on the most profitable areas. In other words, we generate not all possible solutions, but solutions specified by some parameters between the defined values. For the knapsack problem with categorized items, this can be the range of space dedicated for each of the categories, i.e. minimum and maximum space.

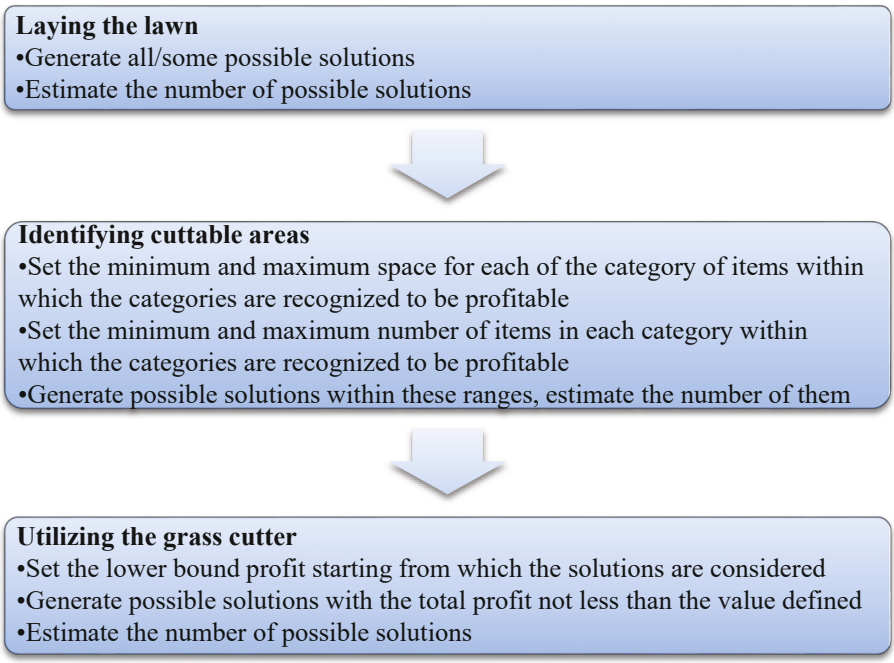

Fig.2. A glance at the consolidated heuristics step

Once the areas to be trimmed are identified, we must adjust the parameters of the grass cutter to optimize efficiency without compromising effectiveness. This entails tweaking factors such as the length of each movement of the cutter, the target height at which the grass should be cut, and the size of the grass box. These adjustments are crucial in balancing the trade-offs between cutting height, time efficiency, and the capacity of the grass box.

Thirdly, estimate the profit which forms the solutions between the range of the space and the range of the number of items. Set the total profit below which the solutions are not considered. This means that we definitely know that the solution will be with a profit higher than some value.

However, it's essential to ensure that the total cutting time remains within acceptable limits. We don't want the process to become overly time-consuming, as this could hinder overall productivity. Therefore, on each step after setting parameters we estimate the number of possible solutions which could be formed. If this number is so large, and if we can't form them in the acceptable time, we modify the tuning parameters, e.g. narrowing the width range, decreasing the variance of items number in each category or increasing the input profit. By optimizing the parameters of the grass cutter, we aim to achieve a balance where the possible solution generation is fast enough while the total profit is satisfactory. Moreover, we must be mindful of the volume of cut grass accumulating in the grass cutter's box. Number of solutions is the size of the grass box. Among them the solution with the maximum profit will be selected. Therefore, we must monitor the volume of cut grass (estimate the number of solutions on each tuning step) closely and adjust our cutting strategy (tuning parameters) as needed to prevent overflow.

5 Application of Grass Cutter Heuristics to Real Problems

5.1 Application of Grass Cutter Heuristics to Shelf Space Allocation Problem

In the shelf space allocation problem there are two decision variables: (1) binary – if the product is placed to the shelf; (2) positive integer – the number of stock-keeping units (SKUs) of each product on each shelf. Therefore, the solution is a sequence of numbers: (1) shelf allocation – a sequence of numbers 0/1, meaning if the product is placed on the shelf; (2) product allocation – a sequence of numbers, meaning how many SKUs are placed on the shelf.

Creating the Grass Lawn:

1. Create a set of shelf allocation sequences that satisfy constraints of allocating products on single shelves, e.g. on what shelves the product are allowed to be placed, what products are allowed to be placed together on the same shelf, if the product may be or must not be placed side by side each other.
2. Create a set of shelf allocation sequences that satisfy constraints of allocating products on multiple shelves, e.g. if the nearby shelf is allowed, if the product is allowed to be placed on multiple shelves, how many shelves are allowed, if the products must be placed on different shelves.

3. Create a set of product allocation sequences for each of the generated shelf sequences with regard to constraints of allocation of product on the shelf, minimum and maximum numbers of SKUs, shelf length, shelf depth, shelf height constraints, the number of SKUs of neighbours (if the product is visible enough among neighbouring SKUs).
4. From the achieved set of product allocation sequences, exclude the ones that do not satisfy the product limit if allocated on multiple shelves, category constraints (e.g. minimum category size, visible category borders on multiple shelves), if products are grouped into categories and constraints on categories, are imposed.

The steps of parameters defining for finding places on the lawn with relatively high grass to be cut, adjusting the grass cutter are explained in Fig. 3. After applying the proposed parameters, a collection of solutions has been generated. The next step involves identifying and selecting the solution that outputs the highest total profit among the set of solutions available. This process ensures that the chosen solution has the maximum profitability, serving as the best outcome from the pool of generated solutions.

5.2 Application of Grass Cutter Heuristics to Media Planning Problem

In media planning problem, there is one decision variable: binary – if the commercial is emitted in the definite channel, in the definite spot of the break. Therefore, the solution is a sequence of numbers: spot allocation - a sequence of numbers 0/1, meaning if the commercial is emitted in the definite channel, in the definite spot of the break.

Creating the Grass Lawn:

1. Create a set of spot allocation sequences that satisfy constraints of allocating commercials on spots on a single channel, e.g. on what spots the commercials are allowed to be placed, in what breaks, between or during what TV programs, what commercials are allowed to be repeated in the same break, in the same channel, in the nearby spot of the break, what commercials must be placed in the first and the last spot of the break, how frequent the commercials must be emitted on the channel.
2. Create a set of spot allocation sequences that satisfy constraints of allocating commercials on multiple channels, e.g. if the commercial must be shown simultaneously on several channels, on how many channels, not simultaneously but after emitting it in the first channel, it must be shown in the next spot of the break on another channel, how frequent the commercials must be emitted on different channels.
3. From the achieved set of spot allocation sequences, exclude the ones that do not satisfy the commercial emission limit if emitted on multiple channels, TV program constraints (e.g. TV program duration, break duration, if the commercial is noticeable while the user switches channels during the TV break) if commercials are grouped into TV topics or target audience ages and constraints on these topics and target audience are imposed.

Figure 4 outlines the process of defining parameters to locate areas of higher grass for cutting, followed by adjusting the grass cutter accordingly. Parameter 5 is not applied for the media planning problem. Once these parameters are applied, a range of solutions is produced. The subsequent stage entails pinpointing and choosing the solution with the

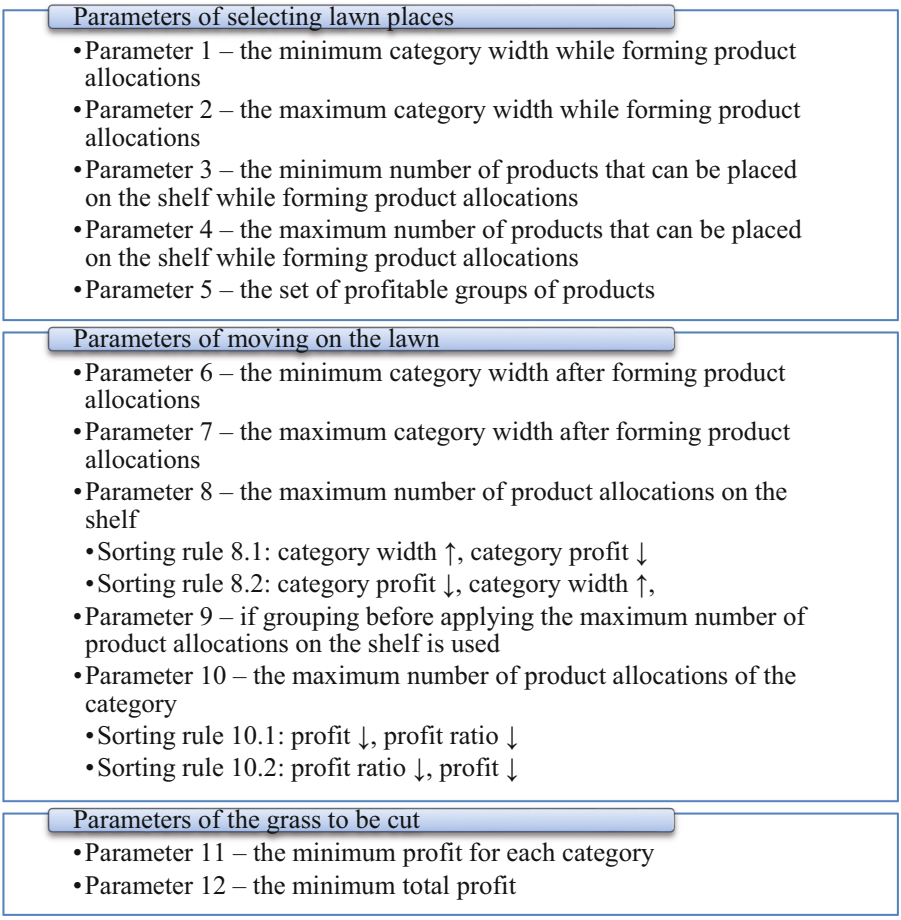

Fig. 3. Grass-cutting parameters in shelf space allocation problem

highest viewership from this set. This selection process guarantees that the chosen solution yields the greatest profitability, representing the best outcome among the generated solutions.

6 Conclusion

Resource allocation poses a pervasive challenge across a multitude of real-world scenarios, constituting a fundamental concern within the realms of engineering and operations research. Media planning involves the strategic allocation of resources to optimize the effectiveness of advertising campaigns across various channels. Shelf space allocation involves the strategic allocation of finite shelf space within a retail store.

In this research, we develop a method which could be applied to solving resource allocation problems, which can be modelled as a knapsack. Because of the similarity to

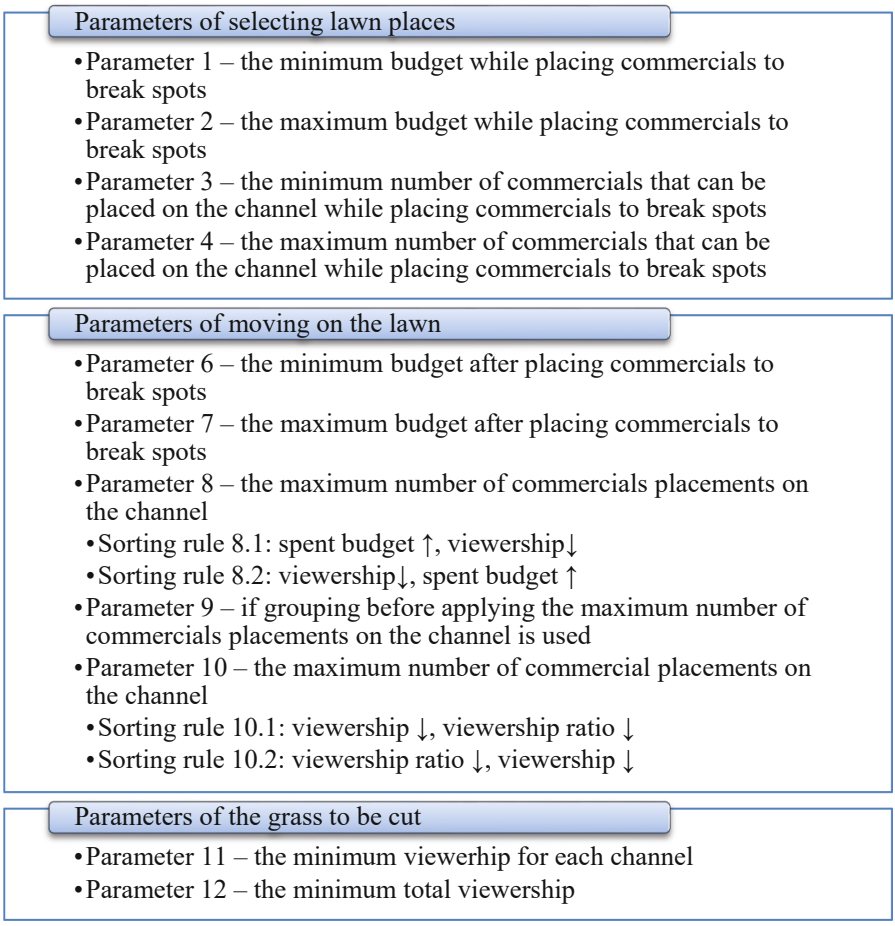

Fig.4. Grass-cutting parameters in media planning problem

the grass cutter, we call it the grass cutter heuristics and create 12 parameters of how it could be tuned. By carefully defining these parameters, we can ensure that the algorithm operates in a targeted manner, focusing its efforts on generating high-quality solutions while avoiding potential traps. We give the example of the usage of the proposed grass cutter heuristics specifically to the following problems:

- Shelf space allocation problem in which the products are located on shelves in retail stores and the number of items of the product on each shelf is specified so that the total profit from selling them is maximized.
- Media planning problem in which the TV commercials are shown on different channels in the TV spots which are the parts of the breaks during program emitting so that the total viewership is maximized.

Both of the problems can be modeled as a knapsack problem.

The limitation of this study is that if the problem size is too large, the set of parameters should be deeply thought. This could be a complicated enough task in real problem environments.

Future research could be directed to the application of the grass cutter heuristics for solving resource allocation problems in other fields. This involves adjusting the tuning parameters as because of them we can unlock the full potential of the grass cutter algorithm, enabling it to operate with specific precision and efficiency.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article

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Markovian Consensus Based on Local Alternatives' Relation

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Ranking data reflects the ordered preferences of subjects such as voters, methods, or judges, expressing their selections over a set of items or candidates referred to as alternatives. A critical aspect of handling such data is aggregating these preferences into a consensus ranking.

A consensus is easy if ranks are agreed upon, but when there are many conflicts, it is usually based on the elitist assumption of choosing the best based on some distance measure. The motivation is to use the influence of local connections between alternatives and avoid strict elitism. The proposed algorithm for consistent rankings works like other well-known methods. However, in a conflicting environment, it controls freedom by learning from local connections and by a damping factor, which makes the technique an attractive alternative for those applications where it is essential to uncover patterns in the subjects' preference sequences.

The proposed technique for rank consensus is based on a stochastic Markov process that follows a probability pattern derived from pairwise rankings. A directed graph describes the transition frequency directly from one alternative to another (local pair comparison). The consensus is achieved as a stationary distribution of a Markov chain in discrete time. The main contribution of this paper is to introduce this new technique, supported by numerical examples, experiments on synthetic data, and comparisons with other ranking aggregation methods.

1 Introduction

Reaching a consensus from different rankings is crucial in various fields. In Multi-Criteria Decision Analysis (MCDA), decision-makers evaluate alternatives based on multiple criteria, with methods such as AHP, TOPSIS, and VIKOR providing different rankings for the same problem [11]. In academia, consensus rankings synthesize multiple reviewers' opinions on articles and submissions [2]. Recommendation systems aggregate personalized rankings generated by different algorithms to enhance user experience [8]. In wireless networks, consensus methods improve the reliability of critical packet

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 224–236, 2024.
https://doi.org/10.1007/978-3-031-78468-2_17

transmissions [12]. These examples illustrate how consensus ranking synthesizes diverse perspectives into a single prioritized list, ensuring balanced decision-making.

The widespread application of consensus rankings makes it an engaging research topic, leading to various proposed methods. The Borda Count assigns points based on alternative positions in rankings, ensuring a fair consensus by considering all preferences [15]. The Copeland Method uses pairwise comparisons to evaluate alternatives [15]. Probabilistic models like Mallows, Luce, and Bradley-Terry provide robust foundations for consensus [3]. Additionally, research has explored graph representations and domination approaches [1, 10, 16].

While many methods perform well in consistent environments, disagreement and ambiguity in rankings remain challenging. In such cases, methods based on pairwise comparisons can be more objective, yet no universal solution exists [4, 14]. We propose the Local Markovian Consensus (LMC) method to achieve consensus in full rankings. Using pairwise comparisons, LMC employs the stationary state of a Markov chain to produce the final aggregate ranking. Our main contribution is this new algorithm, which effectively aggregates consistent and inconsistent rankings.

This paper introduces the basic notation, presents various Markov Chain-based methods, and details our proposed LMC method, including input coding, graph construction, transition matrix calculation, and ensuring ergodicity, illustrated with an example. We rigorously tested our method on ten synthetic datasets, comparing it with well-established methods. The results lead to insightful discussions and conclusions.

2 Preliminaries

This section introduces notations and concepts of ranking sequence, graphs, and the stationary state of a Markov chain.

Definition 1 A full ranking r is a vector representing the order of m items as:

$$r = [ar_1, ar_2, ..., ar_m].$$

Each ar_i is an integer representing the rank of the i-th item, where a rank of 1 indicates the highest, and m the lowest. The length of r is m representing the number of alternatives.

