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PREFACE

Dear participants,

for almost thirty years, the Strategic Management and its Support by Information Systems conference has become a constant in the field of international conferences held in the Czech Republic with the theme of strategic management, information systems and their support using quantitative methods.

Fortunately, the COVID-19 pandemic is over and the conference can be fully restored in its traditional on-site form. A memento of the last few years is the retention of online sessions that allow all participants to present their papers despite their physical absence.

This year, there are almost 40 very high-quality papers, coming primarily from scientists from leading Czech universities, but also individuals from abroad. All articles were subjected to a careful double evaluation by the reviewers. As usual, the conference is enriched by a series of plenary lectures. This year, these are provided by Dr. Dimitrios Sotiros (Wrocław University of Science and Technology), Dr. Henri Pirkkalainen (University of Tampere), and Dr. Milan Vukaćević (University of Belgrade).

I firmly believe that this traditional event will lead to the dissemination of information and news in their respective fields, the establishment of new collaborations and, last but not least, the generation of new ideas on which to build research in the future.

Finally, let me thank all my colleagues who have contributed to the organisation of the conference, led by members of the organising and programme committee, and all the reviewers who help maintain the high standards of the conference. Support by the management of the Faculty of Economics, VŠB - Technical university of Ostrava, headed by the dean Assoc. Prof. Vojtěch Spáčil, is also gratefully acknowledged.

To a successful conference!

František Zapletal

Head of the programme committee

May 2023

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(ABSTRACTS)

Value creation with Industrial Metaverse: Insights on technology adoption

Henri Pirkkalainen [1]

Abstract. New extended reality technologies, including virtual, augmented and mixed realities have recently matured as a technology and are increasingly adopted for industries and often referred to as the Metaverse. The major beneficial use cases are now witnessed for remote collaboration due to overriding the limitations of traditional IT tools, bringing the collaborators in the same shared space and collaborating over 3D content, similar than in face to face settings. The Metaverse has the potential to increase organizational performance by improving the ways organizational knowledge is managed and for collaboration between different stakeholders in industry value chains. However, many of the developments are at an early state and are depending on the alignment of technologies, such as with Artificial Intelligence. The presentation will focus on insights about the potentials of industrial Metaverse and discuss factors that either enable or disrupt its adoption.

Henri Pirkkalainen (PhD) is an associate professor of information and knowledge management in Tampere University. His research interest is in technostress, dark side of information systems use and gamification of knowledge management (e.g., in Metaverse). He leads a research group on Information Systems Adoption and Use with several nationally and internationally funded research projects. His work has appeared in journals such as Management Information Systems Quarterly, Journal of Management Information Systems, Information Systems Journal, Internet Research, Communications of the ACM and Computers in Human Behavior. He serves as Editor at Scandinavian Journal of Information Systems.

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A generalized composition approach for complex structures in Network Data Envelopment Analysis

Dimitrios Sotiros [2]

Abstract. Network Data Envelopment Analysis (NDEA) is an extension of Data Envelopment Analysis (DEA) that takes into consideration the internal structure of Decision Making Units (DMUs) in the efficiency assessment. Notably, in NDEA, every DMU is conceived as a network of several sub-processes (divisions) arranged into a series, parallel or mix of series and parallel structures. In this paper, we develop a fair composition approach to derive the divisional and the overall efficiency scores of DMUs with complex structures. Our approach relies on Multi-Objective Programming (MOP) techniques, but unlike the existing methods in the literature, we identify the divisional efficiency scores in a min-max and max-min sense simultaneously. Specifically, we identify a point on the Pareto Front of the objective functions space that is as close as possible to the highest divisional efficiency scores (Ideal point) and as a far as possible from the lowest divisional efficiencies (Nadir point). Selecting such a unique point that secures the fairness among the divisions is of crucial importance, as it allows to establish a common basis for the comparison of the divisional scores of each DMU as well as to derive the overall efficiency. We compare the introduced method with other prominent methods in the literature and we highlight the differences and the advantages of our new method.

Dimitrios Sotiros has been an Assistant Professor at the Department of Operations Research and Business Intelligence, Faculty of Management, Wroclaw Tech, since October 2020. He has an interdisciplinary academic background with Bachelor in Mathematics, and Master and PhD in Informatics from Greece. Post his PhD, he continued his research activities in Portugal, as a researcher, for three years. His main research interests focus on performance measurement, multi-criteria decision making and multi-objective programming. His findings are published in top-tier journals, and he is a reviewer in several well-respected international scientific journals. Currently, he is the Principal Investigator of the research project “Non-parametric approaches for the performance measurement of units with complex internal structure”, funded under the OPUS competition of the NCN. In cooperation with his team, he aims to shed light on the peculiarities that permeate the models in Network Data Envelopment Analysis (NDEA), to strengthen the mathematical foundations in this area and to extend the applicability and reliability of NDEA in management science.

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Bargaining models for vote aggregation in crowdsourcing settings with limited resources

Milan Vukićević [3]

Abstract. Crowdsourcing and crowd voting systems are being increasingly used in societal, industry, and academic problems (labeling, recommendations, social choice, etc.) due to their possibility to exploit “wisdom of crowd” and obtain good quality solutions, and/or voter satisfaction, with high cost-efficiency. However, the decisions based on crowd vote aggregation do not guarantee high quality results due to crowd voter data quality. Additionally, such decisions often do not satisfy the majority of voters due to data heterogeneity (multi-
modal or uniform vote distributions) and/or outliers, which cause traditional aggregation procedures (e.g., central tendency measures) to propose decisions with low voter satisfaction. In this talk I will discuss motivation and benefits of inclusion of small number of experts in crowdsourcing environments under limited resource setting. Next, I will present machine learning based system for estimation of sparse crowd votes. Finally, I will discuss about problem of vote vote aggregation under multimodal or uniform distributions and present aggregation solution based on bargaining models that are typically used in game theory (Kalai-Smorodinsky and Nash).

Milan Vukićević, PhD is an associate professor in Center for Machine Learning and Decision Making, Faculty of Organizational Sciences, University of Belgrade. He has an extensive academic and industry experience in development and application of Machine learning and Decision-making algorithms in different application areas including Healthcare, HR, Marketing and Education. His main research interests include fair and envy free machine learning and decision making, model interpretability, group decision making and crowdsourcing.

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REGULAR PAPERS

DSS effects in the context of behavioral economics (BE) – proposal of evaluation method for strategic management DSS

Petra Bláhová[1], Helena Brožová [2]

Abstract. Enabled by the development of information technologies, decision support systems (DSS) usage should increase, reflecting the increasing volume of information. However, many studies show the less-than-optimal use of DSS advice, and the quantification of DSS usage does not address strategic management specifics.
This study outlines an experiment to examine the DSS usage level and effect in the context of behavioral economics (BE) cognitive bias, particularly the significance of past experience and level of certainty. In two rounds of the decision experiment, the same decision was made while DSS was provided for the second decision round. Major findings include that experience and certainty level is significant factors of DSS usage, decision adjustment frequency, and size and decision result, with a capacity for cognitive bias effect. Selected decision experiment can be adopted in any organization as a management decision-making style research method when considering DSS implementations.

Keywords: Decision Support Systems, quantified effect, strategic management, cognitive bias, certainty, past experience.

JEL Classification: C83, D91

1 Introduction

The increasing volume of information and rapid digitalization creates a constantly changing environment. Access to constantly changing information is creating an urgency to make more frequent decisions, and an ability to make effective and timely decisions becomes crucial. The decisions frequency is increasing on all management levels in all organizations. Although strategic decisions have a large impact, and the effectiveness of strategic decisions greatly depends on decision-making methods based on integrated automation and informatization (Alieinykov *et al.*, 2019), DSS use in strategic management is limited. The importance of decision grows, and the tendency to rely on quantitative analysis declines (Thaler, 2015). Winter (2014) related, “In many cases, a strategic decision based on emotion or intuition may be more efficient – and indeed better – than a decision arrived at after thorough and rigorous analysis of all the possible outcomes and implications.”. The ability of decision-makers to quickly and effortlessly arrive at a decision is a basic part of the brain’s function, and three general heuristics of decision-making that were identified by Tversky and Kahneman (1974) are availability, representativeness, and adjustment and anchoring. The availability heuristic is an effortless mental process whereby people assess the probability of an event by what is available in memory, favoring more recent information. Using the representativeness heuristic people assess the likelihood of an occurrence by the similarity of that occurrence to the

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stereotype of a set of occurrences. Representativeness involves using categories in decision-making. Judging an occurrence because it is similar to a broader category is usually an effective mental shortcut. Under the third original heuristic, adjustment and anchoring, people make assessments by starting from an initial value and adjusting this value to arrive at the final decision. Anchoring on a starting point reduces the complexity of a decision scenario. The decision maker then makes a judgment of how much to move or change the decision from the anchor point (Arnott and Gao, 2019). Difficult and strategic management tasks are likely to be made based on intuition rather than based on thorough, detailed analysis and complex methods (Thaler, 2015). While general heuristics is a source of effectiveness in human decision-making, they are subject to cognitive processes that can lead to poor decisions and failure (Arnott and Gao, 2019). A key issue is knowing when a particular bias is likely to affect a particular decision, and how. Das and Teng (1999) related “cognitive biases are systematically associated with strategic decision processes”.

The importance and benefits of DSS are generally understood; however, the impact of DSS in strategic decisions in the context of BE dual theory and heuristics and cognitive bias is limited. Research methods in the area of measuring the effect of DSS adding value to measuring the level of usage are, for example: include building an experimental DSS system with interactions of participants in multiple and repeated rounds of decisions with measuring a task motivation and tracking the usage of DSS (Chan *et al.*, 2017), an experimental design of DSS that study how participants revise their initial decision(Burkart, Robert and Huber, 2020) or business simulation game where correct and defective DSS are analyzed in terms of trust in automation, usefulness and intention to use (Brauner *et al.*, 2019). Many aspects of the DSS effect are examined, while not many researches use real-time and realistic decision situation with real decision-makers. As decision-making is best studied in the field with real decision makers, thus this research aim is to design an experiment, in real-time, using real data, with real tasks and real decision-makers (Klein, 2010).

The aim of this study is to evaluate the influence of DSS in a specific experimental decision situation and to identify and quantify the DSS effect in contexts to identified heuristic and cognitive bias. The structure of the paper is as follows. In the next chapter, a contribution is outlined along with the implications of current research questions. The third chapter details the research methodology, discussions, and limitations are outlined in chapter five and concludes with the implications of the findings and direction for future research.

2 Contribution

The main contribution to the DSS effect evaluation research is, first, the experiment based on dual theory, the real-time situation where real decision-makers can use their intuition as well as DSS, including cognitive bias examination in the context of past experience knowledge and perceived certainty. An important contribution is including BE in the research. DSS in context to BE is as well, and many researchers are measuring one specific characteristic in isolation. Previous research has found that DSS has been slow to adopt recent advances in BE, as provided by Arnott and Gao (2019) in the overview of recent DSS/BE research.

Given the relevance of BE in the area of strategic management decisions (Das and Teng, 1999) as well as the importance of connection to DSS, the current study focuses on the decision adjustment evaluation in relation to provided DSS information output, existing past experience with the same decision problem and the level of certainty with the original decision. The study is designed so that the effects can be quantified and thus become key factors for DSS frameworks. The experiment design considering specific behavioral elements is applicable to any organization during the research phase of DSS implementation. The behavioral elements can be expanded or updated according to the organization; otherwise, this simple experiment provides useful results for future users of the system. Senior management decisions are specific and this survey can improve the perception of DSS benefits as well as enables the realization of management style and organizational culture. Assuming that the level of decision adjustment in the second round will be significantly affected by given DSS, past experience, and level of (un)certainty, the research questions to be answered in this study are the following:
RQ1. DSS provided for the second round has a significant effect on decision adjustments.
RQ2. What are the effects of past experience on DSS usage and decision adjustments?
RQ3. What are the effects of certainty with the original decision on the second round with DSS?
RQ4. Portfolio profitability enables the quantification of several factors in the decision process.