Definition 2 A set of n rankings is defined as:

$$\mathcal{R} = \{r_1, r_2, \ldots, r_n\},$$

where each r_i is a full ranking $r_i = [ar_{i,1}, ar_{i,2}, ..., ar_{i,m}]$. Here $a_{i,j}$ is the rank assigned to the j-th alternative ($item_j$) in the i-th ranking.

The set $\mathcal{R}$ can be represented as an $n \times m$ matrix:

$$\mathcal{R} = \begin{array}{c} \\ r_1 \\ r_2 \\ \cdots \\ r_n \end{array} \begin{array}{c} \begin{array}{cccc} item_1 & item_2 & \ldots & item_m \end{array} \\ \begin{bmatrix} ar_{1,1} & ar_{1,2} & \ldots & ar_{1,m} \\ ar_{2,1} & ar_{2,2} & \ldots & ar_{2,m} \\ \ldots & \ldots & \ldots & \ldots \\ ar_{n,1} & ar_{n,2} & \ldots & ar_{n,m} \end{bmatrix} \end{array} \tag{1}$$

A directed graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ represents the order of alternatives in the matrix $\mathcal{R}$, where $\mathcal{V}$ is the set of nodes, and $\mathcal{E}$ is the set of directed edges. An edge (x, y) indicates a direct path from node x to node y. An edge (x, x) is called a loop. The adjacency matrix $A = (a_{i,j})_{m\times m}$ is defined such that $a_{x,y} = 1$ if $(x, y) \in \mathcal{E}$, and $a_{x,y} = 0$, otherwise.

Definition 3 A Markov Chain is a discrete-time stochastic process $\{X_t\}$ with a state space S and the Markov Property:

$$\Pr(X_{t+1} = x \mid X_1 = x_1, X_2 = x_2, \ldots, X_t = x_t) = \Pr(X_{t+1} = x \mid X_t = x_t),$$

for all $t \geq 0$ and $x, x_1, x_2, \ldots, x_t \in S$. The future state X_{t+1} only depends on the current state X_t.

The transition between states is represented by a *transition probability matrix* $P = (p_{i,j})$ where $p_{i,j}$ is defined as follows:

$$p_{ij} = \Pr(X_{t+1} = j \mid X_t = i),$$

The matrix P satisfies:

1. $p_{i,j} \geq 0$ for all i, j,
2. $\sum_j p_{i,j} = 1$ for all i, ensuring probabilities sum to 1.

Definition 4 A stationary state (or stationary distribution) π of a Markov Chain is a probability distribution that remains unchanged over time, satisfying:

$$\pi P = \pi,$$

with: $\sum_i \pi_i = 1$ and $\pi_i \geq 0$ for all i.

The vector π represents the long-term proportion of time the Markov Chain spends in each state. This holds if the Markov Chain is ergodic, meaning it is irreducible (all states communicate), aperiodic (returns occur irregularly), and positive recurrent (expected return time is finite).

3 Related Works

Numerous methods have been proposed for rank aggregation focusing on those using the Markov chain (MC) approach due to their effectiveness in capturing consensus among multiple rankings. Our proposed method also follows this approach.

In rank aggregation, the goal is to create a consensus ranking from multiple ranking lists that reflects preferences across all lists. The Markov chain-based approach achieves this by:

1. Constructing the Transition Matrix: The matrix P captures how preferences transition from one item to another based on the rankings, with probabilities reflecting different assumptions about item relationships.

2. Ensuring Ergodicity: to converge to a unique stationary distribution, mechanisms such as teleportation ensure all items can eventually be reached from any starting point.
3. Finding the Stationary State: The stationary state π of the Markov Chain represents the long-term behavior and corresponds to the consensus ranking with elements representing the probabilities associated with each item.

Different methods primarily diverge in constructing the transition matrix P, reflecting different assumptions and impacting the resulting consensus ranking. Dwork et al. [5] introduced a method for aggregating partial lists using Markov chains, proposing four approaches:

– MC1: Transitions based on moving to a better alternative with probability $1/j$, where j is the average rank of the current item.
– MC2: Similar to MC1 but uses geometric mean ranks for transitions.
– MC3: Uses Borda scores to generate transition probabilities based on score differences.
– MC4: Generalizes Copeland's method using majority contests to determine transitions.

Markov chain-based methods have also been extended to incorporate uncertainty in preferences. Zhou et al. [17] use fuzzy numbers to express uncertainty in expert preferences, while Fu and Chang [6] use interval values for scenarios with incomplete preference information. These approaches construct transition matrices that approximate group interactions through fuzzy or interval-based representations.

Existing studies primarly focus on deriving final rankings from partial lists or using global dominance comparisons. However, there is a lack of analysis on handling conflicts in rankings and ensuring that obtained ranks address disagreements, leading to full rankings with or without ties. This gap is addressed by the research presented in this article.

4 Local Markovian Consensus (LMC) Method

The Local Markovian Consensus (LMC) method addresses uncertainty in ranking preferences by interpreting various rankings as decision-making processes over the same alternatives. Each ranking indicates a sequence of preferences, which the LMC method represents as probabilities of transitioning from one alternative to another. Higher probabilities suggest a greater likelihood of visiting an alternative but imply it is more often dominated. These rankings are depicted as graph connections, allowing for movement between alternatives and forming a consensus ranking.

The LMC method constructs an aggregated ranking by focusing on local patterns and connections rather than a total order, making it effective in scenarios where segments or paths are prioritized. It serves as an effective substitute for traditional aggregation methods for several reasons:

1. It preserves information about the relationships between alternatives in individual rankings, which is often lost in distance- or dominance-based methods.

2. It is more flexible when dealing with heterogeneous data where standard distance measures may not apply.
3. It allows control over the influence of random sequences not present in the given rankings through the d damping factor.

The following subsections detail the steps of the LMC method, concluding with a calculation example.

4.1 Input—Set $\mathcal{R}$

The input data for the LMC is the set $\mathcal{R}$ in the matrix form as shown in eq. 1.

4.2 Constructing the Graph

In the proposed method, a directed graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ represents the order of alternatives in the matrix $\mathcal{R}$. The nodes $\mathcal{V}$ represent alternatives $item_i \in \mathcal{V}$ from the set of rankings $\mathcal{R}$. Edges $\mathcal{E}$ are determined by analyzing transitions in the rankings and examining pairs of alternatives according to their ranks.

An edge (j, k) is created from node $item_j$ to node $item_k$ if $item_k$ follows $item_j$ in a ranking. The loop edge (j, j) is created when the $item_j$ is ranked last.

For the graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ with $m = |\mathcal{V}|$ nodes, we construct an adjacency matrix $A = (a_{ij})_{m \times m}$, using the following conditions:

$$a_{j,k} = \begin{cases} \sum_{i,j,k=1}^{n,m,m} \mathbf{1}_{\{i,j,k\}} & \text{if } ar_{i,k} - ar_{i,j} = 1 \wedge j \neq k \\ \sum_{i,j=1}^{n,m} \mathbf{1}_{\{i,j\}} & \text{if } ar_{i,j} = m \\ 0 & \text{otherwise} \end{cases}, \tag{2}$$

where $ar_{i,j}$ is rank of the j-th item in i-th ranking.

In the LMC method, edges indicate that one alternative is ranked directly ahead of another, without specifying the actual rank. The frequency of these pairwise comparisons across all rankings serves as a frequency indicator.

4.3 Transition Probability Calculation

From the adjacency matrix $A = (a_{ij})$, we construct the transition probability matrix P for the Markov chain, where p_{ij} represents the frequency of edge (i, j) appearing in rankings $\mathcal{R}$. The elements of P are calculated as:

$$p_{ij} = a_{ij}/n, \tag{3}$$

where a_{ij} defined by Equation 2 and n is the number of rankings. Each element p_{ij} satisfies $0 \leq p_{ij} \leq 1$ and the $\sum_{j=1}^{m} p_{ij} = 1$, representing the probability of transitioning between alternatives. Higher probabilities indicate more frequent transitions and suggest dominance by the predecessor.

4.4 Ergodicity

In the proposed method, a Markov stationary process is defined as:

$$r(t+1) = P \cdot r(t), \tag{4}$$

where $r(t) \in \mathbf{R}_{+}^{m}$ is a ranking vector and P is the transition probability matrix. The initial vector $r(0)$ is a stochastic vector, meaning $\sum_{i=1}^{m} r_i(0) = 1$.

The transition rule in LMC is as follows:

If the current state is represented by alternative $item_i$, then the next state is chosen uniformly from alternatives t ranked immediately after $item_i$ in the rankings. If no alternative follows $item_i$ then the transition probability to remain in state $item_i$ is 1.

A key question is whether the Markov chain converges to a stationary distribution for any initial non-zero values $\pi_i(0)$, $i \in \mathcal{V}$. This distribution represents the probability of visiting an alternative due to its dominance.

We expect that the probability vector $\pi(t)$ asymptotically converges to stationary/consensus ranking π^*:

$$\pi(t) \to \pi^* \text{ as } t \to \infty,$$

To ensure convergence, the method incorporates the PageRank assumption known as teleportation [7]. This accounts for transitions not detected in $\mathbf{R}$ assigning a uniform transition probability of $1/m$ to each alternative. The parameter $d \in (0, 1)$ indicates the decision maker's tendency to follow the alternatives listed in $\mathbf{R}$, while $(1-d)$ represents the willingness to follow any alternative with probability $1/m$. The formulation is:

$$\pi(t+1) = \left((1-d)\frac{1}{m}\mathbf{1} + dP\right)\pi(t) \tag{5}$$

where $\mathbf{1}$ is an $m \times m$ matrix with all entries equal to 1, and t is a discrete time.

4.5 Computational Example

Consider a set $\mathcal{R}$ of $n = 5$ rankings for $m = 4$ alternatives, with the preferences distribution shown in Fig. 1. Each ranking displays the order of preferences for the alternatives.

$$\mathcal{R} = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{cccc} item_1 & item_2 & item_3 & item_4 \end{array} \\ \begin{bmatrix} 1 & 2 & 3 & 4 \\ 2 & 3 & 1 & 4 \\ 2 & 1 & 4 & 3 \\ 1 & 2 & 3 & 4 \\ 4 & 1 & 2 & 3 \end{bmatrix} \end{array}$$

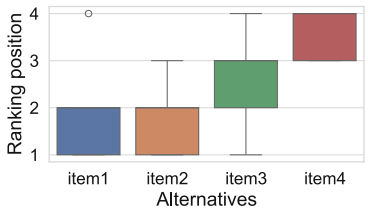
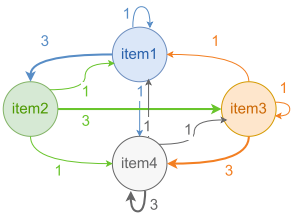


Fig. 1. Matrix $\mathcal{R}$ and its rankings distribution (right diagram)

The distribution diagram in Fig. 1(b) shows minimal conflicts, with $item_4$ following $item_3$ in the rankings. $item_1$ and $item_2$ have similar centrality measures, leading to potential uncertainty in the aggregated ranking.

A directed graph is constructed from $\mathcal{R}$ by creating edges based on rankings. For example, $r_1 = [1, 2, 3, 4]$, creates edges between consecutive items (from $item_1$ to $item_2$, etc), with loops for the last position ($item_4$). This process is repeated for all rankings, and edge counts are updated as necessary.

The graph and corresponding adjacency matrix A derive the transition matrix P, (Fig. 2).



$$P = \begin{array}{c} \\ item_1 \\ item_2 \\ item_3 \\ item_4 \end{array} \begin{array}{c} \begin{array}{cccc} item_1 & item_2 & item_3 & item_4 \end{array} \\ \begin{bmatrix} 0.2 & 0.6 & 0.0 & 0.2 \\ 0.2 & 0.0 & 0.6 & 0.2 \\ 0.2 & 0.0 & 0.2 & 0.6 \\ 0.2 & 0.0 & 0.2 & 0.6 \end{bmatrix} \end{array}$$

Fig. 2. Graph from adjacency matrix A (left), transition matrix P (right)

Using Equation 5 with $d = 0.9$ the stationary state π^* is calculated after $t = 4$ steps, with precision $\epsilon = 0.0001$ and initial $\pi(0) = [0.25] \times 4$:

$$\pi^* = [0.205, 0.1357, 0.216952, 0.442348]$$

The consensus ranking [2, 1, 3, 4] is derived from π^* indicating $item_4$ as most dominant (last) and $item_2$ the first.

5 Experiments

This section analyzes the LMC method for synthetically generated rankings with various properties. We compare LMC with other methods, including MC1, MC2, MC3, MC4 [5], Borda, Copeland [15], Rank Position (RP), and Dominance Direct Graph (DDG) methods [13]. These methods were chosen for relevance: Borda represents a classical approach, Copeland exemplifies pairwise comparison, MC1-MC4 are Markov chain-based prototypes, and DDG and RP are dominance graph-based methods.

The following subsections present evaluation measures, LMC's performance on datasets with varying disagreement levels, and comparisons with other consensus methods.

5.1 Evaluation Measures

The following measures compare rankings and analyze the synthetic dataset [5].

Spearman Footrule Distance measures the sum of absolute differences between corresponding elements in two rankings r_1 and r_2 of length m:

$$\mathrm{SFD}(r_1, r_2) = \sum_{i=1}^{m} |r_1(i) - r_2(i)|. \tag{6}$$

Kendall Tau Distance counts the number of pairwise disagreements between r_1 and r_2:

$$\begin{aligned} \mathrm{KTD} = 2|(i,j)|i < j, \text{ where } r_1(i) < r_1(j), \\ \text{but } r_2(i) > r_2(j)|/(m \cdot (m-1)) \end{aligned} \tag{7}$$

Both SFD and KTD quantify dissimilarity between rankings and can be extended to multiple rankings by calculating pairwise distances and averaging over all pairs.

Consistency Measure evaluates variability among aggregated rankings using standard deviation. For each alternative, calculate the standard deviation across all rankings, then average these values:

$$\mathrm{MStd} = \frac{\sum_{i=1}^{m} \sigma_i}{m}, \tag{8}$$

where σ_i is the standard deviation for the i-th alternative across all rankings $\mathcal{R}$.

5.2 Synthetic Dataset Generator

To evaluate the LMC method under varying levels of disagreement, we generate synthetic datasets using a reference ranking of length m as the baseline. By performing random perturbations on this reference ranking with a specified probability, we create n perturbed rankings. This process simulates different levels of noise in the ranking data, enabling us to test the robustness and performance of the LMC method under diverse conditions of ranking inconsistency.

5.3 Local Markovian Consensus (LMC) Experimental Analysis

To evaluate the properties of the LMC method, we tested it on three synthetic datasets of size $m = 10, n = 1000$ with perturbations [0.01, 0.5, 0.99] as described in Sect. 5.2. A small m allows for easier observation.

Figure 3 shows heatmaps of probability transition matrices P for each dataset. With 0.01 perturbation, the rankings are consistent, showing a clear pattern: from alternative $it5$, to $it6$, to $it9$, and so on, with $it1$as the most probable loop node. The final ranking is [10, 8, 4, 9, 1, 2, 7, 6, 3, 5].

For 0.5 perturbation, the consensus ranking is [10, 5, 9, 4, 1, 2, 7, 6, 3, 8], with the first three alternatives and the last are consistent with the reference ranking.

Figures 4 (a) and (b) compare final rankings for very consistent and highly inconsistent datasets using different consensus methods (generated with the PyMCDM library [9]). 'Ref' represents the reference ranking. LMC variants-LMC5, LMC50, and LMC98-correspond to damping factors $d = \{0.05, 0.5, 0.98\}$, affecting the likelihood of random walks between alternatives. A smaller d increases the chance of moving between alternatives according to the initial transition matrix, resulting in a controlled consensus.

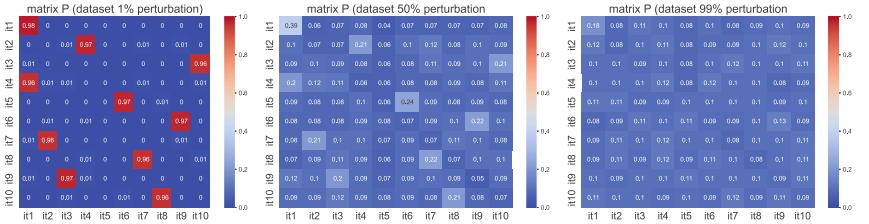
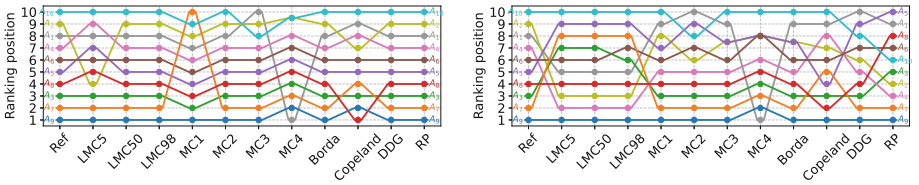


Fig. 3. Probability transition matrices P for datasets with $m = 10$ alternatives and $n = 1000$ rankings with 0.01, 0.5, 0.9 perturbations



(a) (b)

Fig. 4. Comparison of reference and final rankings on datasets with 0.01 (a) and 0.99 (b) perturbation $m = 10$, $n = 1000$

For the 0.99 perturbation dataset, the stationary state π^* after 7 steps with $d = 0.98$ is:

$$pi^* = [0.1083, 0.0985, 0.1009, 0.104, 0.0923, 0.101, 0.0985, 0.0968, 0.0999, 0.0998]$$

With standard deviation close to 0.004 and mean 0.1, π^* is nearly identical to the initial state $[0.1] \times 10$, indicating difficulty in determining a clear order in highly inconsistent environments. By rounding π^* to two decimal places, we get:

$$\pi^* = [0.11, 0.1, 0.1, 0.1, 0.09, 0.1, 0.1, 0.1, 0.1, 0.1]$$

This results in a consensus ranking with ties: [10, 5.5, 5.5, 5.5, 1, 5.5, 5.5, 5.5, 5.5, 5.5] , preserving the first and last alternatives.

In conclusion, the LMC method tends to preserve the first and last alternatives in rankings. Significant disagreement among rankings often results in random ordering for other alternatives, which can be identified by analyzing π^*.

5.4 LMC vs. Other Consensus Methods

This experiment compared the LMC method, using different damping factors, with other consensus methods across various environments using synthetic datasets.

5.4.1 Synthetic Dataset

We generated three sets of seven synthetic datasets with perturbation levels of 0.01, 0.1, 0.2, 0.5, 0.7, 0.9, and 0.99 (using the algorithm described in Sect. 5.2):

Set 1 500 rankings for 10 alternatives, reflecting diverse preferences across a large group.
Set 2 100 rankings for 20 alternatives, illustrating evaluations across a broader range.
Set 3 10 rankings for 100 alternatives, representing a small set with numerous options.

Datasets were analyzed using SFD, KTD, and MStd measures (Table 1). An increase in these measures indicates greater inconsistency. We focused on perturbation levels of 1% (agreement), 10% (moderate disagreement), and 70% (high disagreement) for further testing. All three measures showed similar responses to inconsistency, but KTD was preferred for its scientific acceptance and effectiveness in capturing order changes.

Table 1. Mean standard deviation (MStd) Spearman Footrule Distance (SFD) and Kendall tau Distance (KTD) for synthetic datasets

	$n = 500, m = 10$			$n = 100, m = 20$			$n = 10, m = 100$		
Pert.	MStd	SFD	KTD	MStd	SFD	KTD	MStd	SFD	KTD
1%	0.46	0.02	0.02	0.87	0.03	0.03	1.53	0.02	0.02
10%	1.68	0.23	0.21	3.24	0.23	0.21	10.77	0.19	0.17
20%	2.11	0.37	0.31	4.19	0.37	0.32	18.57	0.36	0.31
50%	2.68	0.58	0.45	5.28	0.57	0.45	24.05	0.56	0.44
70%	2.79	0.63	0.48	5.55	0.63	0.48	25.96	0.63	0.48
90%	2.83	0.65	0.49	5.63	0.64	0.49	26.38	0.65	0.49
99%	2.84	0.65	0.49	5.68	0.65	0.50	26.79	0.66	0.49

5.4.2 Experimental Results

We analyzed how consistency affects final rankings produced by various methods, using KTD to evaluate selected levels of agreement: 0.01, 0.1, and 0.7, across the datasets: Fig. 5 (Set 1), Fig. 6 (Set 2), and Fig. 7 (Set 3).

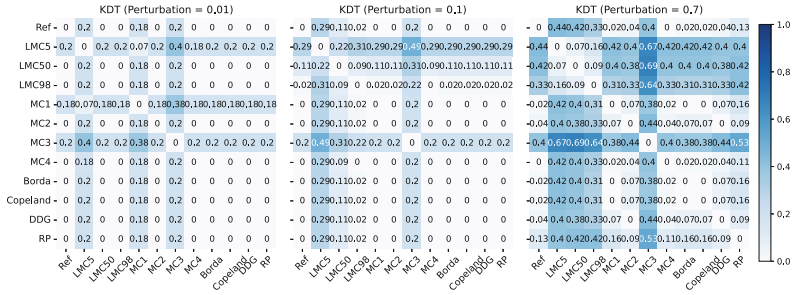


Fig. 5. KTD between final consensus rankings produced by different methods for levels of disagreement (0.01, 0.1, 0.7) for Set 1 ($m = 10, n = 500$)

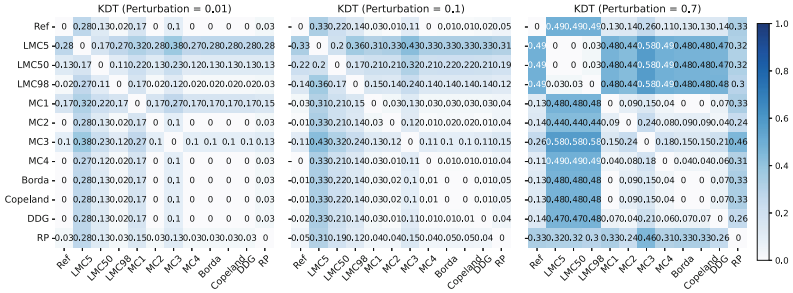


Fig. 6. KTD between final consensus rankings produced by different methods for levels of disagreement (0.01, 0.1, 0.7) for Set 2 ($m = 20$, $n = 100$)

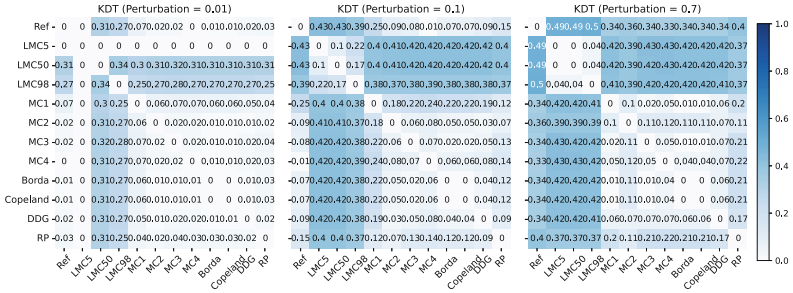


Fig. 7. KTD between final consensus rankings produced by different methods for levels of disagreement (0.01, 0.1, 0.7) for Set 3 ($m = 100$, $n = 10$)

As disagreement increases, the LMC method diverges from others, indicating its unique approach. With a damping factor of $d = 0.98$ (LMC98) algorithm recovers the reference ranking in highly consistent environments (1% perturbation). Smaller d values lead to greater variability, showing a tendency for random switching among alternatives. For Set 3, LMC with $d = 0.05$ (LMC5) results in ties for all but the first and last alternatives.

Increased shading in Figs. 5, 6 and 7 reflects rising inconsistency (increasing m and perturbation size). No method can recover the reference ranking in high-disagreement environments $p = 0.7$ in Fig. 7) due to the absence of the reference pattern in the rankings, which makes pattern recognition challenging with a limited number (10) of distinct rankings.

All LMC variants return more similar consensus rankings in highly conflicting environments, suggesting minimal influence of the damping factor on the final ranking.

Across all experiments, we observed that the performance of all algorithms varies significantly as the level of disagreement increases, highlighting the importance of understanding method-specific behaviors. Further analysis is needed to provide specific recommendations for selecting the most appropriate method in such environments. Understanding each method's nuances in various scenarios will be crucial for developing robust consensus algorithms tailored to particular use cases.

6 Conclusions

This paper presents a novel approach to rank aggregation using the Local Markovian Consensus (LMC), designed to address the challenges of inconsistent rankings. The method applies local connections between alternatives therefore offers a more flexible consensus aggregation. Key findings and contributions include:

1. Effectiveness in consistent environments: The LMC method performs comparably to other established methods when rankings are consistent, demonstrating robust aggregation capabilities and effectively recovering reference rankings, particularly with higher damping factors like $d = 0.98$.
2. Handling inconsistent rankings: The LMC method shows stable convergence to an aggregated ranking even in environments with significant disagreements. It provides a distinctive consensus that does not mimic the behavior of pairwise comparison methods or MCM methods, especially in highly inconsistent scenarios.
3. Useful Alternative: The LMC method is adaptable to heterogeneous data and maintains performance even with a high disagreement in a set of rankings. This makes it a valuable alternative.
4. Experimental validation: Rigorous testing on 10 synthetic datasets with varying characteristics (size and consistency) shows that the LMC method can effectively aggregate rankings in consistent and inconsistent environments. Moreover, the d factor allows control over random transitions in the final ranking.

Despite these promising results, further analysis is required to refine the method and provide specific recommendations for its application in diverse scenarios. This research lays the groundwork for future studies to explore and enhance rank aggregation methodologies in the face of ranking inconsistencies.

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Application of Rough Set Theory to Improve the Efficiency of Higher Education Systems

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Abstract. The purpose of this paper is to show the possibility of application of the Rough Set Theory to improve the efficiency of the higher education system. The study used a dataset describing with 35 attributes 4424 examples. The attributes include information known at the time of student enrollment (academic path, demographics, and social-economic factors) and the students' academic performance at the end of the first and second semesters. The data set was explored using the Rough Set Theory to discover knowledge (recurrence and dependencies in data) represented by decision rules. The attempts to induce decision rules revealed interesting relationships between the characteristics of the examples included in the decision table and the students' success (graduate) or failure (dropout). The relationships take a largely readable and easily interpretable form: if the premise, then the conclusion. The procedure carried out can be easily adapted to the conditions and needs of higher education systems. It will facilitate monitoring the characteristics of students, inferring in the form of clear rules and possibly taking measures directed at reducing the likelihood of students dropping out. This will make it possible to raise the effectiveness of the higher education system (fewer students dropping out) while increasing efficiency (early prediction of risks and spending on measures precisely aimed at eliminating risks). The study verifies the usefulness of the Rough Set Theory to build a rule base for decision-making in order to increase the efficiency and effectiveness of higher education.

Keywords: Rough Set Theory · Management of the Higher Education System · Higher Education Dropout/Success

1 Introduction

Recent years have revealed both global and regional problems, crises and challenges. Reference can be made, for example, to the Covid virus pandemic, armed conflicts, migration or the accompanying adverse economic problems affecting inflation or GDP. In the face of the observed phenomena, decision-makers in individual countries are redefining priorities and modifying the structure of state expenditure. This often leads to reduced funding for basic services provided by the state to citizens. Juxtaposed with

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 237–249, 2024.
https://doi.org/10.1007/978-3-031-78468-2_18

relatively more attractive salaries in the private sector, it leads to an exodus of personnel from the public service sector. Such a scenario, which seems to be experienced by more than one European country, leads to one universal question: how to manage limited resources more efficiently?

This article relates this problem to higher education. By efficiency, the authors mean both the success in achieving the goal, as well as cost-effectiveness, i.e. the rationalization of the cost of achieving the goal. Thus, it is about measures that are intended to increase the chances for students to successfully complete their studies, to achieve their and the higher education system's stated goal. At the same time, these efforts should not generate excessive costs. The authors, therefore, put forward here a proposal that a potential direction of action could be to identify, as quickly and accurately as possible, the individuals who have taken up studies and at the same time are relatively likely to discontinue or excessively prolong their studies. Certain measures can be applied to such people to help them obtain a diploma, preferably within the stipulated time. The idea is to reduce the number of situations when the costs of the student's functioning in the education system were incurred but they failed to graduate, or their path to a degree took longer than it should have, thus increasing the cost of achieving this goal. The identification of students who pose "problems" in the system can be accompanied by the identification of those who smoothly pass the entire path of study. This will make it possible to more precisely focus future assistance efforts only on those who are in need of such support. Thus the postulate of cost-effectiveness of measures, i.e. incurring their costs where they are most justified, limiting spending in areas where they are not necessary, will be met.

In the authors' opinion, the rough set theory, locating itself in the area of increasingly popular artificial intelligence methods and providing an efficient tool for data mining, information processing [9] and extracting information by employing available known knowledge in an information system [22], will be useful for solving a research problem so defined.

In the context of the above, the purpose of this study is to examine the usefulness of the rough set theory in improving the efficiency of higher education by means of proper targeting of support to students identified as highly likely to drop out. A key activity will be an attempt to induce decision rules.

The problem addressed should not be underestimated, as evidenced by an independent report written for the European Commission by the Network of Experts on Social Aspects of Education and Training (NESET). Its authors claim that "too many students in the EU drop out before the end of their higher education course. This is a problem across the EU, as success in higher education is vital for jobs, social justice and economic growth." They emphasize that the dominant factor leading to drop-out for students from under-represented groups is coming from a poor socio-economic background. The report points out that "it is not widening participation per se that causes drop-out. The problem is rather a lack of attention to the needs of a more diverse student population and a lack of a student-centered approach in designing and delivering higher education programs" [17]. According to the figures the most successful country in the EU in terms of university graduation is Denmark with 80% completion. The least successful country is Italy (46%) [17].

2 Research Methodology - Rough Set Theory

The study employs the theory of rough sets, published by Z. Pawlak in 1982 [13, 14] as a response to the problem of "imperfect" knowledge, which was on the minds of philosophers, logicians and mathematicians alike in the past for. "Many science and technology problems involve uncertainties; hence, uncertainty optimization problems are the topic of great interest among researchers" [19].

Moreover, in line with the development of computer techniques, including the artificial intelligence, this issue has also been agitating the minds of computer scientists. Many of problems related to AI are involved in decision making under uncertainty, optimization under uncertainty is imperative for expert systems [20].

From a logical point of view, rough set theory is a mathematical approach to fuzzy concepts, while from a practical perspective, it is a new method of data analysis that helps to search for relationships among data, reduce data redundancy, determine the weights of individual data components, or to derive decision rules from data [3]. Simultaneously, Pawlak [12] pointed out that data analysis should be treated as a special instance of inductive inference which, starting from certain partially known facts about the reality and by way of generalizations, strives to create knowledge about a world broader than the one being the starting point for the considerations. Such efforts are aimed at drawing probable (possible) conclusions, while the validation of hypotheses is performed by way of experiments.

Based on the accuracy of reality measurement, the objects in question can be considered either different or indistinguishable from each other. Yet, the measurements often do not need to be too precise, and instead of differences the similarity of the elements is more interesting. "The elements about which we have received identical information are similar and compose the so-called elementary sets. They provide grounds for reasoning in the rough set theory. The sum of any elementary sets is called a definable set. Sets that are not definable are called rough sets. Obviously, the definable sets can be explicitly described by the properties of their elements, while the rough sets cannot be described in this way. That is why the rough set theory introduces the terms of lower and upper rough sets that enable any non-definable (rough) set to be characterized by two definable sets, i.e. its lower and upper roughness (…) the very essence of the method lies in the introduction of two membership functions $\subseteq$ and $\overline{\in}$ that respectively denote 'certainly belongs' and 'possibly belongs'" [12].

Let $IS = (U,A,V,f)$ be an information system, where U is a nonempty finite set of objects; A is a nonempty finite set of attributes; $V = \bigcup a \in AVa$ and Va is the domain of the attribute a; $f{:}U \times A \rightarrow V$ is an information function, and $f(x,a) \in Va$, where f(x, a) denotes the attribute value of object $x \in U$ with respect to attribute $a \in A$.

For an attribute subset B $\subseteq A$, B determines a binary indiscernible relation denoted by I(B) as follows: I(B) = {(x,y) ∈ U × U: ∀a ∈ B f(x,a) = f(y,a)}.

The I(B) is an equivalence relation on U, and the derived partition is $U/I(B) = \{[x]A{:}x \in U\}$, where $[x]A$ is the equivalence class containing x.

This leads to lower and upper approximations of $X \subseteq U$ which are denoted by B_(X) and B¯(X) and defined as: B_(X) = {x ∈ U: B(x) ⊆ X}, B¯(X) = {x ∈ U: B(x) ∩ X ≠ ∅}.

The set theory terminology is used to describe "rough operations on sets, as well as exact operations on rough sets. (…) The proposed method is based on an imperceptible relation that glues together all the objects that one could not distinguish by available means of observation (measurement) or expression (language)" [13].

As a result of the rough set theory application we obtain decision rules with their far better fit with the human mind than it is the case of black box type techniques such as discriminant functions or neural networks. The decision rules provide an explicit representation of knowledge, which adds to better understanding and explanation of the decision problems under consideration. The significance of this issue is illustrated by the fact that the juxtaposition of these two approaches has earned its own name: data fit versus mental fit [23]. Both Pawlak's classic theory and its emerging extensions have been successfully used in many areas to deal with vague and uncertain data.

We can perceive growing interest in a wide range of applications, among other, in the field of knowledge discovery [2], knowledge acquisition [16], data mining [1], attribute reduction [24], medical diagnosis [7], conflict analysis [5], and of course decision making [6], and so forth and so on. We also refer readers to Wang et al. who mean that "the achievements of rough sets in application fields are low-hanging fruit in many domains (…) They show that the demands of practical use in many real-life fields are one of the driving forces promoting the development of rough set theory" [22]. They give a lot of examples.

3 Research Description

The proposed procedure is based on searching for knowledge in the data and trying to find their repeatability. Potential rules revealed are representations of knowledge about the behavior and ongoing phenomena. They form the basis for decision-making with regard to future phenomena that happen under similar conditions. For the purpose of this study, the following a dataset was used that had been prepared and released in the work [18] which contains 4424 records with 35 attributes. Each record applies to an individual student at Polytechnic Institute of Portalegre enrolled in different undergraduate degrees between the academic years 2008/2009 (after the application of the Bologna Process to higher education in Europe) to 2018/2019. The attributes are the aggregation of information from different disjointed data sources and includes information known at the time of student enrollment (academic path, demographics, and social-economic factors) and the students' academic performance at the end of the first and second semesters. A detailed description of the date and the procedure of preparation of this set can be found in the mentioned paper.