3 Research Methodology

An online survey including a decision situation experiment was chosen as a research method as it enables instant distribution to participants and is easy to use. A decision problem, on which the evaluation of the influence of DSS outputs was performed, was defined as an investor's portfolio decision. Since surveys are designed to provide a picture of how things are at a specific time, and there is no possibility for respondents to control conditions or manipulate variables (Kelley *et al.*, 2003), chosen method is highly suitable for the investor's portfolio decision where provided information to decision-makers are time-sensitive. To increase the interest of participants and their motivation, the experiment is constructed as the real-time situation where decision-makers can use their intuition, past experience knowledge, risk attitude and subjective biased view. The portfolio items were selected to be generally known brands or commodities to allow realistic investment decision.

The participants were presented with the task to allocate \$100 000 among five portfolio items to maximize profit in six months period, firstly without DSS (w/o) and secondly with DSS (DSS). Investment options: Silver, Crude oil, Cocoa, Apple Inc. stocks, and Boeing company stocks with the goal to maximize profit over a given period 1.12.2020 – 31.5.2021.

Information provided in DSS included charts, exact numerical estimations, as well as verbal recommendations and explanations.. The purpose of this experiment was not to provide professional investors 'models as well as professional investors were excluded from this study. DSS included: price evolution charts for the previous month and for 12 months, recommendations and explanations of the analysts, which were sourced from various reliable sources and sometimes were not aligned about the future prediction and provided other information relevant to investor's decision and lastly an estimated profit rate/price evaluation in 6 months. To be able to compare the level of influence of DSS recommendations on each decision maker and quantify other factors of the decision, the reference portfolio decision was created assuming rational and complete acceptance of DSS advice. Other factors were examined: past experience with the same investment to identify potential relevant experiences among respondents and respondents' certainty was examined by differential scale questions on a scale from one to ten, where ten meant absolutely certain. In the two round decisions, the factorial design led to the following decision groups:

w/o	original decision without any DSS information output (n=25)		
DSS	second round decision with DSS provided (n=25)		
Ref	reference portfolio rationally followed DSS advice		
w/o EXP	(n=5)	DSS EXP	(n=5)
w/o no EXP	(n=20)	DSS noEXP	(n=20)

above with Low, Medium, and High certainty levels (n=25)

A total of 50 survey experiments were completed. Participating in this research were final year university students of the Faculty of Economics and Management in CULS with a specialization in Management, Informatics, Systems Engineering, with experience of DSS proposals.

Analytical methods applied ANOVA variance analysis, MAPE for the size of adjustments for comparative analysis for profitability (Gönül, Önkal and Lawrence, 2006) for the purposes of this study as APA absolute percentage adjustment based on the same principle of absolute values for significance and size of the adjustment, not negative or positive. Firstly the measure for the presence/absence of adjustments, counting the adjustments, then measure that quantifies the size of adjustments, thus providing another view of the influence of DSS and its factors measured in Absolute Percentage Adjustment (APA), where:

$$(APA) \quad = \frac{adjusted\ decision - original\ decision\ w/o}{original\ decision\ w/o}\, x\ 100 \qquad (1)$$

4 Results

Results are outlined under four categories: portfolio decision and percentage of original decisions adjusted, size of adjustments made, and portfolio profitability.

4.1 Portfolio decision and percentage adjustments made to the original decision

The results in *Figure 1* represent the selected portfolio distribution by each decision group or decision scenario. Selected scenarios are decision-making without using supporting information (w/o), with provided DSS output (DSS) and rational DSS advice usage (ref).These two decision groups are further divided based on confirmed relevant past experience (EXP) and with no experience (noEXP). Results represent average portfolio distribution for each group.

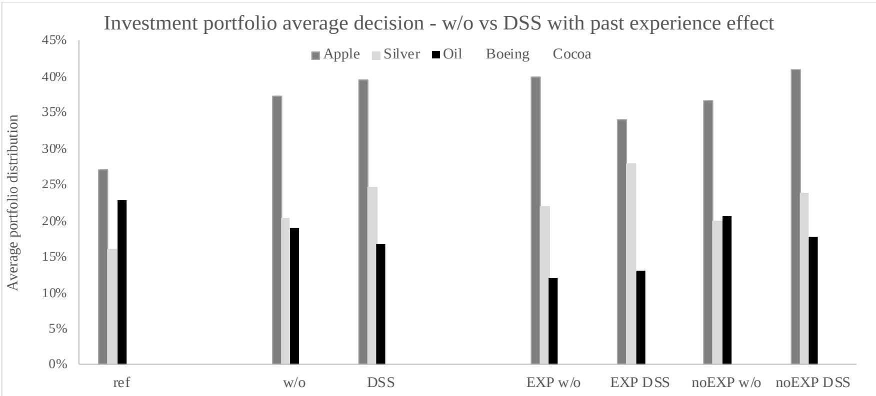

Figure 1 Portfolio average distribution comparison

Examining whether a decision-maker has accepted the DSS advice is likely when a user will want to accept the advice and not make any changes (Gönül, Önkal, and Lawrence, 2006). Adopting the reverse approach, the acceptance will be measured as the frequency and size of the original decision after DSS was provided for second round. The results in *Table 1* represent the comparison between decisions without DSS and with DSS, where the adjustment to original decisions is 82% of the original decision made w/o DSS were adjusted when DSS was used.

Decision DSS Adjustments	Silver	Oil	Cocoa	Boeing	Apple	Total
Number of decision adjustments	19	15	15	12	18	79
Number of original decisions	21	20	20	11	24	96
% of adjustments	90%	75%	75%	109%	75%	82%
Value of decision adjustments	325 000	175 000	225 000	190 000	265 000	1 180 000
Value of original decisions	510 000	475 000	335 000	245 000	935 000	2 500 000
% of adjustments value	64%	37%	67%	78%	28%	47%

Table 1 Decision Adjustment Frequency w/o and with DSS

The total percentage of decisions adjusted for all of the sub-groups is given in *Table 2*, along with the count of adjustments made over the total number of data points in each of the groups reflecting experience (EXP, noEXP) and level of certainty provided by respondents with the original decision (Low, Medium, High). The existence of past experience is the significant decreasing factor of DSS usage, indicating decision-makers adjusted their original decision from 55%. High level of certainty is decreasing the overall count of adjustments.

		Past Experience		Certainty Level		
	ALL	**Yes**	**No**	**Low**	**Medium**	**High**
Apple	90%	50%	100%	100%	100%	50%
Boeing	75%	50%	81%	50%	86%	50%
Cocoa	75%	33%	82%	75%	71%	100%
Oil	109%	75%	129%	0%	125%	33%
Silver	75%	60%	79%	75%	93%	20%
Adj count	79	11	68	13	58	8
w/o decision count	96	20	76	15	63	18
% adj	82%	55%	89%	87%	92%	44%

Table 2 Decision adjustment frequency %

4.2 Size of adjustments made

Results provided in *Table 3* show that the average size of adjustments made to the original decision (measured by APA) is statistically different among the five groups and that the adjustments made were statistically significant.

Groups	***Count***	***Sum***	***Average***	***Variance***	
Apple	18	840%	47%	12%	
Boeing	12	1475%	123%	157%	
Cocoa	17	1773%	104%	60%	
Oil	14	702%	50%	5%	
Silver	19	1604%	84%	67%	
ANOVA					
Source of Variation	***SS***	***df***	***MS***	***F***	***p-value***
Between Groups	6,5022	4	1,6255	2,92901	0,0262
Within Groups	41,624	75	0,555		
Total	48,126	79			

Table 3 ANOVA results for APA made when using DSS

RQ1. DSS provided for repeated decisions to the same decision-makers has a significant effect in increasing both the decision adjustment frequency and size measured by absolute percentage adjustments made to portfolio items. Analysis of variance results shows a significant effect.

For past experience and certainty factors, two ratios are utilized: Absolute Percentage Adjustment of Experience (APAE) and Certainty (APAC), where the APA equation applies. The factors are measured separately, as total decision adjustments divided into EXP and noEXP and then divided among Low, Medium, and High levels of certainty recorded from the original decision. The means of APAE and APAC for each individual data point of adjusted investment decision are provided in *Table 4*.

	APAE (Experience)		**APAC (Certainty)**		
	Yes	**No**	**Low**	**Medium**	**High**
Apple	33%	41%	44%	50%	36%
Boeing	25%	113%	100%	27%	122%
Cocoa	83%	109%	83%	70%	115%
Oil	100%	124%	100%	40%	127%
Silver	67%	113%	48%	150%	114%

Table 4 Mean values for Absolute Percentage size Adjustment

Corresponding variance analysis in *Table 5* examines APA representing all adjustments made in the second round with DSS (already provided in *Table 3*), APAE represents adjustments by past experience, and APAC adjustments by certainty level low, medium and high.

ANOVA Measures	F	*p*-value
APA - Adj All	2,929011	0,026243
APAE - Adj by Experience (yes/no)	3,696892	0,056826
APAC - Adj by Certainty (low/medium/high)	3,977939	0,021203

Table 5 ANOVA Variance analysis

RQ2. Past experience has an effect on decision adjustment being more important than DSS information – twice as fewer adjustments were made by experienced respondents. Variance analysis shows a difference with p=0,0,57 indicating a borderline of significance.

RQ3. The level of uncertainty/certainty with the original decision is important to factor increasing DSS usage and, thus, increasing the level of decision adjustment.

4.3 Profitability

Profitability is a measure including market effect, partial information effect, good intuition, past experience and level of certainty, potential risk attitude in the first round, and adding DSS use effect in the second round. Reference (ref) portfolio was added based on an assumption of absolute acceptance of DSS advice using weighted expected % evaluation. *In Figure* 2, profitability results for two views: profit between w/o, DSS, and ref and with added past experience. Results are measured at 6M to-date result, 12M view is provided as supplemental information.

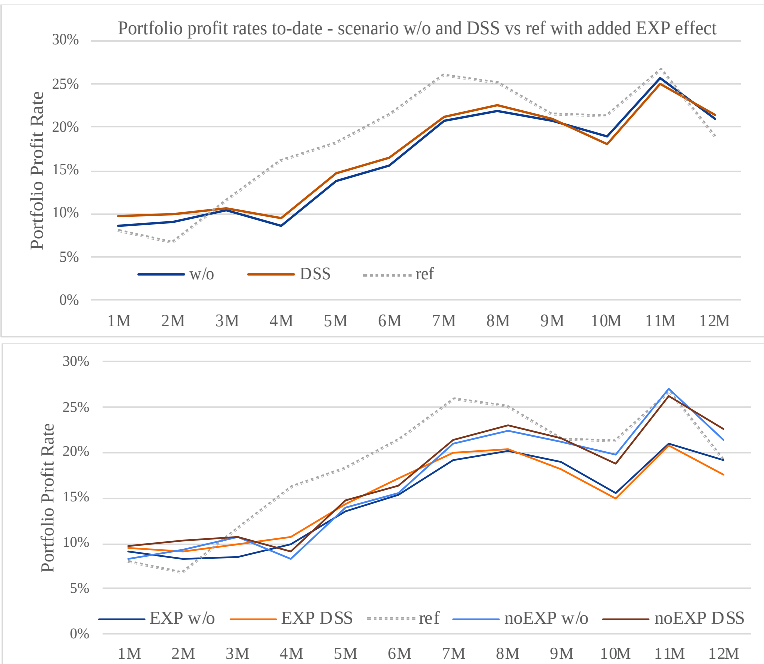

Figure 2 Portfolio profit rates to-date for 1M - 12M investment periods

For market volatility, individual portfolio items evaluation is provided in *Figure 3*. DSS information and actual market values are aligned in the 6M period, except for Oil.