In accordance with the requirements of the rough set theory and the assumption for research and the adopted goal, 34 features from the dataset are conditional variables, the last one - decision variable. The authors of the dataset pointed out that there were different approaches to defining a dropout, which was often distinguished by time (early vs. late) [8]. In this dataset dropouts are defined from a micro-perspective, where field and institution changes are considered dropouts independently of the timing these occur. Consequently, a higher dropout rate is revealed than taking into account macro-perspective which considers only students who leave the higher education system without

a degree. The decision variable (last attribute in set) takes values: dropout, enrolled, graduate. So the main question is: what combinations of conditional variables lead to failure (dropout) and what ones to success (graduate). Table 1 shows all considered conditional variables. Some of them are discrete (i.e. Marital status), some binary (i.e. Gender), some continuous (i.e. Age at enrollment).

The primary decision table was discretized by replacing continuous measurement scales used in the source data with scales operating with three values, where 1 represents a low, 2 - medium, and 3 - high value of a given characteristic. This procedure, which reduces the level of detail in the source data, is expected to increase the likelihood of discovering repeatability in the data, i.e. the induction of decision rules. In the discretization process, an attempt was made to obtain sets that were as equal as possible. In this way, a secondary decision table was created.

The rough set theory makes it possible to identify data redundancy in information tables and eliminate it, i.e. create attribute reducts. Hence, the next step was an attempt to reduce the number of conditional attributes. Potential reducts still allow to identify combinations of condition attributes leading to the selected target (dropout, enrolled, graduate). Unfortunately, no reducts could be created, which means that all the assumed conditional attributes are relevant and none of them can be omitted. Further inference will be made using the full set of 34 conditional attributes.

An attempt was then made to discover decision rules taking into account the levels of satisfaction, including rule firmness and strength of support - backed up by as many examples as possible from the dataset corresponding to both the conditional (premise) and decision (conclusion) sections of the rule. The resulting set of rules was subjected to interpretation and discussion.

Attempting to extract knowledge from data with the use of rough set theory implies the possibility of testing various rule induction algorithms. First, the classic LEM2 algorithm, developed by Grzymała-Busse [4], was used. Like the majority of induction algorithms, it is based on R. Michalski's algorithm for generating successive coverages [10]. The procedure consists in learning a single rule and then eliminating from the input data set the examples covered by it and repeating the process for the remaining examples in the universe. In this way, a set of rules covering the considered set of examples is obtained. This action is often called Basic Minimal Covering.

In the following step, the Extended Minimal Covering was tested with modified ModLEM algorithms [21]. In both of these procedures, the number of rules obtained was very large, ranging from 563 to 1043. These rules mostly covered and supported a small number of cases, thus rendering them of little value.

It was further decided to proceed with the indication of the minimum requirements for rules. Here, it is possible to filter out from the previously generated rules those that are interesting due to the indicated criteria, or to introduce directly into the algorithm the constraints for searching hypotheses and generate rules straight from the data. This was done using the Explore algorithm [11]. In that case, the adopted tuning parameters were: Maximum length = 3, Minimum strength = 30%, and relative and Minimum discrimination level = 70%. That step made it possible to obtain a much shorter number of satisfactory rules that were readable and easy to interpret while providing an interesting

Table 1. Conditional attributes included in the decision table

Symbols for conditional variables	Names of conditional variables
q1	Marital status
q2	Application mode
q3	Application order
q4	Course
q5	Daytime/evening attendance
q6	Previous qualification
q7	Nationality
q8	Mother's qualification
q9	Father's qualification
q10	Mother's occupation
q11	Father's occupation
q12	Displaced
q13	Educational special needs
q14	Debtor
q15	Tuition fees up to date
q16	Gender
q17	Scholarship holder
q18	Age at enrollment
q19	International
q20	Curricular units 1st sem (credited)
q21	Curricular units 1st sem (enrolled)
q22	Curricular units 1st sem (evaluations)
q23	Curricular units 1st sem (approved)
q24	Curricular units 1st sem (grade)
q25	Curricular units 1st sem (without evaluations)
q26	Curricular units 2nd sem (credited)
q27	Curricular units 2nd sem (enrolled)
q28	Curricular units 2nd sem (evaluations)
q29	Curricular units 2nd sem (approved)
q30	Curricular units 2nd sem (grade)
q31	Curricular units 2nd sem (without evaluations)
q32	Unemployment rate

(*continued*)

Table 1. (*continued*)

Symbols for conditional variables	Names of conditional variables
q33	Inflation rate
q34	GDP

picture of the examined fragment of reality. The proposed procedure is in line with the proposals put forward in the literature.

The obtained rules were validated with the k-fold cross validation test with random distribution of examples in decision classes in each fold, with the number of folds (k) = 10. The tests showed a correction for the Dropout class at 83%, for the Graduate class at 70% and for Enrolled class at 0%. Thereby, the rules pertaining to the first two indicated classes were interpreted, while no valuable rules were discovered regarding delayed graduation.

The research was performed using ROSE2 [15] software developed by the Laboratory of Intelligent Decision Support Systems of the Poznan University of Technology.

4 Results and Discussion

Due to large number of records in the dataset a lot of rules were revealed, but the most majority of them had very weak support factor. They described the behavior of an extremely small number of students. Out of the pool of the rules the strength ones were interesting. Initially an attempt was made to find certain rules. Certain means that all cases covered by the rule (cases corresponding to a conditional part of the rule) also support the rule (have the same conclusion).

Attention is drawn to the rule taking the form:

$$\begin{aligned} &\text{If q21} = \{2, 3, 4, 5, 6, 7\} \& \text{q28} = 0, \text{ then d} = \text{Dropout;} \\ &\qquad [215,\ 215,\ 15.13\%,\ 100.00\%]\,[215,\ 0,\ 0] \end{aligned} \tag{1}$$

Given the names of the metrics denoted by the symbols of the rule conditional attributes (Table 1) and taking into account the employed discretization of their values, as well as the decision attribute (d), the rule can be read as:

If Curricular units 1st sem (enrolled) is between 2 and 7 (q21 = {2, 3, 4, 5, 6, 7}) and Curricular units 2nd sem (evaluations) equals 0 (q28 = 0), then Target(d) = Dropout.

The advantage of the rule is its length. The conditional section consists of only 2 attributes, making it readable and easy to interpret. From the analysis of the quality of the rule, it can be read (first square bracket) that the rule covers 215 examples in the decision table: 215 (out of 4424) students are characterized by q21 = {2, 3, 4, 5, 6, 7} and q28 = 0. All these cases (the second 215 in brackets) lead to the conclusion that d = Dropout, so the rule is firm (certain) (100%) - each student from the dataset that can be described in pointed out way (q21 and q28) is characterized by d = Dropout or each occurrence of q21 = {2, 3, 4, 5, 6, 7} and q28 = 0 leads to d = Dropout - study failure.

At the same time, the rule support factor says that 15.13% of students (215 out of 1421) who dropped out (d = Dropout) are students with the combination of conditional attributes (q21 = {2, 3, 4, 5, 6, 7} and q28 = 0) indicated by the rule.

The second bracket with the parameters of the rule indicates that all (215) cases to which the rule applies take the first value of the conclusion (d = Dropout).

The rule indicates a fairly unambiguous mechanism. If a student enrolls in a certain number of courses in the first semester and fails to get evaluations in the second semester, he or she will leave or has already left.

The second rule worthwhile pointing out is:

$$\text{If q4} = \{1, 3, 4, 12, 13, 16, 17\} \,\&\, \text{q15} = 0 \,\&\, \text{q20} = \{0, 1, 2, 3, 4, 5, 8, 9, 10, 12\},$$
$$\text{then d} = \text{Dropout; } [168, 168, 11.82\%, 100.00\%]\,[168,\ 0,\ 0] \qquad (2)$$

It can be decoded to:

If Course (q4) is out of Biofuel Production Technologies (1), Social Service (evening attendance) (3), Agronomy (4), Nursing (12), Oral Hygiene (13), Basic Education (16), Management (evening attendance) (17) and Tuition fees ARE NOT up to date (q15 = 0) and Curricular units 1st sem (credited) takes specific numbers (c20 = 0, 1, 2, 3, 4, 5, 8, 9, 10, 12), then Target(d) = Dropout.

This rule is not so obvious to interpret, but maybe be useful as an indicator of the direction of an in-depth analysis. It covers 168 of students (their characteristics correspond to condition attributes) and is also supported by the same students, all of them have conclusion about dropping out. So this is the certain rule with certain factor equals 100%. Support factor equals 11.82% says that almost 12% of students (168 out of 1421) who dropped out (d = Dropout) are students with the indicated combination of conditional attributes.

Due to the small number of certain and easily interpretable rules, further attention was directed to possible rules, i.e. rules in which not all examples covered by the rule (consistent with the premise) support the rule (are consistent with the conclusion). For pragmatic reasons, rules were sought that have the highest possible certainty factor, high strength (relation of support to the size of the entire set of examples) and at the same time a small number of conditional attributes. This is an attempt to identify factors that have a clear impact on success or failure.

Attention is drawn to 5 similar rules having only one conditional attribute. The first one takes the form:

$$\text{If q15} = 0,\ \text{then d} = \text{Dropout; } [528,\ 457,\ 32.16\%,\ 86.55\%]\,[457,\ 42,\ 29] \qquad (3)$$

And it can be decoded as:

If Tuition fees ARE NOT up to date (q15 = 0), then Target (d) = Dropout.

The rule covers 528 examples from the dataset but is supported by 457 of them, so its certainty factor equals 86.55%. In other words, over 86% of students with overdue payments drop out. It can also be seen (second square bracket) that 42 are enrolled and 29 graduate. What is more, the rule describes the behavior of 32% of leaving students (support factor), with 32% of those who drop off having overdue payments. It is worthwhile

to pay attention to the strength of rule (support divided by total numbers of examples) which equals 10.33% (457/4424). The rule applies to over 10% of all students.

Obviously, we still did not reveal whether the reason for leaving was the problem of money, or they stopped paying because they had already known they were going to leave. But this point could be again an indicator of the direction of an in-depth analysis.

While rule (3) refers to an attribute from the Socioeconomic data class, the other rules from the set taking a similar form (4–7) refer to attribute classes: Academic data at the end of 1st semester and Academic data at the end of 2nd semester. All of them have a length equal to 1, a conclusion taking the value of Dropout and about 80% certainty (so many examples corresponding to the premise have a conclusion consistent with the rule).

$$\text{If q20} = 0, \text{ then d} = \text{Dropout; } [870,\ 727,\ 51.16\%,\ 83.56\%]\,[727,\ 68,\ 75] \quad (4)$$

$$\text{If q23} = 0, \text{ then d} = \text{Dropout; } [718,\ 570,\ 40.11\%,\ 79.39\%]\,[570,\ 71,\ 77] \quad (5)$$

$$\text{If q24} = 0, \text{ then d} = \text{Dropout; } [718,\ 570,\ 40.11\%,\ 79.39\%]\,[570,\ 71,\ 77] \quad (6)$$

$$\text{If q30} = 0, \text{ then d} = \text{Dropout; } [870,\ 727,\ 51.16\%,\ 83.56\%]\,[727,\ 68,\ 75] \quad (7)$$

Decoded rules can be, respectively:

If number of credited curricular units (1st sem) equals 0 (q20 = 0), then Target (d) = Dropout
If number of approved curricular units (1st sem) equals 0 (q23 = 0), then Target (d) = Dropout
If average grade of curricular units (1st sem) is low (q24 = 1), then Target (d) = Dropout
If average grade of curricular units (2nd sem) is low (q30 = 1), then Target (d) = Dropout

Regarding rules (6) and (7), it should be clarified that the source data is recorded in scale.

Regarding rules (6) and (7), it should be clarified that the source data are written on a scale of 0–20, where 0.00–3.40 means Poor, 3.50–9.40 means Weak, 9.50–13.40 means Sufficient, 13.50–15.40 means Very Good and 17.50–20.00 means Excellent. This continuous scale was discretized by replacing it with scales operating with three values, where 1 represents a low (0–9.40), 2 – a medium (9.50–15.40), and 3 – a high (15.50–20.00) value of a given characteristic.

The rules have a high support rate of 51.16% (4) and (7) and 40.11% (5) and (6), respectively. This means that such a percentage of students agreeing with the conclusion (Dropout) is characterized by the premise indicated in the rules. At the same time, the rules have a fairly high strength, for example, rules (4) and (7) equal 19.66% (870/4424), so they describe the behavior of almost one in five students. Despite the fact that they are not certain rules (according to rule (4), 68 people who failed to pass a single subject at the end of the 1st semester continue their studies, and 75 graduated) indicate clear regularities in the population under examination.

So far, attention has been focused on rules indicating failures. It is also worth using positive examples. Also this time a group of rules has been revealed that are similar

and, what is more, operate with a similar set of attributes as before. This may prove the distinctive influence of these variables on the ultimate success or failure.

$$\text{If q17} = 1, \text{ then d} = \text{Graduate; } [1099,\ 835,\ 37.80\%,\ 75.98\%]\,[134,\ 130,\ 835] \quad (8)$$

$$\text{If q20} = 6, \text{ then d} = \text{Graduate; } [965,\ 803,\ 36.35\%,\ 83.21\%]\,[64,\ 98,\ 803] \quad (9)$$

$$\text{If q23} = 6, \text{ then d} = \text{Graduate; } [1171,\ 916,\ 41.47\%,\ 78.22\%]\,[117,\ 138,\ 916] \quad (10)$$

$$\text{If q24} = 3, \text{ then d} = \text{Graduate; } [1027,\ 795,\ 35.99\%,\ 77.41\%]\,[127,\ 105,\ 795] \quad (11)$$

$$\text{If q30} = 3, \text{ then d} = \text{Graduate; } [1032,\ 810,\ 36.67\%,\ 78.49\%]\,[114,\ 108,\ 810] \quad (12)$$

The rules can be decoded to form:

If student is a scholarship holder, then Target (d) = Graduate
If number of credited curricular units (1st sem) equals 6 (q20 = 6), then Target (d) = Graduate
If number of approved curricular units (1st sem) equals 6 (q23 = 6), then Target (d) = Graduate
If average grade of curricular units (1st sem) is high (q24 = 3), then Target (d) = Graduate
If average grade of curricular units (2nd sem) is high (q30 = 3), then Target (d) = Graduate

Again, we are dealing with possible rules, whose certainty coefficient oscillates around 80%. What should be noted is their strength, which varies from 21.81% to 24.84%, and thus indicates regularities in the behavior of an even larger part of the analyzed set of examples included in the dataset.

Following the trail of rule strength, a significant number of rules with relatively lower certainty but considerable coverage and strength have been discovered. At the same time, these are rules of greater length often operating with a wider spectrum of attributes. An example is a rule of the form:

$$\text{If q1} = 1 \,\&\, \text{q14} = 0 \,\&\, \text{q15} = 1 \,\&\, \text{q25} = 0 \,\&\, \text{q31} = 0, \text{ then d} = \text{Graduate);}$$
$$[2962,\ 1788,\ 80.94\%,\ 60.36\%]\,[652,\ 522,\ 1788] \quad (13)$$

which can be decoded as:

If Marital status = Single (q1 = 1) and student is NOT a debtor (q14 = 0) and Tuition fees are up to date (q15 = 1) and number of curricular units without evaluation in 1 sem (q25 = 0) and 2 sem (q30 = 0) equals 0, then target (d) = Graduate.

Although the qualitative analysis of the rule indicates that only 60.36% (1788 out of 2962) of the examples in line with the premise support the conclusion, but as many as 80.94% (1788 out of 2209 total graduates) of the examples with such a conclusion (graduating students), have the characteristics indicated by the conditional part of the rule.

The rule has a support of 40.41%, and so describes the behavior of more than 40% of the examples included in the decision table. Thanks to the investigation, we know that the 4424 examples described in the dataset apply in 40% to singles without a loan with no outstanding tuition payments who in the first two semesters had no subjects without evaluation and completed their studies.

5 Conclusion

The presented proceedings were aimed at analyzing the possibilities of improving efficiency in the field of higher education. It referred to the problem, observed in Europe, of a significant number of people who enroll in college, but fail to graduate. On the one hand, such a system is ineffective, as a large proportion of students do not achieve the goal of graduation, while on the other hand, both the education system and students incur costs that do not translate into the intended results.

The article proposes an approach based on the rough set theory. Using a dataset describing with 35 variables the total of 4424 examples – the characteristics of individual students, efforts were made to induce decision rules that represent the discovered knowledge.

The observed growing popularity of rough set theory results from the dynamic development of IT. On the one hand, more and more large data sets are being created, storing increasingly uncertain data. On the other hand, IT allows you to perform many operations in a short time. Rough set theory methods deal well with these sets given the computational power at their disposal.

The proposed in the paper approach can be used as an element of the university management IT system. It can act as a kind of early warning system and allow to identify problematic situations in advance and initiate corrective actions.