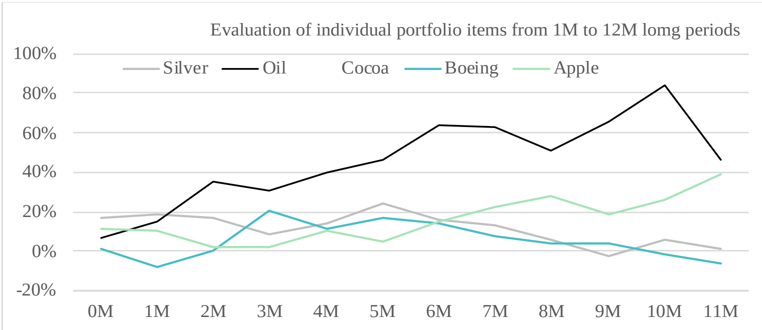

Figure 3 Individual portfolio items evaluation to date for 1M - 12M

The experience factor is included in the results in Table 6 (and Figure 2 above). Results comparison between w/o and DSS with experience factor shows higher profit gained with DSS, contributed by the higher profit of past experience.

w/o vs DSS	**w/o**			**DSS**		
EXP factor	**noEXP**	**EXP**	**Total**	**noEXP**	**EXP**	**Total**
Apple	34 327	9 341	43 667	38 297	7 940	46 236
Boeing	24 987	17 232	42 219	30 156	17 232	47 389
Cocoa	-36 413	-3 582	-39 995	-20 893	-2 985	-26 265
Oil	192 031	27 764	219 795	164 268	30 077	189 718
Silver	95 977	26 394	122 370	113 972	33 592	145 165
Profit	310 908	77 148	388 057	325 800	85 856	402 242
Profit %	15,5%	15,4%	15,5%	16,3%	17,2%	16,1%
DSS Profit Δ				4,8%	11,3%	3,7%

Table 6 Portfolio profitability w/o vs. DSS comparison – with the experience factor

Result comparison between w/o and DSS with experience and certainty factors in Table 7 shows higher profit gained with DSS, positively contributed by experience and medium certainty level. High certainty has a negative effect decreasing the profitability of experienced respondents when using DSS. On the contrary, high certainty has a positive effect on increasing the profitability of inexperienced respondents when w/o DSS. Experience negative effect on w/o and positive effect to DSS profitability indicates biased decision driven experience. And reversely high level of certainty on DSS profitability of experienced respondents, indicates cognitive bias resulting from experience to high perceived certainty.

Scenario	**w/o**					**DSS**				
EXP	**noEXP**	**noEXP**	**noEXP**	**EXP**	**EXP**	**noEXP**	**noEXP**	**noEXP**	**EXP**	**EXP**
Certainty	low	medium	high	medium	high	low	medium	high	medium	high
Apple	9 808	20 549	3 970	5 137	4 203	11 676	21 950	4 670	3 736	4 203
Boeing	0	15 509	9 478	10 339	6 893	1 723	17 232	11 201	10 339	6 893
Cocoa	-13 729	-19 102	-3 582	-3 582	0	-4 179	-13 729	-2 985	-2 985	0
Oil	13 882	150 386	27 764	23 136	4 627	18 509	120 309	25 450	25 450	4 627
Silver	34 792	44 389	16 796	11 997	14 396	39 590	61 185	13 197	19 195	14 396
Profit	44 751	211 732	54 425	47 028	30 120	67 320	206 947	51 533	55 736	30 120
Profit %	9,0%	17,6%	18,1%	15,7%	15,1%	13,5%	17,2%	17,2%	18,6%	15,1%
Profit with DSS Δ %						50,4%	-2,3%	-5,3%	18,5%	0,0%

Table 7 Portfolio profitability w/o vs. DSS comparison – with experience and certainty factor

RQ4. Profitability enables quantification of the past experience and decision-maker certainty impact, enables conclusions of potential positive or negative effects of these factors.

5 Discussion and conclusion

The purpose of this study is to provide a clear and simple method for evaluating organizational senior management decision behavior while complex relationships shall be discovered in the decision process. Discovery and analysis of the complexity in terms of cognitive evaluation are necessary for successful DSS use. Decisions about investment portfolio in this research showed past experience as more important than DSS driving the lowest adjustments in the experiment and that a high level of certainty leads to twice as few adjustments. Certainty level can reflect on risk attitude, especially in this experiment, since investment decisions can be affected by the willingness of the respondents to take a risk and their risk tolerance impacts DSS acceptance (Phillips-Wren, Power, and Mora, 2019).

Decisions from experience and decisions from description can lead to dramatically different choices (Hertwig *et al.*, 2004), and therefore the preference of respondents 'own past experience in this study needs to be considered as potential critical burden of effective usage of potential DSS in an organization. As shown in this study, past experience leads to less accepted DSS advice and preference for past experience, while it does not lead to higher profitability. To avoid preference for decision-maker past experience, that previous experience shall be included in the DSS framework as similarly suggested (Kucharski and Szczerbicki, 2011) and (Ghattas, Soffer and Peleg, 2014). Past experience components will be most visible in collaborative and interactive DSSs which are the future of DSS technology (Shim *et al.*, 2002).

In conclusion, our findings indicate both experience and certainty can be interpreted as heuristics and cognitive bias. The results of this study have many practical implications in DSS implementation process, especially in the initial research phase where any organization may use this experiment to analyze management decision behavior. Future research will continue examining cognitive bias on experiments using managers as study participants.

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Efficiency of intralogistics solutions using the output-oriented DEA CCR crisp and CCR possibilistic models

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Abstract. This research utilizes Data Envelopment Analysis (DEA) as an instrument for evaluating the efficiency of Decision-Making Units (DMUs) in the realm of warehouse automation and intralogistics operations. By employing linear programming, we construct an efficiency frontier representing the boundary of optimal-performing DMUs, derived from the observed data of individual DMU inputs and outputs. While acknowledging the constraints of the traditional CCR DEA model, which presumes the data used in the analysis to be precise and deterministic, this study extends to incorporate a possibilistic CCR output-oriented model, fuzzifying one variable - machine performance. Intriguingly, despite the variable's inherent uncertainty, the evaluation of DMUs efficiencies and non-efficiencies showed constancy irrespective of the model used. Consequently, this application within the domain of intralogistics offers insights into their appropriateness for the provided data, while subtly underscoring the potential for further research.

Keywords: DEA, CCR, efficiency, fuzzification, possibilistic model.

JEL classification: C67, C61

1 Introduction

Effective decision-making is crucial for success, but with a multitude of options and criteria to consider, it can be challenging to select the optimal solution without experiencing decision paralysis. Fortunately, there are tools and methods available to make the decision-making process easier, such as Data Envelopment Analysis (DEA), which is an optimization method that enables the comparison of multi-criteria decision-making units based on their input and output criteria. However, selecting the appropriate DEA model and accurately evaluating and categorizing inputs and outputs are essential to avoid subjective biases.

In this work, an output-oriented model of the DEA method was applied to evaluate the efficiency of a company's warehouse automation and intralogistics operations. Fuzzification was applied to one output to account for data fluctuation, and the obtained results were interpreted and presented. The suitability of the selected models for analyzing the data was also evaluated. The primary goal of this research was to analyze the effectiveness of decision-making units using the DEA method and assess the appropriateness of the models used for the data provided. If an option is deemed inefficient, recommendations will be proposed to improve decision-making efficiency.

2 Theoretical principles

Data envelopment analysis (DEA) is a non-parametric technique assessing the relative efficiency of homogeneous decision-making units (DMUs), initially developed in 1978 by

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Charnes et al. (Charnes et al., 1978). A DMU can be any entity that consumes resources and produces outputs, such as firms, banks, hospitals, and universities. As it is clear, DEA has various applications in different fields, including finance, health care, education, and agriculture. It is used for performance evaluation, benchmarking, and resource allocation, among other things.

DEA uses linear programming to construct an efficiency frontier, a boundary of the best-performing DMUs. The frontier is based on the observed data of inputs and outputs of each DMU, and it serves as a benchmark against which other DMUs can be compared. DMUs that lie on the efficiency frontier are considered efficient, while those that fall below the frontier are deemed inefficient. In 1978 the CCR DEA model was created by Charnes Cooper and Rhodes (Charnes et al., 1978) in order to be able to compare DMUs with multiple input and output variables. The CCR model is able to operate with both, constant or variable returns to scale. The DEA approach allows for multiple inputs and outputs and can handle situations where the DMUs have different combinations of inputs and outputs. Additionally, DEA can identify the sources of inefficiency for each DMU, which can help decision-makers to prioritize improvement strategies. (Garcia et al., 2005; Lertworasirikul et al., 2003)

The CCR model is a traditional DEA model. However, the model assumes that the data used in the analysis is precise and deterministic. In practice, however, decision-making environments often involve epistemic uncertainty and imprecision, which can affect the accuracy of the analysis. We can extend the CCR-O model with fuzzy numbers to address this issue by using a possibility theory to model uncertainty (Zadeh, 1978; Dubois and Prade, 1998, 1978).

In the remainder of the section, we provide the necessary definitions (Guo and Tanaka, 2005; Zadeh, 1965, 1978) to build the conceptual framework. The wording is taken from one of the author's earlier works (Chrubasik, 2022).

Definition 1 (Fuzzy Set)**.** Given a universe of discourse X and an injective function $\mu : X \to [0,1]$, fuzzy set $\underset{\sim}{A}$ is defined as a set of ordered pairs of elements of X and their function values:

$$\underset{\sim}{A} = \big\{(x, \mu(x)) \mid x \in X \wedge \mu(x) \in [0,1]\big\}. \tag{1}$$

Semantically, we say that x *is a member of* $\underset{\sim}{A}$ with a *degree of membership* μ.

For finite discrete X ($|X| = n$):

$$\underset{\sim}{A} = \left\{\frac{\mu_{\underset{\sim}{A}}(x_1)}{x_1} + \frac{\mu_{\underset{\sim}{A}}(x_2)}{x_2} + \cdots + \frac{\mu_{\underset{\sim}{A}}(x_n)}{x_n}\right\} = \left\{\sum_{i=1}^{n} \frac{\mu_{\underset{\sim}{A}}(x_i)}{x_i}\right\}, \tag{2}$$

when X is infinite and continuous, then we can use the following notation to define fuzzy set $\underset{\sim}{A}$:

$$\underset{\sim}{A} = \left\{\int_a^b \mu_{\underset{\sim}{A}}(x)\right\}, \tag{3}$$

where $a = \inf_{x \in X} X$ and $b = \sup_{x \in X} X$.

Definition 2 (ε-cut (also called α-cut))**.** An ε-cut of a fuzzy set $\underset{\sim}{A}$ on X is defined as a set of all elements $x \in X$ whose membership function is greater or equal to some number ε. Formally:

$$\underset{\sim}{A}^{(\varepsilon)} = \left\{x \in X \mid \mu_{\underset{\sim}{A}} \geq \varepsilon\right\}. \tag{4}$$

Definition 3 (Strong ε-cut)**.** Same as Definition 2, but with a sharp inequality. Formally:

$$\underset{\sim}{A}^{(\varepsilon+)} = \left\{x \in X \mid \mu_{\underset{\sim}{A}} > \varepsilon\right\}. \tag{5}$$

Definition 4 (Support)**.** Support is a special case of a strong ε-cut where $\varepsilon = 0$. Formally:

$$\text{supp}(\underset{\sim}{A}) = \underset{\sim}{A}^{(0+)}. \tag{6}$$

Definition 5 (Height)**.** The height of a fuzzy set $\underset{\sim}{A}$ on X is defined as the supremum of its membership function. Formally:

$$h(\underset{\sim}{A}) = \sup_{x \in X} \mu_{\underset{\sim}{A}}(x). \tag{7}$$

Definition 6 (Core)**.** The core of a fuzzy set $\underset{\sim}{A}$ is the set of all $x \in X$ where the membership function equals 1. Formally:

$$\text{core}(\underset{\sim}{A}) = \left\{x \in X \mid \mu_{\underset{\sim}{A}}(x) = 1\right\}. \tag{8}$$

Definition 7 (Normalized fuzzy set)**.** Fuzzy set $\underset{\sim}{A}$ on X is normalized if and only if:

$$h(\underset{\sim}{A}) = 1. \tag{9}$$

In other words, there exists at least one element $x \in X$ such that $\mu_{\underset{\sim}{A}}(x) = 1$.

Definition 8 (Convex fuzzy set)**.** Fuzzy set $\underset{\sim}{A}$ on X is convex if and only if:

$$\mu_{\underset{\sim}{A}}(\lambda x + (1 - \lambda)y) \geq \min(\mu_{\underset{\sim}{A}}(x), \mu_{\underset{\sim}{A}}(y)),\ \forall x, y \in X, \forall \lambda \in [0, 1]. \tag{10}$$

Definition 9 (Fuzzy number)**.** Fuzzy set $\underset{\sim}{M}$ is a fuzzy number if and only if it is normalized, convex, and defined over the set of real numbers i.e., $X = \mathbb{R}$.

Definition 10 (LR number)**.** LR number is a fuzzy number defined as:

$$\underset{\sim}{M} = \left\{ \int_{-\infty}^{s^L - s^\alpha} 0 \ + \int_{s^L - s^\alpha}^{s^L} L(x) \ + \int_{s^L}^{s^U} 1 \ + \int_{s^U}^{s^U + s^\beta} R(x) \ + \int_{s^U + s^\beta}^{\infty} 0 \right\}, \tag{11}$$

where $L(x)$ is a non-decreasing continuous function $L : \mathbb{R} \to [0, 1]$, and $R(x)$ is a non-increasing continuous function $R : \mathbb{R} \to [0, 1]$. $L(x)$ and $R(x)$ can also be defined on $x \in (-\infty, s^L]$ and $x \in [s^U, \infty)$ respectively.

Definition 11 (T-number)**.** T-number (trapezoidal number) is an LR fuzzy number $\underset{\sim}{t}$ such that:

$$\begin{aligned} L(x) &= \frac{x - (s^L - s^\alpha)}{s^\alpha}, \\ R(x) &= \frac{(s^U + s^\beta) - x}{s^\beta}. \end{aligned} \tag{12}$$

A T-number $\underset{\sim}{t}$ is commonly written as $\underset{\sim}{t} = (s^L, s^U, s^\alpha, s^\beta)$.

Definition 12 (Triangular Fuzzy Number)**.** A triangular fuzzy number is a special case of a T-number. A triangular fuzzy number is a T-number $\underset{\sim}{t} = (s^L = s^U, s^U = s^L, s^\alpha, s^\beta)$.

Definition 13 (Isosceles Triangular Fuzzy Number (ITFN))**.** Isosceles triangular fuzzy number is a special case of a triangular fuzzy number such that $s^\alpha = s^\beta$. We will denote isoceles numbers as $\underset{\sim}{t} = (s^C, s^\gamma)$, where s^c is the core and s^γ denotes both s^α and s^β.

Given an ITFN $\underset{\sim}{t} = (s^C, s^\gamma)$, the possibility distribution of an event $x \geq \underset{\sim}{t}, x \in \mathbb{R}$ is:

$$\pi(x \geq \underset{\sim}{t}) = \begin{cases} 1 & x \geq c, \\ L(x) & s - s^\gamma \leq x \leq c, \\ 0 & \text{otherwise.} \end{cases} \tag{13}$$

For the events mentioned above (denoted by A), we get the necessity distribution as follows:

$$N(A) = 1 - \pi(\neg(A)). \tag{14}$$

3 Data and Methodology

The CCR-O model is given as follows:

$$\sum_{j=1}^{m} v_j x_{jk} = e_q \to \min \tag{15}$$

$$\text{s.t.:} \sum_{i=1}^{r} u_i y_{ik} = 1, \tag{16}$$

$$\sum_{j=1}^{m} v_j x_{jk} - \sum_{i=1}^{r} u_i y_{ik} \geq 0, \tag{17}$$

$$v_j, u_i \geq \varepsilon. \tag{18}$$

With one fuzzy output:

$$\sum_{j=1}^{m} v_j x_{jk} = e_q \to \min \tag{19}$$

$$\text{s.t.:} \sum_{i=1}^{r} u_i y_{ik} + u' \underset{\sim}{y}' = 1, \tag{20}$$

$$\sum_{j=1}^{m} v_j x_{jk} - (\sum_{i=1}^{r} u_i y_{ik} + u' \underset{\sim}{y}') \geq 0 \tag{21}$$

$$v_j, u_i \geq \varepsilon. \tag{22}$$

We converted the CCR-O model with fuzzy coefficients in the output By selecting a given possibility/necessity level ε and taking the inverses of 13 and 14 where i is the number of inputs, j is the number of crisp outputs. ψ is either $\pi^-1(\varepsilon)$ or $N^-1(\varepsilon)$. By employing both functions, we get an optimistic (possibility) and a pessimistic (necessity) scenario for a particular ε level.

$$\sum_{j=1}^{m} v_j x_{jk} = e_q \to \min \tag{23}$$

$$\text{s.t.:} \sum_{i=1}^{r} u_i y_{ik} + u_\varepsilon \psi^{-1}_{z \geq \tilde{y}}(\varepsilon) = 1, \tag{24}$$

$$\sum_{j=1}^{m} v_j x_{jk} - (\sum_{i=1}^{r} u_i y_{ik} + u_\varepsilon \psi^{-1}_{z \geq \tilde{y}}(\varepsilon)) \geq 0, \tag{25}$$

$$v_j, u_i, u_\varepsilon \geq \varepsilon'. \tag{26}$$

The resulting dual model was then used to make a recommendation for changing the given output to become relatively efficient, either in absolute units or in relative percentages relating to the current state.

This paper aimed to analyze the data using the CCR output-oriented model and possibilistic CCR output-oriented model with one variable fuzzified and focus on comparing the obtained data and DMUs efficiencies of these two applied models. The data used in this study was provided by a company specializing in warehouse automation and intralogistics. The data consists of 14 homogeneous Decision-Making Units (DMUs), each comprising three input variables and two output variables (Table 1). The input variables are the total solution price (I_1), the number of people required to operate the machines (I_2), and the built-up area (I_3). The output variables are machine performance (O_1), given in units of orderline/hour, and the amount of stored material for a specific location (O_2). For this paper, the output-oriented evaluation models were chosen based on the availability of the possible data influence. This dataset was used in a previous study (Bordacsova, 2023), with machine performance represented as a crisp number. However, in this study, machine performance of the possibilistic model had been fuzzified into isosceles triangular fuzzy numbers (see Table 3) using the population standard deviation as s^γ.

	I_1	I_2	I_3	O_1	O_2
DMU1	1700.00	9.00	440.00	1840.00	15000.00
DMU2	1900.00	13.00	470.00	3360.00	15000.00
DMU3	1500.00	7.00	380.00	1080.00	15000.00
DMU4	1400.00	10.00	370.00	1840.00	15000.00
DMU5	1600.00	14.00	400.00	3360.00	15000.00
DMU6	1200.00	8.00	310.00	1080.00	15000.00
DMU7	1500.00	5.00	410.00	1700.00	13500.00
DMU8	1200.00	6.00	360.00	1700.00	13500.00
DMU9	1600.00	5.00	410.00	1900.00	12500.00
DMU10	1300.00	6.00	360.00	1900.00	12500.00
DMU11	2100.00	5.00	330.00	2000.00	13000.00
DMU12	1800.00	6.00	310.00	2000.00	13000.00
DMU13	1900.00	5.00	330.00	2200.00	13000.00
DMU14	1600.00	6.00	310.00	2200.00	13000.00

Table 1 Data from the CCR crisp model.

DMU	(O) 1	(O) 2	eff	Δ (O) 1	Δ (O) 2	Δ% (O) 1	Δ% (O) 2	(O) 1 ideal	(O) 2 ideal
DMU1	1840	15000	1.21	+382	+3117	20.78%	20.78%	2222	18117
DMU2	3360	15000	1.03	+104	+1906	3.11%	12.71%	3464	16906
DMU3	1080	15000	1.02	+758	+330	70.23%	2.2%	1838	15330
DMU4	1840	15000	1.05	+95	+771	5.14%	5.14%	1935	15771
DMU5	3360	15000	1.00	+0	+0	0.0%	0.0%	3360	15000
DMU6	1080	15000	1.00	+0	+0	0.0%	0.0%	1080	15000
DMU7	1700	13500	1.00	+0	+0	0.0%	0.0%	1700	13500
DMU8	1700	13500	1.00	+0	+0	0.0%	0.0%	1700	13500
DMU9	1900	12500	1.01	+16	+107	0.86%	0.86%	1916	12607
DMU10	1900	12500	1.00	+0	+0	0.0%	0.0%	1900	12500
DMU11	2000	13000	1.00	+200	+0	10.0%	0.0%	2200	13000
DMU12	2000	13000	1.01	+17	+109	0.84%	0.84%	2017	13109
DMU13	2200	13000	1.00	+0	+0	0.0%	0.0%	2200	13000
DMU14	2200	13000	1.00	+0	+0	0.0%	0.0%	2200	13000

Table 2 Recommendations for $\varepsilon = 1$, crisp.

	I_1	I_2	I_3	$\tilde{O}_1$	O_2
DMU1	1700.00	9.00	440.00	(1840.0, 639.27)	15000.00
DMU2	1900.00	13.00	470.00	(3360.0, 639.27)	15000.00
DMU3	1500.00	7.00	380.00	(1080.0, 639.27)	15000.00
DMU4	1400.00	10.00	370.00	(1840.0, 639.27)	15000.00
DMU5	1600.00	14.00	400.00	(3360.0, 639.27)	15000.00
DMU6	1200.00	8.00	310.00	(1080.0, 639.27)	15000.00
DMU7	1500.00	5.00	410.00	(1700.0, 639.27)	13500.00
DMU8	1200.00	6.00	360.00	(1700.0, 639.27)	13500.00
DMU9	1600.00	5.00	410.00	(1900.0, 639.27)	12500.00
DMU10	1300.00	6.00	360.00	(1900.0, 639.27)	12500.00
DMU11	2100.00	5.00	330.00	(2000.0, 639.27)	13000.00
DMU12	1800.00	6.00	310.00	(2000.0, 639.27)	13000.00
DMU13	1900.00	5.00	330.00	(2200.0, 639.27)	13000.00
DMU14	1600.00	6.00	310.00	(2200.0, 639.27)	13000.00

Table 3 The result of fuzzification.

3.1 CCR output-oriented crisp model

Table 2 shows the data after applying the CCR output-oriented model with machine performance (and all the variables as well) represented as a crisp number. As can be seen in this table, there are 7 DMU evaluated as efficient; more specifically, they are DMU5, DMU6, DMU7, DMU8, DMU10, DMU13, and DMU14. The remaining 7 DMU - DMU1, DMU2, DMU3, DMU4, DMU9, DMU11 and DMU 12 were evaluated as non-efficient. The necessary adjustments to the values of individual outputs of inefficient DMUs are also captured in this table. Changes are expressed as both a numerical increase and a percentage change for better representation. Subsequently, these changes are reflected in the ideal values of each output.

3.2 Possibilistic CCR output-oriented model

The possibilistic CCR output-oriented model is a adapted fuzzy linear programming model from Fiedler et al. (Fiedler et al., 2006). The possibilistic CCR-O DEA model was applied to compute the efficiency of DMUs under optimistic and pessimistic scenarios.