The work undertaken has uncovered many cognitively interesting relationships, a selection of which (within the limit available for this type of publication) have been presented and discussed. It remains an open question, and perhaps an inspiration for further research, how to select data and their sources for further study and adapt them to specific conditions, an individual country or university. Unsuccessful attempts to reduce data redundancy in the used dataset suggested that redundancy does not exist. They did not allow for the obvious elimination of some conditional variables without compromising the classification quality. However, decision rule induction algorithms looking for repeatability in the data clearly favored a certain limited set of arguments, omitting, for example, macroeconomic data such as the unemployment rate, inflation rate or GDP. This allows the authors to conclude that some characteristics may prove more useful than others in predicting success or failure. The rough set theory, on the other hand, can be successfully used to search for knowledge in large data sets in the subject area addressed in this publication.

Acknowledgments. This study was co-financed by the Minister of Science under the "Regional Excellence Initiative" Program.

Disclosure of Interests.. The authors have no competing interests to declare that are relevant to the content of this article.

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Distances Between Successive Vehicle Position Measurements in the Decision Rule for an Intelligent GNSS Signal Spoofing Detection System Using a Single Antenna

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Abstract. The article presents the concept of a decision rule for the needs of an intelligent GNSS signal spoofing detection system using a single antenna. GNSS spoofing detection using a single antenna is essentially similar to GNSS spoofing detection using two antennas. The main difference is that position measurements made simultaneously at two different points in space are replaced by two successive position measurements spaced in time. It turns out that based on the course of the distance between successive measurements of the position of a vehicle moving at a known speed, it is possible to effectively design a decision rule for the needs of an intelligent GNSS signal spoofing detection system using a single antenna. This is because when determining the distance between successive measurements of the vehicle's position, a significant proportion of the measurement errors of the satellite positioning system are reduced. This significantly reduces the dead zone of GNSS spoofing detection using a single antenna. The proposed approach was positively verified in tests conducted in real conditions.

Keywords: GNSS signal spoofing · GNSS signal spoofing detection · Cybersecurity of vehicles · Intelligent GNSS signal spoofing detection system · Decision rule

1 Introduction

The most popular and dominant method of determining location used in commercial civil and military solutions is GNSS (Global Navigation Satellite System), but it is not without its drawbacks. The most common threats to this system are jamming and undergrowth. Due to their shortcomings, both civilian and military circles have understood that it is necessary to determine ways and methods to prevent and solve the problem. This has created an important research problem on how to effectively detect GNSS spoofing [1].

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 250–260, 2024.
https://doi.org/10.1007/978-3-031-78468-2_19

Current GNSS spoofing detection methods are divided into many branches. The most widely used can be divided into two main categories, cryptographic and non-cryptographic [2]. Cryptographic methods are divided into two types, i.e. encryption methods [3] and methods of authenticating the received satellite signal [4], but both of these types of methods are associated with high complexity, and thus generate high costs of use. In the case of non-cryptographic methods, DOA (Direction of Arrival) and RAIM (Receiver Autonomous Integrity Monitoring) are differentiated. In the case of DOA, it is crucial to determine the direction of transmission of the incoming signal, the direction can be determined locally or using cloud resources [5, 6]. Another possibility is RAIM [7, 8], a method based on the integrity of a navigation receiver with the implementation of a spatial signal [9]. The RAIM method is based on the analysis of measurement results, i.e., differences between predicted and actual pseudorange measurements from satellites. RAIM allows for detecting errors in these measurements and excluding them to ensure navigation integrity. An experiment [10] showed that the proposed measurement exclusion technique reduced the average positioning error by 66%. The RAIM method can be divided into 2 categories. The traditional RAIM algorithm uses a snapshot method based on least squares estimation to detect single errors. Advanced RAIM (ARAIM) employs the ARAIM algorithm using a solution separation method in the location domain to detect multiple errors [11].

Another group of non-cryptographic methods for detecting spoofing attacks on GNSS receivers are techniques that use a larger number of signal receivers to detect redundant pseudo-distance measurement errors. Thanks to the non-cryptographic method, it is relatively cheaper than the cryptography method to detect attacks and make a preventive attempt without the use of more equipment and simpler implementation of solutions. The disadvantage of this method is the potential difficulty of multi-antenna systems to dissolve GNSS signal interference from spoofing attacks [12].

Due to the complexity of the research methods and instrumentation, and the time required to collect GNSS benchmark data to detect a threat, the problem of spoofing remains. Among the methods currently in use, there is no easy, reliable and inexpensive solution to the problem. And no single method of anti-spoofing remains foolproof. Therefore, there is a need to create methods to prevent GNSS receiver interference, and potential effective solutions are artificial intelligence applications based on the received signal based on decision-making algorithms [13–16].

The integration of AI in GNSS anti-spoofing measures could revolutionize the field by providing more adaptive, robust, and efficient solutions. AI systems can learn and improve over time, potentially outpacing traditional methods that rely heavily on predefined parameters and static models. By leveraging AI, it is possible to create a dynamic defense mechanism that continuously evolves to counter increasingly sophisticated spoofing techniques.

The article presents the concept of a decision rule for the needs of an intelligent GNSS signal spoofing detection system using a single antenna. The principle of operation of a single-antenna GNSS spoofing detection system is similar to that of a dual-antenna GNSS spoofing detection system [17]. The main difference is that the simultaneous measurement of position at two points in space is replaced by two consecutive position measurements spaced apart in time. The proposed approach is advantageous in that it

does not require additional navigation equipment (additional antenna). In fact, it can be used at a low cost in any satellite signal receiver. However, the disadvantage of detecting GNSS signal spoofing with a single antenna is that it is not possible to use this method in a stationary vehicle or moving at a relatively low speed. This is due to the fact that due to the measurement errors of the satellite positioning system, using only GNSS signal measurements, it is not possible to measure the actual distance between two positions that are too closely located. However, itturns out that when determining the distance between successive measurements of the vehicle's position, a significant part of the measurement errors (correlated errors) of the satellite positioning system are reduced. This significantly reduces the dead zone of GNSS spoofing detection using a single antenna. For this reason, it seems that the decision-making rule in this respect should be designed on the basis of the course of the distance between successive measurements of the position of the vehicle moving at a known speed. This approach is an important alternative to existing GNSS signal spoofing detection solutions, in line with the development of vehicle cybersecurity.

The article after the introductory part is as follows. The second chapter presents the concept of a decision rule for an intelligent GNSS signal spoofing detection system using a single antenna. The third chapter presents the results of research conducted in real conditions, the aim of which was to verify the presented approach. The summary of the article is formulated in the fourth chapter.

2 Decision Rule Concept for Intelligent GNSS Spoofing Detection System Using a Single Antenna

The error of the satellite positioning system at the i-th moment can be written as follows (distance between the measurement and the actual position):

$$E_i = \sqrt{\left(x_i^* - x_i\right)^2 + \left(y_i^* - y_i\right)^2 + \left(z_i^* - z_i\right)^2} \tag{1}$$

where (x_i, y_i, z_i) is the actual position being measured, and (x_i^*, y_i^*, z_i^*) is the measurement of this position (Fig. 1).

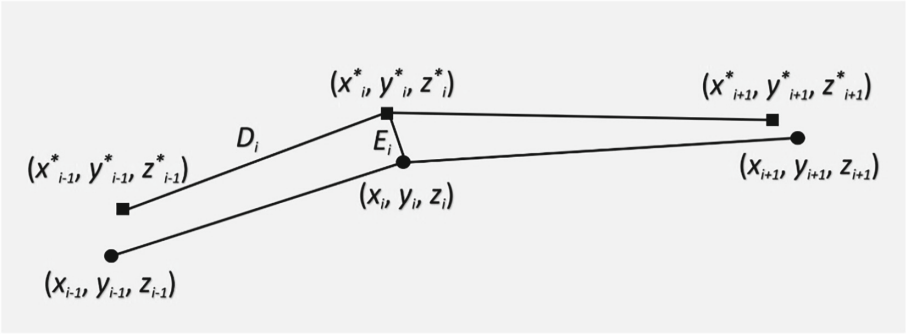

Fig. 1. Coordinates of the position and its measurement.

In civil mode, the error of the satellite positioning system (1) usually ranges from a few to several meters, and in unfavorable conditions it can reach up to several dozen meters [18]. It depends on the number of visible satellites, atmospheric conditions (ionosphere, troposphere), obstacles (buildings, trees), and the quality of the receiver. It turns out that if position measurements are made often enough, then in the case of calculating the distance between successive position measurements, a significant part of the satellite positioning system error will be reduced (due to the correlation of this error in the short time domain). This could prove helpful in improving measurement precision and further integrating them, among other things, for integration with data to determine position on a 3D map [19]. The distance between the i-th and i-1 position measurement can be written as follows (Fig. 1):

$$D_i = \sqrt{\left(x_i^* - x_{i-1}^*\right)^2 + \left(y_i^* - y_{i-1}^*\right)^2 + \left(z_i^* - z_{i-1}^*\right)^2} \tag{2}$$

Knowing the speed of the vehicle in i-1 moment v_{i-1}, error between the actual distance traveled in time Δt, , and the distance determined by the distance between successive position measurements (taken at least one Δt) at the moment of i-1 and i, can be written with the expression:

$$D_i - v_{i-1}\Delta t \tag{3}$$

Error (3) usually ranges from a dozen to several dozen centimeters and is usually many times smaller than error (1). For this reason, in the process of detecting GNSS signal spoofing, it is more convenient to use not directly raw measurements of the vehicle's position, but a more sophisticated form of them in the form of the distance between successive measurements of the vehicle's position.

It should be remembered that the effectiveness of this approach depends on the appropriately selected frequency of measurements. If the frequency is too low, the correlation of the satellite positioning system error in subsequent measurements will be imperceptible, which will make the error (3) comparable to the error (1). If, on the other hand, the frequency of measurements is too high, the distance traveled by the vehicle in time Δt will be within the error range (3), which will make it impossible to analyze this error for the purposes of detecting GNSS signal spoofing.

GNSS signal spoofing is the process by which the navigator's positioning system, which is the target of a spoofer attack, calculates false coordinates [20]. A spoofer is a device that generates fake GPS signals to deceive a GPS receiver about its actual location and time. The spoofer can emit signals that closely resemble genuine GPS signals but are aimed at tricking the GPS receiver into believing it is in a different location or time. This is a more advanced and dangerous form of signal interference than simple jamming because the receiver may not be aware that it is being deceived [21]. As a result of this attack, the navigator in the area of operation of the spoofer, receives fixed coordinates (x_s, y_s, z_s) with a measurement error, which are inconsistent with the actual position of the vehicle [22]. However, when the vehicle moves further away from the spoofer than its range, the navigator's positioning system will return to normal operation. In this mode, the navigator will receive real GNSS signals and calculate the actual coordinates of the vehicle (x_i, y_i, z_i) with a measurement error. In

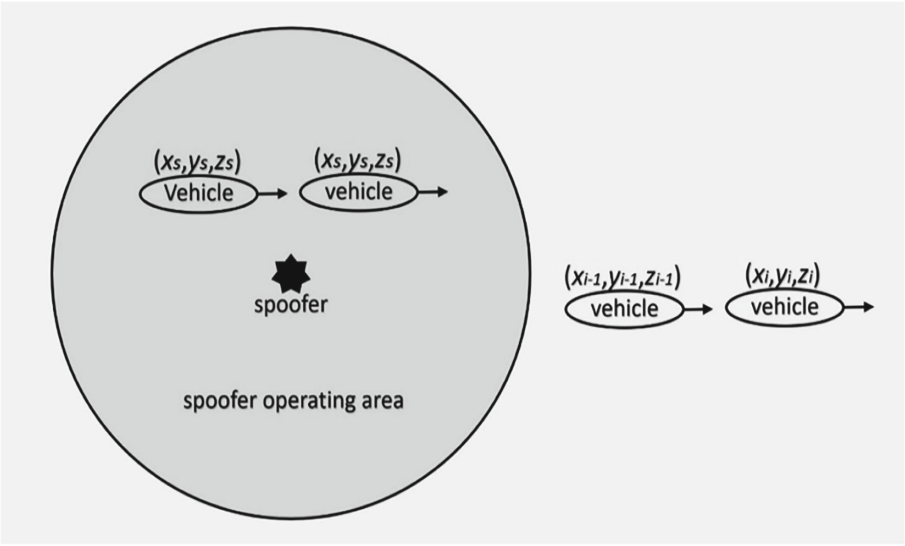

Fig. 2. Visualization of the spoofer operation.

this way, the satellite positioning system will regain its correct functionality, determining the exact position of the vehicle according to the actual GNSS signals (Fig. 2).

Considering the above, it is concluded that in the event of an attack, the following occurs:

$$\begin{gathered}(x_{i-1}, y_{i-1}, z_{i-1}) = (x_s, y_s, z_s) \\ (x_i, y_i, z_i) = (x_s, y_s, z_s) \\ D_i \cong 0\end{gathered} \tag{4}$$

Hence, the decision rule for detecting GNSS spoofing using a single antenna can be written in general terms as follows:

$$if\ D_i \cong 0\ then\ goto\ \{Spoofing\} \tag{5}$$

Decision rule (5) will correctly detect GNSS signal spoofing when the vehicle is moving at a sufficiently high speed. To refine the decision rule (5), an upper limit of error (3) should be set experimentally. This limit will depend on the characteristics of the GNSS receiver.

3 Research Conducted in Real Conditions

The real-world tests were designed to compare error (1) and error (3) and to verify whether the decision rule (5) for GNSS signal spoofing detection designed on the basis of the distance between successive positions of the vehicle is effective. The MITCOM GPS-R75BT-5V GNSS receiver with AGPSM-HV60 antenna (Fig. 3) was used for the study. The antenna supports a range of 1575 to 1606 MHz and a maximum gain of

55dBi. The receiver has wireless Bluetooth communication, processes signals for GPS, GLONASS and GALILEO systems and returns the signal in the NMEA 0183 standard, being able to receive 99 channels with a sensitivity of 170dBm.

Fig. 3. GNSS receiver used during research.

The research experiments consisted in placing a GNSS receiver at a reference point with known coordinates, and then performing position measurements at a frequency of 1 Hz. In this way, it was possible to determine the course of the satellite positioning system (E_i) error as a broken with vertices being a sequence of distances between the reference point and subsequent position measurements. It should also be emphasized that the distances between successive position measurements (D_i) were an error (3), because the GNSS receiver was not moving (the distances between subsequent vehicle position measurements should be 0).

Figures 4, 5, and 6 present examples of the results of the research experiments carried out, characteristic of the tests performed. In total, several dozen tests were performed for various environmental conditions (different reference points). In all the cases studied, when determining the distance between successive measurements of the vehicle's position, a significant part of the error (1) of the satellite positioning system was reduced. The error (3) at the confidence level of 0.99 did not exceed 30 cm, although the error (1) in the extreme case was 25 m. Experiments have shown that the reduction of error (1) by using the proposed approach can be up to eighty-fold.

It should be noted that error (3) may occasionally exceed the experimentally established upper limit (30 cm), so this fact should be considered in the detailed decision rule.

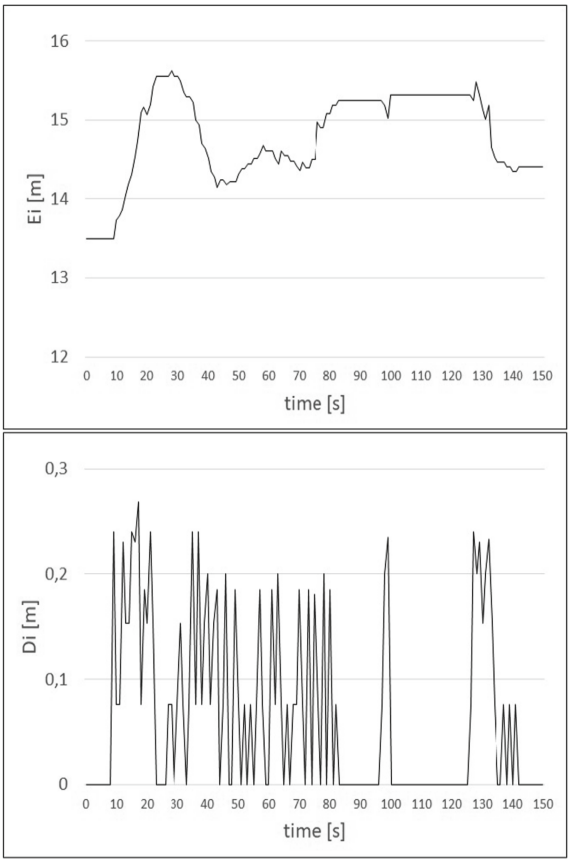

Fig. 4. Comparison of the positioning error (E_i) and the distance between successive measurements of the vehicle position (D_i) – the first example.

The tests carried out in real conditions confirmed the effectiveness of the proposed decision rule (5) for GNSS signal spoofing detection, designed based on the distance between successive positions of the vehicle.

4 Conclusions

The article is a preliminary stage of research aimed at designing an intelligent system for detecting GNSS signal spoofing using a single antenna. The article proposes a decision rule in a general form, whose logical formula refers to the distance between successive measured positions.