For the fuzzification, Output 1 was chosen. The machine's performance can be influenced by numerous factors, including external conditions, operator skills, maintenance, and variations in operational parameters. The fuzzification was applied to capture the variability and imprecision associated with the performance of the machine. By incorporating fuzzification in the analysis of machine performance, it becomes possible to model and evaluate the performance under different conditions and uncertainties. This enables better understanding and optimization of the machine's behavior, leading to improved operational efficiency and decision-making in various domains such as manufacturing, automation, and intralogistics.

The model considers epsilon confidence levels between zero and one with 0.1 granularity. Then the fuzzification of the O_1 output was done. The DMUs are fuzzified using isosceles triangular fuzzy numbers. The standard deviation of DMUs O_1 values is computed to obtain the s^{γ} value.

Figure 1 shows that changing the ε "confidence" levels may affect units in various and unpredictable ways. This is because variability in fuzziness across DMUs affects their relative efficiency standings. Due to fuzzification, attitudes towards uncertainty, and several levels of ε, it would not be realistic to display all possible outputs according to individual attitudes towards uncertainty and level of ε. We may look further into the results by selecting a particular ε level and a particular attitude toward uncertainty (pessimism/optimism) and get the recommendations for that particular level. For this reason, a slicing level of ε = 0,5 was chosen to demonstrate both optimistic and pessimistic attitudes toward uncertainty.

The efficiency measure for each DMU was obtained using the possibilistic CCR-O DEA model. The results have been analyzed to identify the efficient and inefficient DMUs. The inefficient DMUs were further analyzed to provide recommendations for changes required to reach the efficient frontier. Table 4 demonstrates the possibility CCR-O model with fuzzified input values of Output 1, representing the machine performance, assuming an optimistic attitude towards uncertainty for slicing level of ε = 0.5. As it is clear from this table, 7 DMU have been evaluated as efficient. These efficient DMUs are identical to the efficient units from the previous CCR-O crisp model. Table 5 demonstrates the possibility CCR-O model with fuzzified input values of Output 1, representing the machine performance, assuming a pessimistic attitude towards uncertainty for slicing level of ε = 0.5. As well as in the previous case, there were 7 non-efficient DMUs and 7 efficient DMUs. Obtained results are identical to our previously-applied models (CCR-O crisp and possibility CCR-O model.)

4 Discussion

The fuzzification of the coefficients can provide more comprehensive insight into possible scenarios; however, presenting the results in a pure tabular form may not bring the desired value to human stakeholders. Performing eleven ε-cuts from 0 to 1 of the ε-level for both possibility and necessity for 14 DMUs for two outputs, results in $11 \times 2 \times 14 \times 2$ recommendations, which requires a multi-indexed table to represent. One possible solution might be

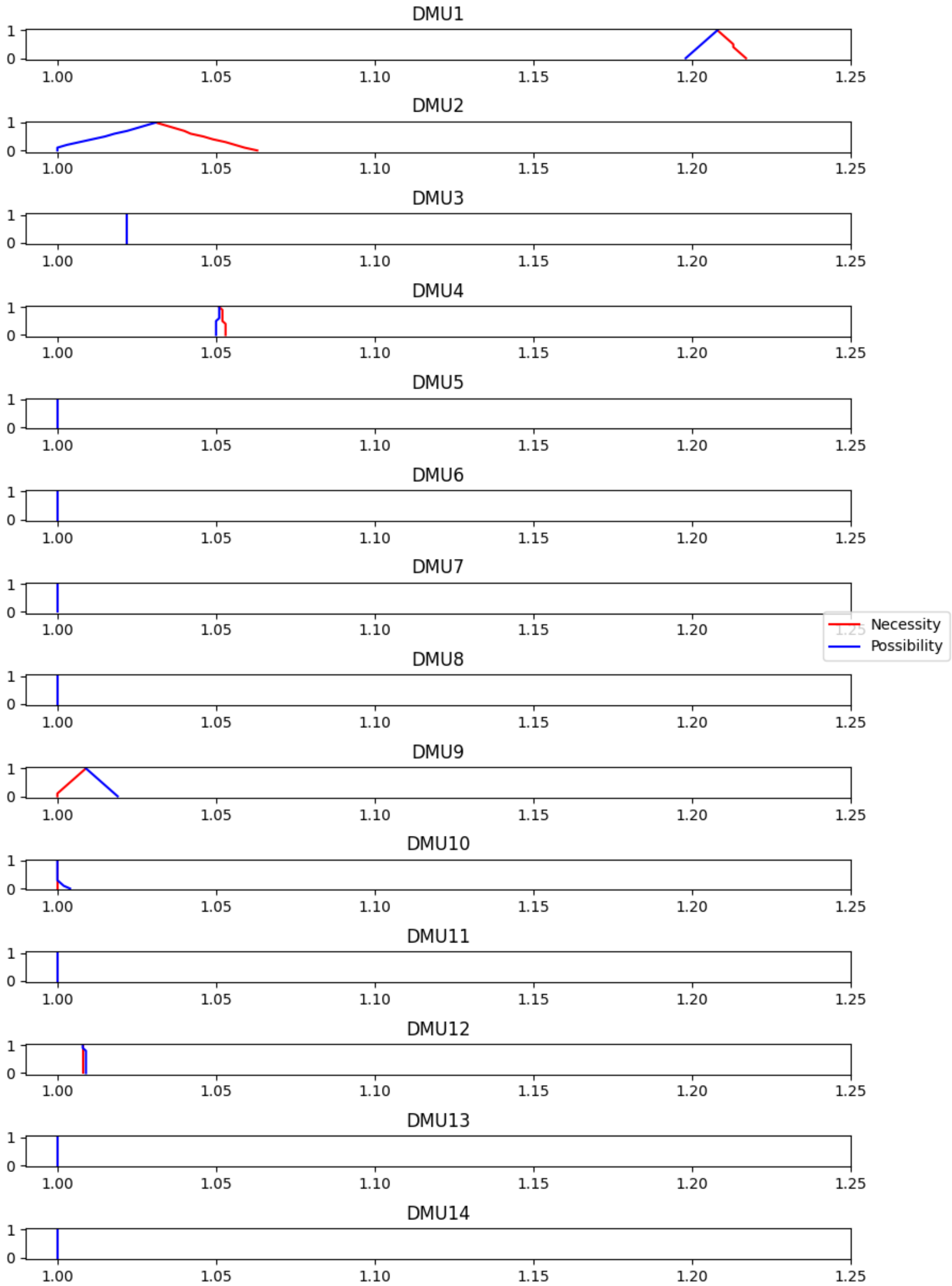

Figure 1 Plot of calculated efficiencies for all ε levels.

DMU	(O) 1	(O) 2	eff	Δ (O) 1	Δ (O) 2	Δ% (O) 1	Δ% (O) 2	(O) 1 ideal	(O) 2 ideal
DMU1	2160	15000	1.20	+309	+3046	20.3%	20.3%	2469	18046
DMU2	3680	15000	1.01	+44	+1906	1.46%	12.71%	3724	16906
DMU3	1400	15000	1.02	+722	+330	94.98%	2.2%	2122	15330
DMU4	2160	15000	1.05	+77	+756	5.04%	5.04%	2237	15756
DMU5	3680	15000	1.00	+0	+0	0.0%	0.0%	3680	15000
DMU6	1400	15000	1.00	+0	+0	0.0%	0.0%	1400	15000
DMU7	2020	13500	1.00	+0	+0	0.0%	0.0%	2020	13500
DMU8	2020	13500	1.00	+0	+0	0.0%	0.0%	2020	13500
DMU9	2220	12500	1.01	+22	+171	1.37%	1.37%	2242	12671
DMU10	2220	12500	1.00	+0	+0	0.0%	0.0%	2220	12500
DMU11	2320	13000	1.00	+200	+0	11.9%	0.0%	2520	13000
DMU12	2320	13000	1.01	+15	+113	0.87%	0.87%	2335	13113
DMU13	2520	13000	1.00	+0	+0	0.0%	0.0%	2520	13000
DMU14	2520	13000	1.00	+0	+0	0.0%	0.0%	2520	13000

Table 4 Recommendations for $\varepsilon = 0.5$, possibility (optimistic).

DMU	(O) 1	(O) 2	eff	Δ (O) 1	Δ (O) 2	Δ% (O) 1	Δ% (O) 2	(O) 1 ideal	(O) 2 ideal
DMU1	1520	15000	1.21	+459	+3188	21.25%	21.25%	1979	18188
DMU2	3040	15000	1.05	+168	+2527	4.56%	16.85%	3208	17527
DMU3	760	15000	1.02	+795	+330	56.78%	2.2%	1555	15330
DMU4	1520	15000	1.05	+113	+786	5.24%	5.24%	1633	15786
DMU5	3040	15000	1.00	+0	+0	0.0%	0.0%	3040	15000
DMU6	760	15000	1.00	+0	+0	0.0%	0.0%	760	15000
DMU7	1380	13500	1.00	+0	+0	0.0%	0.0%	1380	13500
DMU8	1380	13500	1.00	+0	+0	0.0%	0.0%	1380	13500
DMU9	1580	12500	1.00	+8	+46	0.37%	0.37%	1588	12546
DMU10	1580	12500	1.00	+0	+0	0.0%	0.0%	1580	12500
DMU11	1680	13000	1.00	+200	+0	8.62%	0.0%	1880	13000
DMU12	1680	13000	1.01	+19	+106	0.81%	0.81%	1699	13106
DMU13	1880	13000	1.00	+0	+0	0.0%	0.0%	1880	13000
DMU14	1880	13000	1.00	+0	+0	0.0%	0.0%	1880	13000

Table 5 Recommendations for $\varepsilon = 0.5$, necessity (pessimistic).

to elicit just one or two alpha levels for either necessity or possibility, depending on the risk aversion/confidence. For example, consider a model situation where a decision has been made to include just $\varepsilon = 0.5$ possibility measure. The result then collapses into a comprehensive table similar to the one including just a crisp solution. We then recommend that future endeavors be focused on the problematics of determining the appropriate alpha level.

By implementing the previously mentioned CCR crisp and modified method, we came to the conclusion that in this case the fuzzification of one output variable has no effect on the efficiency/inefficiency of the investigated units. We've got the same amount of the same DMUs marked as an efficient and inefficient in all 3 cases. Assessments of those units were as well very identical.

Furthermore, using standard deviation for fuzzification in DEA can be problematic when the data has extreme outliers. Standard deviation assumes that data is normally distributed, which may not be the case when there are outliers. Extreme outliers can skew the mean and standard deviation, leading to inaccurate fuzzification. In future research, methods, such as using trimmed means or interquartile ranges, could be considered an alternative.

5 Conclusion

In this paper we analyzed the efficiency evaluation of individual 14 DMUs and we compared the efficiencies using two different models, which are DEA CCR crisp model and possibilistic CCR model with one output fuzzified. Both of these models were output-oriented models. The analysis was therefore focused primarily on the comparison of the use of CCR-O models and the obtained efficiency results. The CCR-O crisp model was previously created and interpreted in a previous work of one of these authors (Bordacsova, 2023). In this paper, the given model was modified by fuzzifying one output variable. However, the fuzzification of the given input did not bring any change in the evaluation of the DMUs efficiencies and non-efficiencies. In conclusion, it could be said that no new results to ease the decision-making were gained even if the different model was chosen.

For future work, we were promised to expand the data by at least 3 more decision-making units, which could result in a better evaluation of the assessed units. We would also like to apply other different DEA models to see what works the best for this and find the most suitable one to deal with this problem.

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Implementation of Industry 4.0 in Continuous Production

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Abstract. The aim of this contribution is to analyze the possibilities of applying Industry 4.0 concepts and technologies in continuous production. Since Industry 4.0 was designed primarily for discrete production, characterized by a high degree of automation and robotization, the application of these procedures in continuous production (as raw materials industry or metallurgy) is slower and limited. Possible areas of application the Industry 4.0 approaches in continuous production are presented on case studies from the raw materials industry.

Keywords: Industry 4.0, MES, continuous production, coal preparation plant control system, coal sales management, RFID.

JEL Classification: O3, L6, L86

1 Introduction

Development of a versatile and general MES (Manufacturing Execution System) system that could be implemented into any business and type of production is not advisable. This is due to the different nature of technological processes, different management practices and often specific topology of technologies. Nevertheless, we can define the basic categorization of MES systems according three fundamentally different types of production: discrete, batch and continuous. MES system for each type of production solves specific problems. For example, in discrete production the crucial activities are planning of operations, management of product lifecycle, product identification or diagnostics of defective pieces (Meyer, 2009).

To create a well-designed MES system, the understanding of the nature of the processes and technologies controlled is fundamental. It is also essential that the design and implementation of MES systems is not only a matter of managing IT technologies. A development of information system for production control is always an interdisciplinary discipline. The design of its architecture is influenced by the technology used, topology of equipment, control method, method of evaluation of quality, as well as the nature of business processes.

The concept of Industry 4.0, presented for the first time more than 10 years ago in Germany, was defined mainly for the needs of engineering production and automotive industry. In continuous production, new IT technologies are applied with some delay, this type of industry is characterized by a more conservative approach. Nevertheless, even continuous production cannot avoid changes and the implementation of Industry 4.0 principles.

The aim of this article is to describe possible applications of Industry 4.0 concepts for control systems in continuous production.

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2 State of Art and Literature Review

In the past, the authors of this work participated in the analysis and development of information systems for the management of coal preparation plants. A search of available resources of Industry 4.0 concepts and implementation was carried out. Another source of information was the preparation for teaching the subject "Innovation for Industry 4.0 and Smart Industry" at VŠTE in České Budějovice and experience within several research projects.

Banerjee (2013) describes basics benefits of MES systems. Deployment of MES systems for continuous production have the following substantial benefits:

- Higher awareness and more objective decision-making of executive staff
- Higher technological discipline of the production process
- Higher proceeds – optimum raw material utilization
- Ensured observance of quality parameters
- Energy savings – e.g., by registration of machines idling
- Increased hourly capacities, reduced operating time of the preparation plant
- Monitoring of quality during production in real-time

The complexity of continuous production is that a single fault can degrade production extensively and even cause process disruption. The paper (Chacón et al, 2021) proposes the Holonic Production Unit (HPU) architecture as a solution to control continuous production processes. An HPU is created as a holon unit depicting resources in a continuous process. This unit can detect events within the environment, evaluate several courses of action, and change the parameters aligned to a mission.

Since continuous production is typical for the raw materials industry, waste management will also be a key success factor in the near future (Matušková et al., 2021). Sufficient information support will be required for this area.

Critical success factors of implementation Industry 4.0 are analyzed in (Pozzi and Secchi, 2021). Authors compared incremental/evolutionary and radical/revolutionary improvements approach. Innovation is mentioned as a revolutionary modification to an existing business model. The goal of adoption Industry 4.0 technologies is a realization of a cyber system in which all elements are connected and digitalized. As critical factors of implementation are mentioned the role of top management, project plan, team structure and training.

The exploitation of emerging Industry 4.0 technologies in the pharmaceutical industry describes (Ntamo et al, 2022). Paper presents integrated digital architecture using Siemens cloud service called MindSphere[3]. MindSphere is an open operating system and cloud solution for the Industrial Internet of Things, which is used to connect various devices to the cloud and collect data in real time.

Khademolqorani (2022) presents the data mining in steel company utilized to predict the possible required stoppages and their duration. The real production time of order was obtained through the improved time series classification model based on fuzzy support vector machine

[3] https://siemens.mindsphere.io/en

and genetic algorithm (by RapidMiner software). In the suggested model, the data mining process was first applied to analyze the stop points and then a method was utilized to minimize the stoppage times (a machine learning-based method for prediction).

Industry 4.0 in area of continuous production is linked with logistics. Overview about new challenges in logistic domain presents (Barreto, Amaral and Pereira, 2017). Logistics 4.0 paradigm can be summarized as the optimization of inbound and outbound logistics which must be supported by intelligent systems, embedded in software and databases from which relevant information is provided and shared though Internet of Things systems, in order to achieve a major automation degree.

3 Industry 4.0 concept in continuous production

Continuous production is different from discrete or batch production. A typical example of such a production is the raw material industry (mining), metallurgy or chemical production. In most cases, the identification of products and parts typical for engineering production is completely absent. Continuous quality control in real time and the provision of fault-tolerant solutions for control systems are essential. Continuous monitoring of technological processes is important, which produces a significant volume of data that is subsequently used in the information system for calculating balances, trends and forecast.

Based on the conducted research is possible formulate following trends in the application of Industry 4.0 concepts in continuous production control:

- Data processing in cloud
- Close loop between Simulation of production, APS (Advance Planning System) and MES
- Manufacturing analysis by networking the machines, sensors and software that enables prediction of production results
- Adaptation to the individual market requirements
- Lowering energy use
- Needed for high-speed connectivity (e.g. 5G)
- Big data processing
- IoT data collection
- Usage of expert systems or artificial intelligence for evaluating technological situations and alarms and providing assistance to dispatchers

Problems with implementation of Industry 4.0 technologies:

- Lack of standards (the existence of standards is an essential condition for the implementation of technologies from different manufacturers)
- New business models are required (news skills for managers)
- Cyber-security
- Workers’ compatibility with new technologies (new skills)
- Upgrading the existing machines and systems

4 Case Study: Coal Preparation Plant Control System

As an example of MES for continuous production an information system for coal preparation plant management is given. Such a system includes support for control at all control levels. At the process control level, it includes a direct control of technologies or devices and control of particular processes like sorting, treatment or drainage. The dispatcher control level is focused at control of the technology nodes, monitoring of technological processes, control of quality parameters of coal and the coal expedition management. On the managerial control level there is solved planning, sales management, production balance and presentation of data for the executive.

In the coal industry and coal preparation plants, control systems have evolved from centralized control systems based on mainframes with the VMS[4] operating system (1990s) to current standardized solutions focused on SCADA (Supervisory Control and Data Acquisition) systems (mainly SCADA system Promotic[5]) and data processing via relational databases. In the Czech Republic, the leader in control systems for coal processing plants is ATP Soukup Ltd (Danel, 2009). The most important task in the management of coal processing plants is to maintain the required quality of output products according to customer requirements. This requires monitoring of quality parameters during production and their processing in real time in the information system (Danel, 2017). Since 2003 coal preparation plant information systems from individual plants have been linked with central sales information system of OKD (coal mining company, the only Czech producer of black coal) and theirs SAP[6] R/3 ERP system[7]. In the last ten years, there has been a slowdown in the mining of hard coal, and it was assumed that mining would end completely in 2023. For this reason, the demand for the application of the latest technologies has decreased. However, in connection with the current energy crisis, plans to stop mining have been revised and are currently expected to be extended by at least two years. The coal preparation plant can also function even after the end of mining, when waste from the past, allocated in sludge ponds, will be further processed.

In the field of controlling the technological processes of the coal preparation plant, we can identify the following areas of application of advanced technologies:

- Utilization of neural networks for control support
- 3D visualization of technological processes for the purpose of learning - can be used for dispatcher training
- Utilization of the virtual reality for control of technological processes - it can be used to simulate and train dispatchers to respond to accidents and technological problems
- Utilization of RFID (Radio Frequency Identification) for the identification of materials, machines, products, and support for logistic processes
- Utilization of distributed databases for advanced data analytics

[4] VMS (Virtual Memory System) is a mainframe operating system provided by Digital company (nowadays part of a Hewlett Packard company). The VMS was popular since 1970s to 1990s.
[5] SCADA Promotic is developed by Microsys s.r.o., company located in Ostrava, the Czech Republic
[6] SAP R/3 is a name of ERP system produced by German company SAP. Nowadays it is a leader at ERP system market
[7] ERP (Enterprise Resource Planning) is a type of company information systém focused on company management and economic issues

4.1 Neural networks in dispatching control

Ten years ago, VŠB - TU of Ostrava started working on an expert system for coal preparation plant dispatching based on the use of neural networks (Řepka, Danel and Neustupa, 2013). The system with a neural network were connected to the existing information systems of coal preparation plants operated in OKD and analyzed alarm data, data from SCADA systems monitoring the progress of technological processes and data about activities of dispatchers (theirs's reaction to alarms). Multilayer neural networks can be used in applications where the control is non-deterministic. The neural network was designed to learn from dispatchers' responses to alarms. Back propagation algorithm has been used. Subsequently, when technological problems arise, the neural network can provides dispatchers with recommendations for interventions based on recorded interventions in the past. So the intelligent control system will continuously adapt to the operator's requirements and the longer it will be in operation, the better it will be able to react to the situations that occur. The project of using a neural network to support dispatchers is still in the state of testing on test data and has not yet been put into operation.

4.2 Virtual reality in monitoring and control of technological processes

The use of virtual reality for monitoring and controlling the technological processes of the preparation plant has also been addressed in the past (for example, at VŠB has been solved grant GA105/09/1366 leaded by associate professor Vladimír Kebo). Use of virtual reality in the control of technological processes has an advantage particularly in situations where such operations and technologies are controlled that are dangerous or inaccessible or in situations where direct human participation should be eliminated. At the managerial control level, one of the possible applications of virtual reality is presentation of the preparation plant as a whole, allowing a global view of the process state, with an emphasis on strategic information such as the current quality parameters of coal in the loading in progress. The virtual scene presents the amount of raw material in the bins, the amount of raw material on the conveyor belt (hourly capacity) and also the amount of coal processed in individual technologies with a simultaneous presentation of quality parameters (ash and water content, calorific value).

4.3 RFID technology in raw industry

RFID technologies are commonly used in industry to identify products. Vestenický at al (2017) gives overview of methods for locating RFID markers. In continuous production, however, the result is usually not a particular product, but a certain volume of raw materials. RFID tags can be used in the raw materials industry to control the flow of material on conveyors belt. The RFID laboratory at the Faculty of Mining and Geology conducted studies on the possible use of RFID tags, which would be added to the mined raw material during the processing of hard coal. Such a tag would contain data on the quality of mined coal (known on the basis of analyzes from geological probes) in the form of an identifier corresponding to the given workings from which the coal was mined. In the coal preparation plant, the origin of the coal can be unambiguously identified by using RFID gates and then selectively sorted into storage bins. Avoiding the mixing of coal of different quality during transport to the storage bins significantly increase the efficiency of the coal processing and make it possible to achieve the quality required in contracts with customers at lower costs. The cost of one RFID gate including the antenna is around 50,000 CZK, the prices of RFID tags are in crowns for the standard design and tens of crowns for the special cover with protection against damage.

4.4 Databases and data analytics

The last, but very important area of use of new technologies is data analysis. The existing information systems used in OKD were implemented with standard software tools and relational databases for data storage.

A technology that can be definitely used in the control of technological processes is big data. The average control system of a preparation plant contains around two thousand sensors, of which around 300 to 400 are analog. The analog sensors are sampled with a relatively short sampling period (on the order of seconds) and produce a huge amount of data. Another source of a larger data volume are alarms - recorded events from the technological processes, which can be further used for dispatch control or retrospective analysis of these processes. In the information system of the coal preparation plant Darkov (implemented in 2006; coal mine in Karvina region operated by OKD company) 10 million records were collected in the alarm table over three years. Any advanced data analyses have been missed in this system.

One possible solution for more efficient work with operational data generated from sensors in continuous processes is the use of a NoSQL database[8]. This would make it possible to distribute data from the above-mentioned alarm tables, which now contain data from all workplaces of the preparation plant. In a distributed database, each dispatching center would contain a data node with data related to a given workplace, but it would still be possible to enter complex queries over all workplaces.

On the one hand, using relational databases led to the creation of tables with extensive data sets in the order of tens of millions of rows, on the other hand, isolated database systems were created, between which shared data have to be transferred.