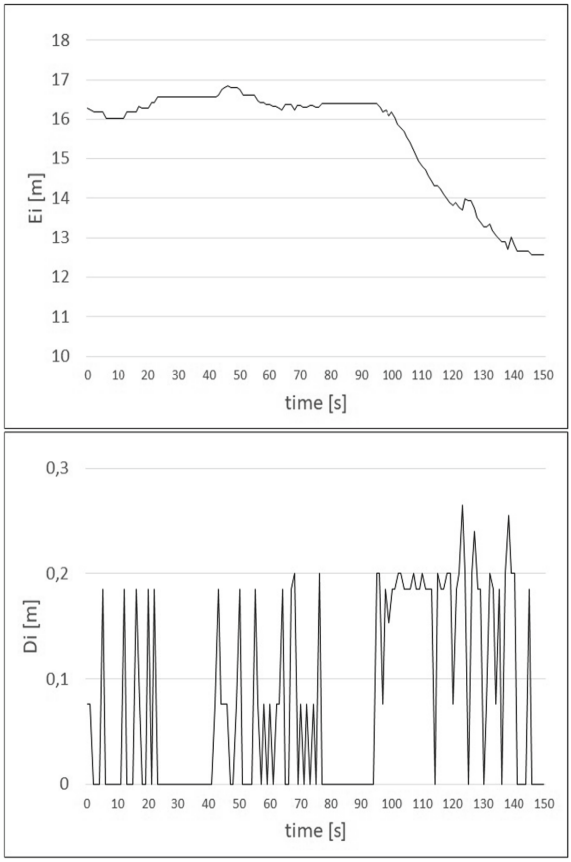

Fig. 5. Comparison of the positioning error waveform (E_i) and the distance between successive measurements of the vehicle position (D_i) – second example.

Real-world research confirms that this approach is more effective than using position measurements alone. This is because when calculating the distance between successive position measurements, a significant proportion of the measurement errors of the satellite positioning system is reduced. Experiments have shown that the reduction can be up to eighty-fold. This significantly reduces the dead zone of GNSS spoofing detection using a single antenna. The proposed solution concept, combined with monitoring other parameters of satellite signals using artificial intelligence, could significantly enhance security against spoofing attacks [23–26].

Next, the authors plan to specify the decision rule proposed in the work so that it can be used to effectively detect GNSS signal spoofing using a single antenna.

The proposed approach provides an important alternative to existing GNSS signal spoofing detection solutions, in line with the development of vehicle cybersecurity.

It should be emphasized that the issues presented by the authors in this article are important not only from the point of view of the development of cybersecurity research. Vehicle cybersecurity is of particular importance for transport and transport-dependent

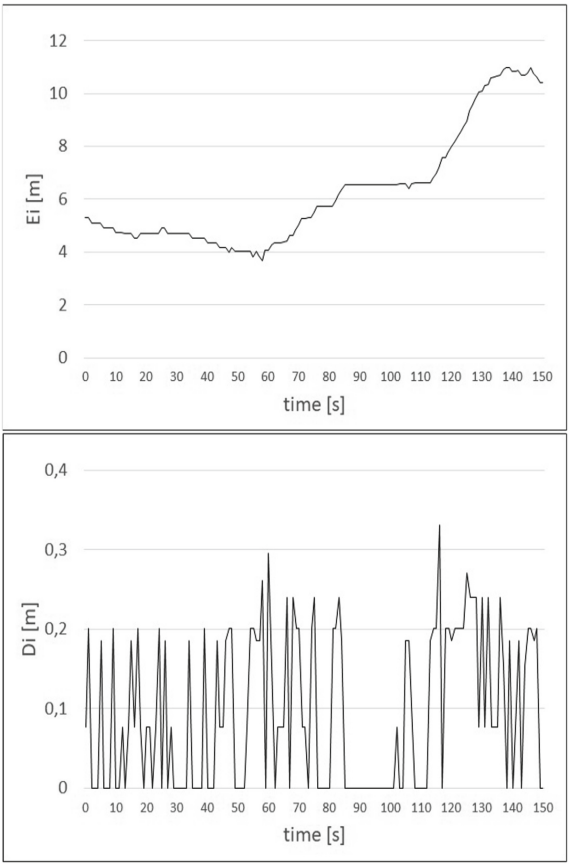

Fig. 6. Comparison of the positioning error waveform (E_i) and the distance between successive measurements of the vehicle position (D_i) – the third example.

companies. For this reason, the implementation of the proposed solutions brings utility values in a broader sense, also in the area of management and quality.

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Methodical Aspects of Offshore Wind Energy Transformation Modelling in Poland

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Abstract. Offshore wind energy has the potential to play a key role in Poland's energy transition. This paper explores the methodological aspects of modelling the contribution of offshore wind energy to Poland's energy transition, focusing on economic, social and environmental factors. Using simulation techniques and real data, this study aims to provide a comprehensive framework for assessing the potential for offshore wind energy participation in Poland's economic development and energy system transformation. The paper will be complemented by an excerpted assessment of the challenges of integrating offshore wind energy into the Polish energy system.

Keywords: offshore wind energy · energy transformation · polish energy policy

1 Introduction

The global energy landscape is undergoing significant changes as countries seek to reduce carbon emissions and transition to renewable energy sources. The geopolitical situation is forcing the world to remodel its energy systems, change the rules for supplying the economy with fuel and energy, and rebuild fuel and energy supply chains to provide electricity to consumers at the lowest possible price.

Poland, with its significant offshore wind energy (OWE) potential, is well placed to exploit this resource as part of its energy transition strategy.

Offshore wind energy is a technology that is developing rapidly worldwide in and Europe, bringing a range of environmental, social and economic benefits. European plans expect it to be a pillar of the electricity system. In Poland, too, it will play a key role in the transformation of the Polish electricity system. In the context of the current global geopolitical situation, increasing energy use, planned shutdowns of conventional coal-fired power plants, and the increasing environmental burden on the power system, offshore wind energy is an interesting alternative for electricity generation.

This article aims to explore the methodological aspects of modelling the contribution of offshore wind energy to Poland's energy transition. Given the importance of the strengthening of the economy that should accompany the energy transition, this paper uses modelling based on the potential social, environment and economic benefits that could accompany the transformation of the energy sector through offshore wind development.

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 261–272, 2024.
https://doi.org/10.1007/978-3-031-78468-2_20

2 Importance of Offshore Wind Energy in Poland

The electricity sector in Poland is based in more than 70% on centrally dispatched conventional generating units, producing electricity mainly from coal [17]. According to "Poland's Energy Policy until 2040" (PEP2040, installed capacity in offshore wind farms (OWF) is expected to reach 5.9 GW by 2030 and 11 GW by 2040 [15]. The current international situation affects many aspects of energy policy and necessitates immediate and decisive steps, but also a review of long-term policy assumptions. The Polish government is planning to amend PEP2040. The new RES development scenario assumes that, by 2040, around half of electricity generation will come from renewable sources (an increase from the previous plans of 32% by 2040). 20% of the planned installed RES capacity is to be OFW (35% of the electricity planned to be produced by RES in 2040) [14].

Currently, the installed capacity of all generation sources in the Polish national electricity system is approximately 67.7 GW, of which RES amount to 27.2 GW [19]. No OFW installed yet, but the real potential of offshore wind energy is 33 GW. Exploiting the full offshore potential in Poland would allow the sector to meet up to 57% of the country's total electricity demand [17].

Energy demand in Poland is forecast to grow dynamically - the PEP2040 assumes an average annual growth of 1.5% [15], while the transmission grid operator assumes it to be about 1.7% on average per year. Significant in the Polish context are the planned shutdowns of conventional coal-fired sources (almost 20 GW) [24]. This means that over the next thirteen years, there could be a significant decrease in available capacity generation in the national electricity system. An additional aspect is the increasing level of electrification of economies, including the Polish economy, motivated by climate and energy policies consistently implemented by the European Union. RePowerEU assumes that the electrification of the EU will reach 35% by 2030 and 61% by 2050 [6]. At the same time, studies show that the electrification rate has been almost flat over the last decade and has remained at 22%-23% for the last five years [5].

The capacity that OWE can provide in Poland is invaluable in the context of the need to meet energy demand, which will certainly be greater than assumed in Polish strategic documents a few years ago. Another aspect of shaping the energy mix should be an analysis of the costs of energy production by different technologies, as well as an analysis of the costs and revenues that different technologies will generate for the national economy. Electricity prices have risen significantly in recent years, so the key is to shape it in such a way that they are as low as possible, assuming the significant impact of individual technologies on economic growth and development.

3 Methodical Aspects of Modelling Offshore Wind Energy

3.1 Data Collection and Analysis

The article focuses on the analysis of sustainability in a broad sense. The author made an estimation of the costs of the benefits that may accompany the development of OWE sector in Poland. For the purpose of the calculations, a number of simplifying assumptions were made due to the lack of availability of measurement data and analyses carried out

for individual investments (wind data, geological data, data on the marine environment, data on planned turbine deployment, etc.).

First, the most advanced OWF projects with a total installed capacity of 5.9 GW were analysed. These are projects, for which the location permit has been granted, connection agreements have been signed, the environmental decision has been obtained, and a part of them has already obtained the construction permit. The remaining projects under construction in Poland (two projects with a total capacity of approx. 2.5 GW) are at an early stage of development (location permit and grid connection conditions have been obtained) and, on the one hand, the design details that would enable similar calculations to be made are not known, and, on the other hand, the assumptions used may not be valid for these projects in the future.

There are currently nine offshore wind farm projects in Poland in the so-called two phases of development (see Table 1). The first phase consists of projects that have received public support in the form of a differential contract on the basis of a decision by the President of the Energy Regulatory Office. The second phase refers to projects at an earlier stage of development, which will compete for support in an auction in the future.

Table 1. Offshore wind energy project pipeline in Poland [20].

No	Company	Project	Capacity [MW]	COD	Wave
1	Polenergia / Equinor	Bałtyk II	720	2027	I
2	Polenergia / Equinor	Bałtyk III	720	2027	I
3	PGE / Ørsted	Baltica 2	1 498	2027	I
4	PGE / Ørsted	Baltica 3	1 045	2026	I
5	RWE	FEW Baltic II	350	2026	I
6	PKN Orlen / NPI	Baltic Power	1 200	2026	I
7	Ocean Winds	B&C Wind	400	2027	I
8	Polenergia/Equinor	Bałtyk I	1 560	2030	II
9	PGE	Baltica 1	896	2031	II

Location permits have been issued for a further 10 sites in Poland for further offshore wind farm projects. Their capacity could be around 10 GW and will be developed after 2030 [20].

The detailed assumptions along with the methodology used in the calculations are presented below. As a result, a model was created to estimate the benefits of offshore wind energy development in three dimensions: economic, environmental and social.

3.2 Environment Factors Assumptions.

Reducing emissions of harmful substances and particulates into the atmosphere.

Environmental effect such as CO_2 and SO_2 emissions avoided was calculated using emission factors published annually by research institute – KOBiZE for 2022 [12, 13]. The emission factor determines the burden of CO_2, SO_2, NO_x, CO and total dust emissions per megawatt hour of electricity generated. In this study, the level of emissions of these substances that will not be emitted into the atmosphere due to the production of electricity from offshore wind farms was calculated. In addition, the total greenhouse gas emissions over the entire life cycle of the offshore wind farm were taken into account when calculating the environmental effect in relation to CO_2 (higher the upper range of the values shown in [2]).

The projected emission reductions achieved by OWF electricity generation were calculated using the following formula:

$$R = E_f \cdot P_r \tag{1}$$

where:

R – predicted reduction in emissions of harmful substances [t/year],
E_f – emission factor [kg/MWh].

Saving of energy resources.

The following assumptions were made in order to estimate the scale of energy resource savings from the production of electricity in 5.9 GW offshore wind farms:

- coal consumption factor for electricity production - coal in natural units [t/MWh] - 0.359 [18],
- coal price in 2022 - PSCMI index 1/t [PLN/t] - 408.66 [23].

For the calculation of the amount of carbon (in natural units) that will be saved by the production of electricity from OWF with a total capacity of 5.9 GW, the following indicator was used:

$$C_A = C_C \cdot P_r \tag{2}$$

where:

C_A – amount of coal in natural units [t/MWh],
C_C – coal consumption rate for electricity generation – coal in natural unit [t/MWh].

3.3 Economic Benefits Assumptions

Savings from the purchase of co2 emission allowances.

A growth path for energy prices until 2051, i.e. until the end of the life cycle of the OWF under construction, resulting from the assumed lifetime of the investments, was calculated. A linear increase in the price of emission allowances was assumed, taking into account:

- the weighted average price of emission allowances until January to December 2022, which was €79.80.84 EUR/tCO_2 [12],
- the International Energy Agency's projected average allowance price in 2050 of €187/tCO_2 [11].

Using the variables identified above, allowance values for emissions were estimated for the period 2023–2051, followed by annual savings resulting from offshore wind farm electricity generation.

Savings from importing energy raw materials.

In order to indicate the savings in monetary terms, it is necessary to estimate the costs of purchasing raw material. These have been calculated using the following calculation formula:

$$C_{PLN} = C_A \cdot C_W \tag{3}$$

where:

C_{PLN} – raw material savings - hard coal [million PLN],
C_A – amount of coal in natural units [t/MWh],
C_P – coal price in 2022 - PSCMI index 1/t [PLN/t].

Budgetary revenue from issued permits and decisions (location permit and concession).

In this article, two important sources of income to the state budget related to the development of OWF in Poland are considered. The first source is the fee for issuing a permit to erect and use artificial islands, structures and equipment in Polish maritime areas for OWF (location permit). The value of this fee is equivalent to 1% of the value of the planned project - 1% of CAPEX [26]. It was estimated using the equation:

$$R_{LP} = CAPEX \cdot 1\% \tag{4}$$

where:

R_{LP} - revenue to the budget for issuing location permit for OWF [million PLN].

The production of electricity in an OWF requires the payment of a concession fee which is the product of the installed electric capacity expressed in MW, resulting from the concession for the production of electricity in this OWF, and an appropriate coefficient, expressed in PLN, specified in specific provisions [25]. The value of this coefficient has been set at the maximum level possible under the current legislation and amounts to PLN 23,000 [21]:

$$R_C = C \cdot 23000 \tag{5}$$

where:

C - planned installed capacity [MW]
R_c - revenue to the budget from the concession fee [million PLN].

3.4 Social Benefits Assumptions

New jobs.

This paper estimates direct and indirect employment [23], based on the empirical data from other countries. The total employment impact of offshore wind energy was estimated on the basis of the employment rate, calculated according to the following indicator:

$$I_E = \frac{E}{C} \tag{6}$$

where:

I_E - employment rate [employees /MW],
C - planned installed capacity [MW],
E - number of people employed in the offshore wind energy sector [number of employees].

On the basis of industry reports [3, 8, 9, 22], employment rates were calculated for the UK, Denmark, Germany and Scotland, and then the average values of the rates for indirect and intermediate employment were calculated and used in the estimation of employment in Poland.

Coverage of household electricity demand.

The number of households covered by offshore wind farm production was calculated based on statistical data [10] using the following indicator:

$$\mathrm{H} = \frac{P_r}{E_c} \tag{7}$$

where:

H – number of households,
E_c – average annual household electricity consumption [MWh/year].

4 Results

4.1 Estimation of Electricity Production and Coverage of Household Electricity Demand.

See Table 2.

4.2 Estimation of Environmental Benefits

See Tables 3 and 4.

4.3 Estimation of Economic Benefits

See Table 5.

Budgetary revenue from issued permits and decisions (location permit and concession).

See Table 6.

Table 2. Model assumptions for estimating benefits and costs of offshore wind farms in Poland and projected household electricity demand coverage from offshore wind farms in Poland.

Project	Forecast production [TWh/year]	Number of households whose electricity needs will be covered by the project
Bałtyk II	2′882.40	1′455′826
Bałtyk III	2′882.40	1′455′826
Baltica 2	5′996.90	3′028′927
Baltica 3	4′183.50	2′112′970
FEW Baltic II	1.40	707′693
Baltic Power	4′563.80	2′305′058
B-C Wind	1′601.30	808′792
Total	**23′511.50**	**11′875′094**

Table 3. Decarbonization of the Polish economy through offshore wind farms - reduction of CO_2, SO_2 and particulate emissions.

Project	Reduced CO2 emission [million t/year]	Reduction of SO2 emissions [tonnes/year]	NO2 reduction [tonnes/year]	Total dust [tonnes/year]
Bałtyk II	2.16	1′565.14	1′565.14	66.29
Bałtyk III	2.16	1′565.14	1′565.14	66.29
Baltica 2	4.50	3′256.36	3′256.36	137.93
Baltica 3	3.14	2′271.62	2′271.62	96.22
FEW Baltic II	1.05	760.83	760.83	32.23
Baltic Power	3.42	2′478.14	2′478.14	104.97
B-C Wind	1.2	869.52	869.52	36.83
Total	**17.63**	**12′766.74**	**12′766.74**	**540.76**

4.4 Assessment of Social Benefits

See Table 7.

5 Interpretation

Calculations using averaged assumptions showed that OWF, implemented in Poland as part of the so-called phase I of development, could generate about 23.5 TWh of electricity annually, which is about 13% of the national electricity production and about 14% of the 2022 consumption. Taking into account the forecasts of PSE S.A. in terms of electricity demand in 2030, the energy generated by offshore wind farms implemented under Phase

Table 4. Projected coal savings from offshore wind generation in Poland.