This is probably most visible with the sales management system for OKD, which was developed twenty years ago. Local sales management systems are implemented at individual coal preparation plants (since 1990s), dealing with operational management (mainly loading and shipping). These systems already give management support for production quality control in accordance with ISO 9001 (Kozel et al, 2017). Later, a complex sales control system was created (2001-2005 by ATP Soukup Ltd), which centralizes data from local control systems, from the branches of the transport companies and is subsequently connected to the central ERP system (in the case of OKD SAP R/3). Unfortunately, the system was not linked to the geological probes database, which contain information on the expected quality of coal from the coal seam months in advance. Connections with the systems of cargo carriers (now AWT or ČD CARGO) and connections with the information systems of large customers (which is especially desirable in the case of coke plants) are also proposed. Such interconnected systems would enable advanced data analytics that could significantly optimize synergies between mining, coal processing, transportation and business operations.

[8] NoSQL is an acronym for database model that, comparing with a relational model, has no schema and allows easily partitioning (distribution of data to several nodes)

However, practical implementation at OKD is limited by the perspective of mining and it is not very likely that investments would be made in the development of proposed complex system. It is also not even realistic to consider the application of the system in other countries, as the proposed solution reflects specific conditions in the Czech Republic (mining of two groups of coal differing in quality, topology of preparation plants, separation technology used...).

5 Conclusion

Advanced information technology is entering the raw materials industry and continuous manufacturing with some delay. This is due to the nature of technological processes, which are not as massively robotized as engineering production or the automotive industry. Even this industry cannot ignore the latest trends and concepts, otherwise it will cease to be competitive and economically inefficient. Also important is the environmental impact of the raw material industry, which in the past created considerable ecological damage, which is no longer legally possible today. There is therefore considerable scope for innovation.

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ICT Professionals in the Czech Business Before and During Pandemic Era

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Abstract. The Covid-19 pandemic had an impact on various sectors of the economy, including on ICT professions. The aim of the article is to analyze the trend in gross nominal wages/salaries of people working in information and communication technologies – ICT Professionals (ICT Managers, ICT Specialists and ICT Technicians) before and during the pandemic. Another goal was to analyze the trend in the Gender Pay Gap during the same time periods. For our analysis, we used data for the Czech Republic compiled by Trexima, a.s. in 2017-2021. The results show that nominal wages/salaries of ICT employees grew throughout the analyzed period; the pandemic only slowed down the dynamics of this growth. In the case of the Gender Pay Gap indicator, we demonstrated its permanent drop for the group of ICT Managers. As to the other two groups of professions, the Gender Pay Gap indicator kept decreasing before the pandemic, but increased marginally (up to one percentage point) during the pandemic, both in terms of average and median wage.

Keywords: ICT Professionals, ICT Specialists, ICT Technicians, Gender Pay Gap, gross nominal wage.

JEL Classification: C82, E24, E64, J16, L86

1 Introduction

Next to workers in the healthcare sector and in the financial sector, ICT Professionals belong to one of the best paid professions in the economies of developed countries (U. S. Bureau of Labor Statistics, 2022). The importance of these professions was highlighted to a great extent by the Covid-19 pandemic, where working from home became widespread and the performance of many professions moved from the real world to the virtual world and there was in particular a major expansion of online stores. As a typical example, we can mention education, financial services, shopping, including grocery shopping, etc., whose share in online shopping increased significantly during the Covid-19 pandemic (quotation). For example, the Czech Rohlík Group.

The impact of the Covid-19 pandemic on some activities was in fact crucial. As mentioned in Tverdostup's elaboration (2022). *"Childcare and home-schooling responsibilities were disproportionately allocated among parents, with women taking a leading role."* Other more detailed aspects can be found, for example, in the elaborations (Chung et al., 2021; Blundell et al., 2020; Özkazanç-Pan and Pullen, 2020; Manzo and Minello, 2020). The situation in Hungary is analyzed in detail in (Fodor et al., 2020). Based on this, we wondered to what extent the Gender Pay Gap among Czech ICT Specialists had changed, if at all.

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2 Problem Formulation

The impact of the Covid-19 pandemic on ICT Professionals in the Czech economy was significant, especially in the first spring wave of the pandemic in 2020, where the economy was shut down and most work took place online, if at all. As part of our ongoing research concerning ICT and the wages of ICT Professionals, we followed up on our research from 2020 (Nedomova and Doucek, 2021) and focused on the trend in the wages of ICT Professionals during the pandemic - RQ1. Our workplace also constantly pays attention to the trend in the Gender Pay Gap not only in the Czech economy, but also among ICT Professionals - RQ2. We combined these two areas of our interest in the article presented here.

- RQ1: What was the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021)?
- RQ2: Did the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021) change the Gender Pay Gap?

3 Methodology and Data Collection

First, we had to define the categories of ICT Professionals in Business. Then we had to obtain information about their wages/salaries in the Czech economy. And finally, we had to process data.

3.1 Categories of ICT Professional in Business

The international standard classification of occupations (ISCO, i.e. CZ-ISCO) has been used for the purposes of statistical employment surveys in the Czech Republic since 2011. According to this methodology, job positions in the field of ICT - ICT Professionals are divided into three main groups of professions (CZSO, 2017). These are in particular: CT Managers (CZ_ISCO 133), ICT Specialists (CZ_ISCO 25) and ICT Technicians (CZ_ISCO 35). Descriptions and job descriptions of individual groups of ICT Professionals are available at (CZSO, 2017).

3.2 Data Collection

The data we used for our analysis were collected by Trexima, a.s. as part of the processing of the so-called sample group of the Average Earnings Information System - AEIS (ISPV, 2022). The survey is harmonized with the structural survey of the European Union under the name "The Structure of Earnings Survey," which is promulgated by Commission Regulation no. 1916/2000. The group contains data on earnings in the second quarter of each year, since the second quarter of each year has the highest available working time pool, contains the least number of holidays, and earnings most closely correspond to basic salaries or wages. This annual survey is conducted under the auspices of the Ministry of Labor and Social Affairs.

3.3 Used Methodology

We analyzed the data obtained from the AEIS (ISPV, 2022) by ICT profession, i.e. separately for ICT Managers, ICT Specialists and ICT Technicians.

Basis for answering RQ1. When analyzing the trend in the wages/salaries of ICT Professionals, we came across a significant difference between wages/salaries in the business and non-business sectors. We did not focus on this difference in our article mainly due to its limited scope. Gender, i.e. a difference between men's and women's wages/salaries, was another aspect of ICT wages that we analyzed. **Basis for answering RQ2.**

The analyzed data are shown in the gross nominal wage/salary in Czech Crowns. In addition to average wages/salaries, we also focused on their median. The reason for using the median is that it reflects better actual wages/salaries in the population, as the average can be influenced by a relatively small number of high wages (this applies especially to the ICT Managers category). Another limitation of the dataset is that it includes wages up to 100,000 CZK. If the monthly income is higher than this amount, it is not included in a higher income category. Considering inflation and overall salary growth, this fact should be taken into account in the future and another income category should be added. We analyzed the obtained data using MS Excel tools and statistical functions. Some research outputs were programmed in the R programming environment. We used the linear regression method to determine trends. To compare and evaluate trends, we used the regression line coefficient in the figure and tables.

4 Results

The presented results are divided into two main blocks based on the research questions. The Czech economy employs approximately 194,000 ICT Professionals. Our research sample includes approximately 35% of all workers employed in ICT professions in the Czech economy. In 2020, the individual professions are represented as follows:

- ICT Specialists: 44% out of 106,100 employees
- ICT Technicians: 31% out of 74,900 employees
- ICZ Managers: 29% out of 13,000 employees.

We can see that ICT Specialists with the largest absolute number of employees have the most frequent representation. This group includes analysts, developers and database and network specialists, who by their very nature are a key part and a condition for the functioning of all projects that are managed by ICT Managers and ICT Technicians.

4.1 Identified trends in wages

This part of our article provides an answer to the following RQ1: What was the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021)?

The following Figure 1 and Figure 2 show the trend in wages before and during the Covid-19 pandemic. Both figures clearly show that ICT Managers had the highest wages, ICT Specialists the second highest wages and ICT Technicians the lowest wages.

Figure 1 shows a positive trend in the development of gross wages. Average gross nominal wages went up during the entire analyzed period. The wages of ICT Managers grew the fastest, followed by the wages of ICT Specialists, whereas the wages of ICT Technicians show the slowest growth.

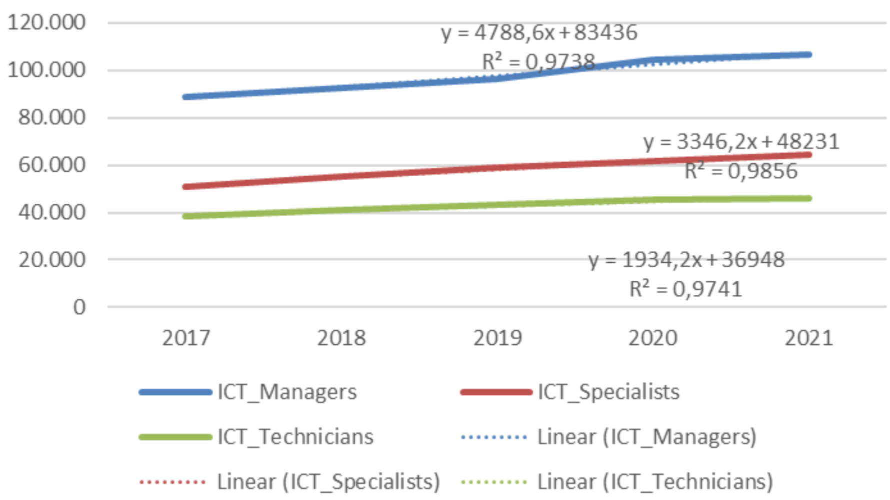

Figure 1 Trend in average wages during the entire analyzed period

Another interesting finding is that average wages are higher than median wages. This means that especially a relatively high number of ICT Managers receive wages that are significantly higher than the median.

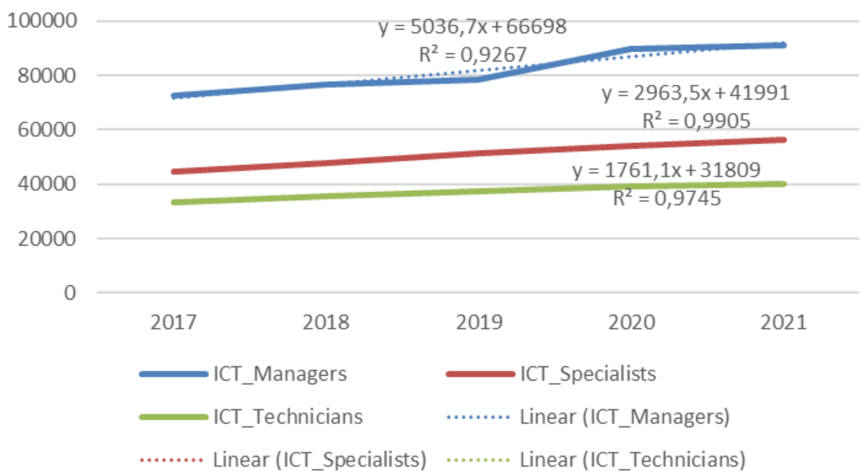

Figure 2 Trend in median wages during the entire analyzed period

The trend in median wages was very similar. Median wages increased throughout the entire period in the following order: ICT Managers, ICT Specialists and ICT Technicians. A very interesting moment is between 2019 and 2020, especially in the case of ICT Managers. The step-increase (Figure 2) means that there was a blanket increase in wages for the entire sample. Average wages went up as well, but not as high as median wages.