Project	Raw material savings - hard coal in the life cycle of an OWF [million tonnes]	Raw material savings - hard coal in the life cycle of an OWF [billion PLN]
Bałtyk II	25.87	10.57
Bałtyk III	25.87	10.57
Baltica 2	53.82	22.00
Baltica 3	37.55	15.34
FEW Baltic II	12.58	5.14
Baltic Power	40.96	16.74
B-C Wind	14.37	5.87
Total	**211.02**	**86.23**

Table 5. Projected amount of savings related to the purchase of CO2 emission allowances in 2026–2051, achieved through the production of electricity from offshore wind farms in Poland and projected coal savings from offshore wind generation in Poland.

Project	Savings - purchase of CO2 emission allowances between 2026 and 205 [billion PLN]	Raw material savings - hard coal in the life cycle of an OWF [million tonnes]	Raw material savings - hard coal in the life cycle of an OWF [billion PLN]
Bałtyk II	36.70	25.87	10.57
Bałtyk III	35.73	25.87	10.57
Baltica 2	76.36	53.82	22.00
Baltica 3	51.86	37.55	15.34
FEW Baltic II	17.37	12.58	5.14
Baltic Power	56.57	40.96	16.74
B-C Wind	20.39	14.37	5.87
Total	**294.98**	**211.02**	**86.23**

I could cover about 11% of energy demand in 2030 in the baseline scenario and about 10% in the scenario of a significant increase in energy demand.

Coal consumption for electricity generation in Poland in 2021 was 30.5 million tons. The savings in raw material achieved through the production of electricity in the OWF analyzed over the lifetime of these investments will be almost seven times the annual consumption of this raw material.

The projected total savings from the purchase of CO_2 emission allowances will amount to more than PLN 290 billion between 2026 and 2051, which means an average

Table 6. Projected revenue to the state budget from offshore wind farm development.

Project	Budget revenue - concession fee [million PLN/year]	Budget revenue - fee for issuing location permits [million PLN]
Bałtyk II	16.56	89.12
Bałtyk III	16.56	89.12
Baltica 2	34.45	185.43
Baltica 3	24.04	129.35
FEW Baltic II	8.05	43.32
Baltic Power	26.22	141.11
B-C Wind	9.20	49.51
Total	**135.08**	**726.99**

Table 7. Model assumptions for estimating benefits and costs of OWF in Poland.

Project	New direct jobs [full-time equivalent jobs over the life cycle of an OWF]	New indirect jobs [equivalent to full-time jobs over the life cycle of an OWF]
Bałtyk II	1'793	3'557
Bałtyk III	1'793	3'557
Baltica 2	3'730	7'400
Baltica 3	2'602	5'162
FEW Baltic II	872	1'729
Baltic Power	2'839	5'632
B-C Wind	996	1'976
Total	**14 624**	**29 013**

annual saving of approximately PLN 11.80 billion. The level of savings to be achieved will be linked to the actual price of emission allowances.

Coal consumption for electricity generation in Poland in 2021 was 30.5 million tonnes. The savings in raw material achieved through the production of electricity in the offshore wind farms analysed over the lifetime of these investments will be almost seven times the annual consumption of this raw material.

Approximately 135 million will go to the state budget each year from the concession fee, while the total revenue from the fee for issuing location permits for offshore wind farm projects with a total capacity of 5.9 GW will amount to approximately PLN 726 million.

OWF with a total installed capacity of 5.9 GW could generate around 44 000 new jobs in Poland, of which around 15 000 direct jobs and around 29 000 indirect jobs.

With an estimated annual electricity production of 23.5 TWh, offshore wind farms will be able to cover the energy needs of almost 12 million households per year.

6 Discussion and Conclusions

Studies have shown that offshore wind energy development can bring a range of social, environmental and economic benefits. This is important in building countries' energy mixes in the face of the need to simultaneously meet the targets set out in European energy and climate policy.

Offshore wind farms can have a positive impact on the social and economic environment in Poland. The analysis showed that investments with a total installed capacity of 5.9 GW, implemented in Poland under Phase I of support, could bring the following benefits:

- Annual production of clean, green electricity of about 23.5 TWh, which is about 13% of national electricity production and about 14% of 2022 consumption. Taking into account PSE's projections for electricity demand in 2030, energy generated by OWF could cover about 11% of energy demand in 2030 in the baseline scenario and about 10% in the scenario of a significant increase in energy demand.
- OWF of the above-mentioned capacity could generate approximately 44 000 new jobs in Poland, of which approximately 15 000 would be direct jobs and approximately 29 000 indirect jobs.
- With an estimated annual electricity production of 23.5 TWh, OWF will be able to cover the energy demand of nearly 12 million households per year.
- The construction of OWF, assuming a 25-year equipment operation period, may reduce CO_2 emissions by 447 million tonnes and SO_2 and NO_x emissions by 319,000 tonnes, thus contributing to the achievement of Poland's energy policy goals and supporting European targets.
- The projected total savings from the purchase of CO_2 emission allowances may amount to more than PLN 290 billion between 2026 and 2051, which means an average annual saving of approximately PLN 11.80 billion.
- The saving on coal, achieved through the production of electricity in the analysed OWF over the entire life cycle of these investments, could be almost seven times the annual consumption of this raw material (211.02 million tonnes in the case of hard coal worth PLN 86.23 billion).
- Annually, the state budget may receive approximately 135 million from the concession fee, while the total value of revenue from the fee for issuing location permits for OWF projects with a total capacity of 5.9 GW will be approximately PLN 726 million.

It should be noted that the analysis carried out is based on a number of simplifying assumptions made due to the lack of available actual data, such as wind conditions, turbine deployment, actual capacity factor, etc. Additionally, the level of benefits achieved will ultimately depend on a number of factors, including accurate metering, installed capacity, market conditions, etc. Market and political issues in the country are also very important.

The greater the political support, the more favourable the administrative procedures and the more ambitious long-term targets, the higher the level of offshore wind energy development will be possible, bringing tangible results and benefits.

Acknowledgments. A third level heading in 9-point font size at the end of the paper is used for general acknowledgments, for example: This study was funded by X (grant number Y).

Disclosure of Interests. The author have no competing interests to declare that are relevant to the content of this article.

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Heuristics for Flexible Job Shop Scheduling Problem with Simultaneous Tasks Execution on Different Workplaces of a Single Machine

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Abstract. We investigate the flexible job shop scheduling problem on multi-workplace machines that can serve several workplaces simultaneously. We developed four heuristics for the production of the product elements for the cases if the sequence of products in an order is determined and not determined. The sequence of product elements in a product was set for both modeled cases. Our goal in investigating heuristic approaches is to push the limits of production scheduling and provide insight into current state-of-the-art methodologies. Heuristics were evaluated by comparing the obtained solution with the optimal solution provided by the CPLEX solver. Heuristics 1, 2, and 3 exhibited superior performance when dealing with cases that necessitated a specific sequence of produced products. Conversely, Heuristics 4 proved to be more effective in solving cases where the sequence of produced products was not determined.

Keywords: job shop scheduling problem · flexible job shop scheduling problem · heuristics · constraint programming

1 Introduction

Many emerging nations are under intense pressure to increase their competitiveness and improve production efficiency because of the fierce competition in the market. A key strategy for achieving this is efficient production scheduling [1]. Allocating resources (machines, tools, labor) efficiently to complete jobs on time while minimizing idle time and maximizing resource utilization is a crucial factor.

In the research, we use the general constraint programming model for flexible job shop, which we adjust in a way that it could be used for solving the two variants of a problem: (1) the problem with the sequence of produced products in an order required; (2) the problem with the sequence of produced products in an order not required. The sequence of production of the product elements in a product is required in both variants of a problem. We model the problem so that there are many workplaces of different types on a machine on which the tasks can be executed simultaneously. Our goal is

M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 273–285, 2024.
https://doi.org/10.1007/978-3-031-78468-2_21

to provide manufacturers with the knowledge and skills necessary to successfully deal with the production problem and reach new insights into productivity, adaptability, and competitiveness by utilizing the power of heuristics. Thus, four heuristics for flexible job shop scheduling problems were designed.

The remainder of this paper is organized as follows. The literature review is discussed in Sect. 2. The problem definition and model formulation are given in Sect. 3. Section 4 describes the heuristic proposed here, while Sect. 5 reports on the computational experiments. Finally, we draw some conclusions in Sect. 6.

2 Related Literature

2.1 A Note to Production Scheduling

The complexity of manufacturing processes has made it imperative that production scheduling software and larger IT systems integrate seamlessly. Critical business activities are managed by ERP systems, material flow is supervised by SCM systems, and shop floor operations are managed by MES systems. By combining these technologies with cutting-edge scheduling software, an integrated ecosystem that increases productivity and decreases manual intervention can be established.

Aghezzaf et al. (2007) investigated a periodic preventive maintenance (PM) problem with integrated production scheduling. They made the assumption that the production system is prone to sporadic breakdowns and that any maintenance performed on it within a given time period lowers the system's capacity for production [2].

A single-machine scheduling problem linked with PM activities was examined by Qi et al. (1999) [3] and Sortrakul et al. (2005) [4] with the goal of minimizing the overall completion time of executed jobs. Qi et al. (1999) tried to simultaneously schedule jobs and machine maintenance because the main aim was to develop a computer aided production planning system for a real factory [3]. Sortrakul et al. (2005) developed a genetic algorithm to solve the integrated production scheduling and preventive maintenance planning problem for a single machine [4].

Zheng et al. (2014) discussed how to cope with uncertainty in a manufacturing system by focusing on the flexible job shop scheduling problem (FJSP), a basic optimization problem in operations research. They proposed condition-based maintenance, a type of preventive maintenance, as a means of reducing equipment unavailability [5].

To achieve overall operational excellence in manufacturing operations, as well as to maximize equipment uptime, minimize downtime, and optimize resource use, effective coordination and integration of maintenance and production activities are crucial.

2.2 Job Shop and Flexible Job Shop Scheduling

The traditional job shop scheduling problem (JSP) calls for a series of tasks, each consisting of a set of ordered processes, to be processed on a set of machines. It was first described by Fischer and Thompson (1963) [6]. The machine that performs each operation—known as job routing—is preconfigured, and it is anticipated that jobs will be accessible for processing whenever needed. One action at a time, undisturbed by any

interruptions, is processed by each machine. As a result, a JSP solution offers an order of actions for every machine. The classic JSP searches for a solution that minimizes the makespan, or the total amount of time needed to perform all job activities. This problem is one of the best-known NP-hard combinatorial optimization problems [7].

An extension of the traditional JSP is the FJSP [8]. The two subproblems of the FJSP are the operation sequence and machine assignment. The goal of machine assignment is to choose a processing machine for each operation from a pool of candidate machines. The goal of the operation sequence is to plan every machine's operation in order to produce workable and satisfying solutions. Therefore, it has been demonstrated that FJSP is an NP-hard problem [7].

The flexible JSP is one of the JSP extensions that have been studied by Shen et al. (2018) [9]. The idea that every operation can be performed on a set of machines (either all or a subset of the specified machines) leads to problems with flexibility. Since work routing is no longer predetermined, the FJSP is a generalization of the JSP and consists of two subproblems: job routing and machine scheduling. It is necessary to address these two subproblems concurrently [9].

Determining the order in which jobs should be processed at each workstation leads to optimize overall production efficiency. The FJSP, which is widely employed in discrete manufacturing and process industries, is a hot topic in the field of intelligent manufacturing and industrial automation research at the moment. The organization can increase economic efficiency and command, control, and regulate the effective resources more sensibly by finding a solution to the FJSP [10]-[15].

Flexible scheduling solutions are necessary for industries like semiconductor fabrication, electronics, aerospace, and automobile manufacture, which frequently deal with complex production processes. These sectors often produce a wide range of goods with distinct processing needs; therefore, in order to meet production expectations, the production equipment may need to be used effectively across a number of jobs. The use of scheduling strategies to maximize production processes in manufacturing environments with multiple workstations, a variety of job requirements, and dynamic operating circumstances is the industrial domain for flexible job shop scheduling.

3 Problem Definition and Formulation

We investigate the following manufacturing problem. There is a factory that operates in the field of production services and produces metal construction elements. The factory relies on order production for products defined in the design database.

For the production plan, the construction manager registers orders and creates work cards for the products in the order that should be performed based on the technology card. For each product, there is a process defined in the technology card, which explains from which elements the products must be created. The product element must be produced in the defined workplace. Workplaces of the same type are available on different machines. There is only one workplace of the definite type on a machine, i.e., there are no duplicated workplaces on one machine. On one machine many workplaces can run simultaneously. The sequence of product production is an option. In the 1st variant of a problem, the task order is random. But in the 2nd variant of the problem, the products must be produced in a required order. The sequence of producing elements in a product is always required.

The classical job shop scheduling problem, in which the assignment of operations to machines is required before the sequencing of activities, is generalized and extended as the flexible job shop scheduling problem. The investigated problem is similar to the flexible job shop combinatorial optimization problem.

The production makespan is the amount of time within which the products are produced on all machines. The longest cumulative production time of the product becomes the maximum makespan time for the defined scheduling problem. The goal is to determine what product elements must be produced on what workplaces of machines and create a schedule for the production of all these product elements in all orders, minimizing the maximum makespan.

In this study, we use the following mathematical model. Indices and sets: M—number of workplaces; i—index for a workplace, $i = 1, ..., M$; N—number of products; j—index for a product, $j = 1, ..., N$; O_j—number of elements of a product j; k, l—index for an element of a product j, $k, l = 1, ..., O_j$. Parameters and indices: p_k—position of the element k in the sequence of elements of the produced product; t_{kij}—processing time of the producing of an element k of a product j on a workplace i. The position of the last produced element of the product j is O_j. Decision variables: x_{kij}—an optional interval variable for the processing time t_{kij} of element k of the product j on the workplace i; y_{kj}—an interval variable to indicate producing of an element k of the product j; z_i- a sequence variable having the order of the x_{kij} interval variable on the workplace i.

Minimize the makespan of producing products:

$$\min \max_{j=1,...,N,k=O_j} \text{endOf}(\text{y}_{kj}) \tag{1}$$

Subject to:

Production of an element l must start after the production of a previous element k in a product j is finished:

$$\forall(j, k, l : p_l = 1 + p_k)[\text{endBeforeStart}(y_{kj}, y_{lj})] \tag{2}$$

A product j (or elements of a product j) cannot be produced simultaneously in two or more workplaces:

$$\forall(k)[\text{alternative}(y_{kj}, \text{all}(t_{kij})x_{kij})] \tag{3}$$

One workplace i can produce only one product at a time.

$$\forall(i)[\text{noOverlap}(z_i)] \tag{4}$$

The proposed model is used for solving both variants of a problem, i.e., if the sequence of produced products is required and not required. We adjust the input data to solve the problem without changing the model.

4 Heuristics

Heuristics play a crucial role in production planning sessions, facilitating the execution of planning tasks with efficiency and accuracy. There are various types of heuristics commonly used in optimization. In this research, we focus on constructive heuristics,

developing four heuristics for solving different sets of input data. Constructive heuristics, in general, are useful tools for rapidly coming up with workable solutions to challenging optimization issues, especially when exhaustive search approaches are impractical. Constructive heuristics can produce solutions of varying quality; therefore, to increase solution quality, they are frequently combined with other optimization strategies. By iteratively adding components to an empty or partial solution, constructive heuristics build solutions step by step until a complete solution is achieved. These techniques are frequently applied when there is too much of the solution space to thoroughly investigate.

The main procedure of schedule creation consists of the following steps: (1) Assigning operations of production of the product elements to the workplaces on machines; (2) Calculation of the start and end time of all operations of production of the product elements in workplaces on machines; (3) Calculation the makespan.

Assigning production of the product elements to the workplaces on machines is executed according to the following rules. (1) If any workplace on a machine can produce more than one product element in the product or an order, assign these product elements to such workplaces on machines. If more than one workplace is available for the product elements, choose any of them randomly. (2) If any product element can be produced in only one workplace on a machine, assign such product elements to such workplaces on machines. (3) For the production of the product elements and workplaces on machines, calculate the number of product elements that can be produced on workplaces on machines. If any workplace on a machine can produce only one product element, assign product elements to it. (4) For the rest possible workplaces on machines assign the production of product elements randomly.

After these steps, all product elements are assigned to workplaces on machines, but there is no sequence of production of these elements on workplaces on machines created.

Calculation of the start and end time of production of all product elements in workplaces on machines is executed according to the following rules. While the clashes in workplaces on machines exist, correct those shifting production of overlapping product elements forward. There are two types of clashes that are solved: clash of production of product elements; clash on workplaces on machines.

If the sequence of produced products is required, sort the produced products in an order. Next, sort the elements of the produced product according to their position in a product. Find the start and end time of production of each product element. At this step, the clash of production of product elements may appear. Correct it shifting production of overlapping product elements forward.

For each workplace on a machine, apply the following heuristic rule based on the selected heuristics: Heuristics 1—Sort the production of product elements in ascending order of the start time in the given workplace on a machine. Heuristics 2—Sort the production of product elements in ascending order of the end time in the given workplace on a machine. Heuristics 3—Sort the production of product elements in ascending order of the total processing time of the order. Heuristics 4—Sort the production of product elements in descending order of the total processing time of the order.

For Heuristics 3 and Heuristics 4, perform the next sorting of the production of product elements in ascending order of their position in the product. At this step, a clash in the workplace on a machine may occur. Correct it, shifting the production of

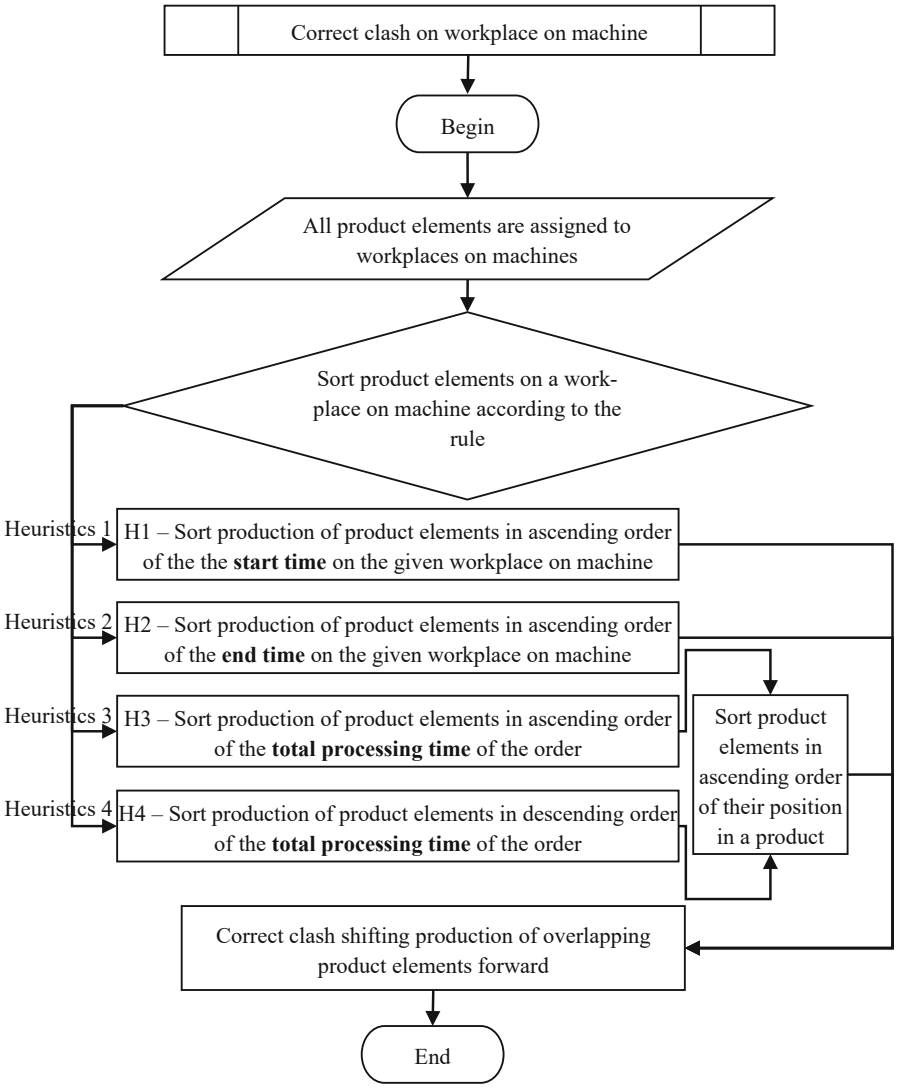

Fig. 1. Procedure "Correct clash on a workplace on machine"

the overlapping product elements in the workplace on the machine forward. Figure 1 presents the detailed algorithms of the workplaces on machine clash correction. If no clashes exist, calculate the makespan.

Because the step of random assignment of production of the product elements sometimes happens, repeat the whole schedule creation several times and select the best obtained solution for each tested instance. The number of repetitions is an input parameter of the schedule creation.

5 Experiment

The computational experiment simulates the intricate dynamics of a manufacturing setting, aiming to assess the efficacy of the devised heuristics in generating solutions. Table 1 introduces the 3 settings sets used for the numerical experiment. The experiment was conducted for the multi-workplace machines in which many workplaces are available on a machine at a time, each of which can produce different product elements simultaneously. We test the heuristics according to setup where the sequence of produced products is required and not required. The sequence of product elements is always required. The idea of task sequencing was taken from practice because sometimes it is important to set up maintenance tasks to be executed in a specific order.

The same constraint programming model was employed to tackle the problem of arranging product production within an order in a predetermined sequence as well as in an arbitrary sequence. For this goal, we provide adjustments in the input data. This decision underscores a deliberate choice to focus on the model's capabilities and robustness in addressing the task sequencing and not only manipulating the input parameters. By adhering to this approach, we aimed to maintain the integrity and consistency of the problem-solving methodology, ensuring that the proposed approach remained grounded in the model's intrinsic logic and principles.

Table 1. Data instances

Settings sets	Instances	Orders	Products	Product elements	Time [s]	Workplaces
1	10	1..10	1..5	1..3	1..60	226
2	10	1..15	1..10	1..5	1..60	226
3	10	1..100	1..5	1..3	1..60	226

Table 2 provides the comparison of the quality of Heuristics 1–4 for the 1st settings set, in which the sequence of produced products is not required and required.

Compared to the CPLEX solver, for the case with the sequence of produced products not required, Heuristics 1 exhibited an average quality rate of 95.86%, demonstrating a range from 83.33% to 100.00%. However, Heuristics 2 was overcome by Heuristics 1, achieving an average quality rate of 89.06%, with a variation spanning from 74.32% to 100.00%. These comparative results underscore the efficacy of Heuristics 1 over Heuristics 2 in achieving higher-quality solutions on average, with improved consistency evident in the range of quality values. In the other case, if the sequence of produced products required, Heuristics 2 presented better results surpassing Heuristics 1. Heuristics 1 achieved an average quality rate of 98.60%, showing a range from 92.49% to 100.00%. However, Heuristics 2 surpassed Heuristics 1, achieving an average quality rate of 99.35%, with a variation spanning from 94.58% to 100.00%.

Compared to the CPLEX solver, for the case with the sequence of produced products not required, Heuristics 3 came from an average quality rate of 85.60%, varying from 58.50% to 100.00%. However, Heuristics 4 surpassed Heuristics 3, achieving an average

quality rate of 88.73%, varying from 64.39% to 100.00%. These comparison results show that Heuristics 4 is more effective than Heuristics 3 at producing, on average, higher-quality solutions. The range of quality values shows increased consistency as well. In the other case, if the sequence of produced products is required, Heuristics 4 outperformed Heuristics 3 in terms of results. Heuristics 3 achieved an average quality rate of 86.33%, varying from 52.57% to 100.00%. However, Heuristics 4 surpassed Heuristics 3, achieving an average quality rate of 87.16%, varying from 65.77% to 100.00%.

Table 2. Quality of Heuristics 1, 2, 3, 4 for the 1st settings set

Instance	Seq. of produced products is not required		Seq. of produced products is required		Seq. of produced products is not required		Seq. of produced products is required	
	Heur. 1 %	Heur. 2 %	Heur. 1 %	Heur. 2 %	Heur. 3 %	Heur. 4 %	Heur. 3 %	Heur. 4 %
1	89.83	89.83	92.49	100	89.83	72.03	92.49	100
2	100	74.32	100	100	83.78	83.78	100	100
3	100	81.40	98.90	98.90	70.54	100	55.25	71.55
4	100	100	100	100	100	100	100	69.52
5	83.33	83.33	100	100	83.33	88.27	100	69.85
6	100	76.35	100	100	100	100	52.57	65.77
7	100	100	94.58	94.58	100	87.32	62.98	100
8	98.29	98.29	100	100	82.91	98.29	100	100
9	100	100	100	100	58.50	93.20	100	100
10	87.12	87.12	100	100	87.12	64.39	100	94.95

Table 3 shows the comparison of the quality of Heuristics 1 and Heuristics 2 for the 2nd and the 3rd settings sets, in which the sequence of produced products is not required and required.

Compared to the CPLEX solver, for the case with the sequence of produced products not required, Heuristics 1 reached an average quality rate of 60.17%, varying from 38.32 to 100.00%. However, Heuristics 2 was worse than Heuristics 1, reaching an average quality rate of 51.85%, varying from 16.17 to 100.00%. For the 2nd setting set for the case, if the sequence of produced products is not required, Heuristics 1, 2 demonstrate the lowest quality. Undoubtedly, Heuristics 1, 2 achieved significantly better results if the sequence of produced products is required. Hence, if the sequence of produced products required, Heuristics 2 surpassed Heuristics 1 in terms of quality. Heuristics 1 got an average quality rate of 94.41%, varying from 90.21 to 100.00%. However, Heuristics 2 outperformed Heuristics 1, getting an average quality rate of 97.16%, varying from 91.62 to 100.00%.

Compared to the CPLEX solver, for the case with the sequence of produced products not required, Heuristics 1 received an average quality rate of 83.17%, varying from 62.83 to 96.72%. On the other hand, Heuristics 2 was slightly better than Heuristics 1, getting an average quality rate of 84.17%, varying from 56.78 to 97.83%. Per contra Heuristics 1, 2 demonstrated results of lower quality if the sequence of produced products is required. Thus, if the sequence of produced products required, Heuristics 1 slightly surpassed Heuristics 2 in terms of quality. Heuristics 1 received an average quality rate of 64.82%, varying from 45.56 to 80.59%. However, Heuristics 2 falls behind Heuristics 1, getting an average quality rate of 59.63%, varying from 42.86 to 79.36%. There were no cases in which Heuristics 1 and Heuristics 2 obtained an optimal solution for the 3rd settings set.

Table 3. Quality of Heuristics 1, 2 for the 2nd and the 3rd settings sets

Instance	Seq. of produced products is not req		Seq. of produced products is req		Instance	Seq. of produced products is not req		Seq. of produced products is req	
	Heur. 1 %	Heur. 2 %	Heur. 1 %	Heur. 2 %		Heur. 1 %	Heur. 2 %	Heur. 1 %	Heur. 2 %
11	71.84	46.60	93.00	91.62	21	81.78	56.78	69.34	69.58
12	100.00	100.00	90.71	100.00	22	62.83	78.76	80.59	69.41
13	38.32	16.17	93.87	99.06	23	90.25	90.25	57.14	42.86
14	63.03	63.98	90.21	93.58	24	75.10	70.95	70.92	55.58
15	63.10	63.10	100.00	100.00	25	88.12	81.23	67.45	63.47
16	54.71	44.71	95.14	98.94	26	90.00	88.15	78.30	79.36
17	55.74	50.27	97.47	98.25	27	68.58	86.21	63.27	65.51
18	52.04	60.20	92.45	98.91	28	84.06	97.83	48.87	43.51
19	61.11	31.67	96.58	96.58	29	94.21	94.21	66.81	63.85
20	41.76	41.76	94.69	94.69	30	96.72	97.38	45.56	43.17

Heuristics 3 and Heuristics 4 are not appropriate for 2nd and 3rd settings set because when the number of assigned product elements to workplaces on machines is large, sequencing them based on the total processing time of the order is not appropriate. This solution would be profitable for a small number of operations in a workplace on a machine when the product elements of the order are assigned to many workplaces on machines. Therefore, Heuristics 3 and Heuristics 4 are applied only to the 1st setting set. Because of this there is no experimental result presented.

The execution time of Heuristics 1–4 for the 1st settings set is comparable for all instances and took about 1 s (Table 4). Thus, for the case in which sequence of produced products is not required, the average computation time of Heuristics 1 was 0.94 s and varied from 0.73 to 1.33 s. On the other hand, the average computation time of Heuristics

2 was 0.95 s and varied from 0.72 to 1.32 s. For the case in which sequence of produced products is required, the average computation time of Heuristics 1 was 0.95 s and varied from 0.73 to 1.35 s. On the other hand, the average computation time of Heuristics 2 was 0.96 s and varied from 0.73 to 1.36 s.

Table 4. Execution time of Heuristics 1, 2, 3, 4 for the 1st settings set

Instance	Seq. of produced products is not req		Seq. of produced products is req		Seq. of produced products is not req		Seq. of produced products is req	
	Heur. 1 [s]	Heur. 2 [s]	Heur. 1 [s]	Heur. 2 [s]	Heur. 3 [s]	Heur. 4 [s]	Heur. 3 [s]	Heur. 4 [s]
1	0.74	0.74	0.73	0.73	0.69	0.74	0.70	1.12
2	1.22	1.18	1.18	1.18	1.13	1.17	1.18	2.01
3	1.20	1.21	1.20	1.22	1.14	1.15	1.21	1.76
4	0.81	0.81	0.80	0.82	0.77	0.78	0.78	1.43
5	0.73	0.72	0.73	0.74	0.76	0.72	0.73	1.18
6	0.96	0.96	1.00	1.01	0.99	0.98	1.03	1.50
7	1.33	1.32	1.35	1.36	1.34	1.36	1.99	1.94
8	0.86	0.92	0.89	0.89	0.85	0.86	1.37	1.33
9	0.78	0.82	0.81	0.81	0.84	0.80	1.20	1.27
10	0.77	0.78	0.79	0.82	0.79	0.82	1.14	1.15

The runtime of Heuristics 1 and Heuristics 2 in the 3rd settings set remains consistent across all instances; the average value varies by approximately 3 s (as illustrated in Table 5). Consequently, in scenarios where the sequence of produced products is not a factor, Heuristics 1 had an average processing time of 66.13 s, with fluctuations ranging from 38.68 to 90.50 s. Conversely, Heuristics 2 showed an average processing time of 64.87 s, with variations spanning from 37.52 to 87.04 s. In cases where the sequence of produced products is required, Heuristics 1 exhibited an average processing time of 67.12 s, with variations ranging from 38.98 to 90.02 s. Meanwhile, Heuristics 2 had an average processing time of 69.62 s, with variations extending from 39.89 to 95.79 s.

Table 5. Execution time of Heuristics 1, 2 for the 2nd and the 3rd settings sets

Instance	Seq. of produced products is not req		Seq. of produced products is req		Instance	Seq. of produced products is not req		Seq. of produced products is req	
	Heur. 1 [s]	Heur. 2 [s]	Heur. 1 [s]	Heur. 2 [s]		Heur. 1 [s]	Heur. 2 [s]	Heur. 1 [s]	Heur. 2 [s]
11	9.71	9.56	9.70	9.61	21	65.49	63.73	65.45	64.91
12	6.10	6.08	6.04	6.17	22	45.60	46.14	47.67	48.22
13	15.99	15.76	16.00	15.96	23	90.50	87.04	90.02	95.79
14	16.92	16.86	16.73	16.87	24	75.50	75.34	76.83	81.68
15	4.33	4.30	4.38	4.40	25	38.68	37.52	38.98	39.89
16	19.01	19.08	19.07	18.94	26	66.01	64.48	67.26	67.66
17	12.75	12.47	12.62	12.64	27	82.01	80.33	84.28	88.82
18	22.22	22.44	22.19	22.33	28	59.07	57.86	60.52	63.75
19	21.35	21.39	21.17	21.51	29	75.93	74.09	77.14	79.06
20	10.84	10.81	11.00	11.17	30	62.48	62.15	63.02	66.44

6 Conclusion

In this research, we investigate the flexible job shop scheduling problem and develop four heuristics for sequencing the product element production on multi-workplace machines that can serve several workplaces simultaneously with the goal of makespan minimization. Thus, our planning focus was on resources and operations.

Heuristics 1 and Heuristics 2 differ by the sorting order parameter of the production of product elements in the given workplace on a machine, i.e., for Heuristics 1 this is the start time, and for Heuristics 2 this is the end time. For Heuristics 3 and Heuristics 4 the sorting parameter is the same, i.e., total processing time of the order, but for Heuristics 3 this is ascending order, for Heuristics 4, this is descending order. Heuristics 3 and 4 are appropriate only for small instances, while Heuristics 1 and Heuristics 2 could solve small and large problem sizes.

For the case with the sequence of produced products not required, compared to the CPLEX solver, Heuristics 1 showed an average quality rate of 79.73% considering 30 test instances. However, Heuristics 2 was slightly worse than Heuristics 1, obtaining an average quality rate of 75.03% considering 30 test instances. Heuristics 3 received an average quality rate of 85.60%, considering 10 test instances. However, the result found by Heuristics 4 was higher. Thus, Heuristics 4 got an average quality rate of 88.73%, considering 10 test instances.

For the case with the sequence of produced products required, compared to the CPLEX solver, Heuristics 1 showed an average quality rate of 85.94% considering 30 test instances. However, Heuristics 2 was slightly worse than Heuristics 1, obtaining an average quality rate of 85.38% considering 30 test instances. Heuristics 3 received an

average quality rate of 86.33%, considering 10 test instances. However, the result found by Heuristics 4 was higher. Thus, Heuristics 4 got an average quality rate of 87.16%, considering 10 test instances.

Overall, Heuristics 1, Heuristics 2 and Heuristics 3 demonstrated higher results for the cases with the sequence of produced products required, while Heuristics 4 solved better the cases with the sequence of produced products not required. This suggests that different heuristics surpass distinct scenarios based on the requirements of the sequence of produced products in an order.

The proposed in this research heuristics serve as the foundation for a method, which could be applied in the production planning process. Whether utilized interactively by human planners or autonomously in automated systems, heuristics serve as indispensable tools for enhancing planning effectiveness and facilitating informed decision-making in the realm of production planning. Future research may focus on improving assignment to machine techniques and reducing the number of random workplaces on machine selection.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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M. Hernes et al. (Eds.): ECAI 2024, LNNS 1218, pp. 287–288, 2024.
https://doi.org/10.1007/978-3-031-78468-2