Profession	**2017-2019**		**2020-2021**	
	Avg	**Med**	**Avg**	**Med**
ICT Managers	3896,5	2991,9	2228,0	1538,6
ICT Specialists	4063,7	3489,1	2394,6	2395,8
ICT Technicians	2345,8	2211,6	825,1	911,39

Table 1 Coefficients of linear regression functions for professions in different periods

When looking in more detail at the individual periods before and during the Covid-19 pandemic, we can see from Table 1 that wage growth decreased significantly during the pandemic, both the calculated average and median of the analyzed sample. But it is still growth. The wages of ICT Specialists show the smallest growth decrease during the Covid-19 pandemic, which may indicate an increase in the need for consulting services or an increase in internal projects. The average wages of ICT Technicians almost stopped growing during the Covid-19 pandemic.

4.2 The trend in the Gender Pay Gap

This part of the article provides an answer to our second research question. RQ2: Did the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021) change the Gender Pay Gap?

Looking at Figure 3 and Figure 4, we can clearly see that ICT Managers (Figure 3) show the biggest Gender Pay Gap – it was 36.76% at the beginning of the analyzed period and 24.30% at the end of the analyzed period, which is a drop by 12.46 percentage points. However, this is still a very high Gender Pay Gap compared to the European average, which has been at approximately 14.1% during the last decade (European Commission, 2022). The Gender Pay Gap in the case of ICT Specialists decreased by 2.19 percentage points and in the case of ICT Technicians group by only 1.51 percentage points.

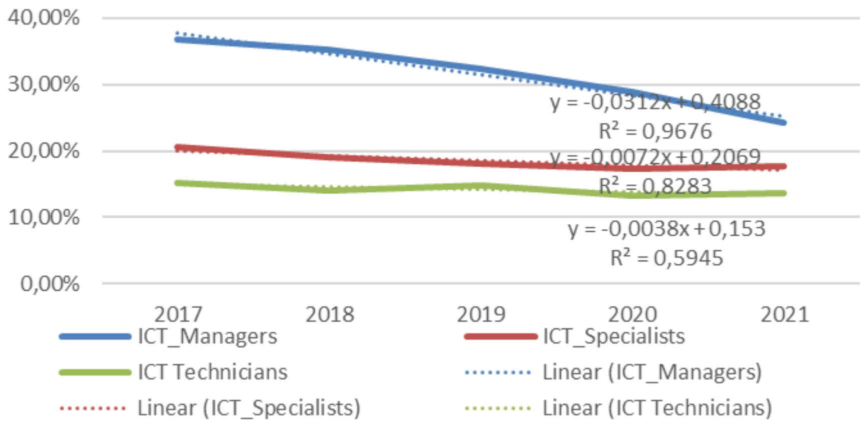

Figure 3 Trend in the gender pay gap - average wages for the entire analyzed period

This means that women's wages in the ICT Manager group increased, especially in the higher income categories. The Gender Pay Gap in the case of other professions in the ICT industry remained virtually the same.

Figure 4 shows a very similar trend in the median. ICT Managers show a drop by 8.29 percentage points to 28.39%, ICT Specialists a drop by 1.85 percentage points to 19.43% and ICT Technicians a drop by 2.35 percentage points to 10.96%.

The ICT Manager group shows a very interesting thing in 2020 - an increase in the Gender Pay Gap with the onset of the Covid-19 pandemic. This leads us to the conclusion that there was a step-increase in the wages of men in the best-paid positions of ICT Managers. The situation was similar in the case of ICT Technicians in 2019, i.e. before the onset of the Covid-19 pandemic, where the Gender Pay Gap increased by 1.28 percentage points.

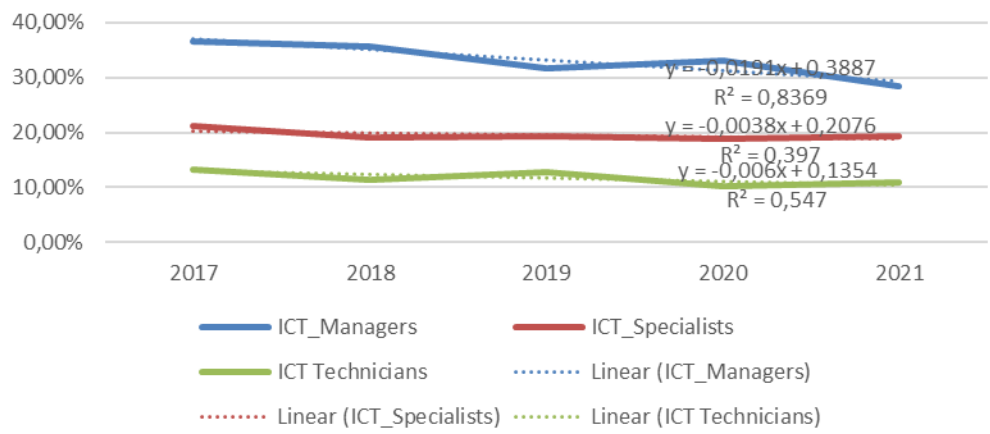

Figure 4 Trend in the gender pay gap - median wages for the entire analyzed period

Profession	2017-2019		2020-2021	
	Avg	**Med**	**Avg**	**Med**
ICT Managers	-0,0218	-0,0244	-0,0461	-0,0482
ICT Specialists	-0,0117	-0,0094	0,032	0,0055
ICT Technicians	-0,0017	-0,0027	0,0032	0,0076

Table 2 Coefficients of linear regression functions for the Gender Pay Gap of different ICT professions

A partial view of the period before and during the Covid-19 pandemic is quite neutral. The biggest Gender Pay Gap, i.e. the gap in the ICT Manager group, is shrinking more even during the Covid-19 pandemic, and even faster than before the pandemic. In the case of ICT Specialists and ICT Technicians, the positive trend in the Gender Pay Gap stopped and the Gender Pay Gap even slightly increased – in the case of ICT Specialists by 0.55 percentage point and in the case of ICT Technicians by 0.77 percentage point with respect to median wages/salaries.

5 Conclusions and Discussion

For our analyses concerning the 2017-2021 period, we had a sample of data on wages/salaries of ICT Professionals, which included a total of 59,132 records in 2017 and a total of 73,701 records in 2021. This sample represented approximately 35% of all employees working as ICT Professionals in the Czech economy. Therefore, our findings can be considered conclusive. The data we processed are limited by the fact that the wage/salary categories end at CZK 100,000.

To answer our research questions, we came to the following conclusions:

RQ1: What was the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021)?

Answer: The overall trend in gross nominal wages, both in terms of average and median, during the entire analyzed period was positive – i.e. wages grew (Figure 1). The same conclusion applies to the individual sub-periods, i.e. wages grew, but the growth dynamics decreased year-on-year during the pandemic.

An interesting situation is the increase in average and median nominal wages/salaries, but this trend is not supported by GDP growth in the analyzed period, especially between 2019 and 2020. Table 3 shows a comparison of GDP changes in individual selected years and the increase in the wages/salaries of ICT Professionals. Growth in the second year of the Covid-19 pandemic started to follow the Czech Republic's GDP growth rate.

Year/Category	Annual Δ HDP in %	Annual Δ Wages %	
		Avg	**Med**
2019	2,4	6,63	6,65
2020	-5,6	20,31	10,70
2021	3,3	3,20	3,81

Table 3 Comparison of the year-on-year change in wages/salaries and GDP in percentages (CZSO, 2022)

RQ2: Did the trend in average gross nominal wages (median wage) of ICT Professionals before the Covid-19 pandemic (2017-2019) and during the Covid-19 pandemic (2020-2021) change the Gender Pay Gap?

Answer: The permanent increase in wages before the Covid-19 pandemic reduced the Gender Pay Gap among ICT Professionals in the Czech Republic, both in terms of average and median wages. The greatest reduction was achieved in the ICT Manager group, a lower reduction in the ICT Specialist group and the lowest reduction in the ICT Technician group. The trend in the Gender Pay Gap during the Covid-19 pandemic was different. There was a decrease in the Gender Pay Gap in the ICT Manager group, both in the terms of average wages (a decrease by 4.61 percentage points) and median wages (a decrease by 4.82 percentage points). This fact points to the decrease in the Gender Pay Gap in the highest income groups of ICT Managers. The trend in the Gender Pay Gap is completely different in the ICT Specialist group and the ICT Technician group. The Gender Pay Gap in both groups increased during the Covid-19 pandemic, although not dramatically. In the case of ICT Specialists, the Gender Pay Gap increased by 0.32 percentage points for average wages and by 0.55 percentage points for median wages. In the case of ICT Technicians, the Gender Pay Gap increased by 0.32 percentage points for average wages and by 0.76 points for median wages. These figures indicate a very slight increase in the wages/salaries of men in these professions compared to the wages/salaries of women, especially in lower income professions.

Even this Gender Pay Gap in the ICT Professional group is very high compared to other European countries (around 20% in the CR (du Parc, 2020) 14.1% in EU Member States). Other factors, which we analyzed in another research, play a significant role in the trend in the Gender Pay Gap. These factors include e.g. an employee's age, where the Gender Pay Gap is significantly lower, sometimes even negative, in the case of newly hired female employees, and the type of sector, where the Gender Pay Gap is much lower in the public sector than in the private sector (Nedomova, Maryska and Doucek, 2017).

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Strategic customer behavior in revenue management systems

Petr Fiala[1], Renata Majovská [2]

Abstract. Revenue management is the art and science of predicting customer demand in real time and optimizing the price and availability of products according to demand. What is new in revenue management is not the demand management decisions themselves, but rather the way in which these decisions are made. The real innovation in revenue management lies in the way decisions and information systems are made. Revenue management systems collect information and make decisions based on it, using modelling of ongoing processes. A significant opportunity is in modelling approaches. Conventional modelling approaches assume that customers are passive and not involved in any decision-making processes. This simplification is often unrealistic for many practical problems. In response, there has been interest in incorporating strategic customer behavior in recent years. This paper presents network management models with consumer demand for multiple products and intertemporal substitutions. The models are based on linear programming approximations with Data Envelopment Analysis methods.

Keywords: revenue management systems, strategic customer, modeling, discrete choice, substitution.

JEL Classification: M00, C44

1 Introduction

Revenue management (RM) is the art and science of forecasting customer demand in real time and optimizing price and product availability in response to demand. RM is the process of understanding, predicting, and influencing customer behavior in order to maximize revenue or profits from fixed, ephemeral resources (see Fiala, 2015). Revenue management has seen great success in recent years, especially in the airline, hotel and car rental industries. Nowadays, more and more industries are exploring the possibility of adopting similar concepts. What is new about revenue management is not the demand management decisions themselves, but rather the way these decisions are made and the information systems. Revenue management systems gather information and make decisions based on that information using modeling of ongoing processes. The real innovation in revenue management lies in the way decisions are made. Many appropriate methods have been proposed for specific problems (see Talluri and van Ryzin, 2004a).

Multi-source, quantity-based revenue management is referred to as network revenue management. This class of problems is found, for example, in the management of airlines, hotels and railways. In the case of airlines, it involves managing the capacity of a set of connecting flights within a network, the hub-and-spoke network. In the case of a hotel, it is the management of room capacity on consecutive days when customers stay for multiple nights.

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Revenue management models in a network seek to maximize revenue when customers purchase multiple resource packages. The dependency between resources in such cases is created by customer demand.

An important limitation of the applicability of classical models is the assumption of independent demand. In response, there has been interest in recent years in incorporating customer choice into these models, further increasing their complexity. Revenue management has paid increasing attention to modelling individual customer behavior. Today's customers are actively evaluating alternatives and making choices. Revenue management is paying increasing attention to modelling individual customer behavior. Strategic customer behavior is being analyzed. An approach to modeling strategic customer behavior is proposed.

Approaches to strategic customer behavior in revenue management can be divided into two groups:

- consumer demand for more products,
- inter-temporal substitutions.

The first group of approaches studies customer choice in managing returns from multiple products environment. It focuses on how customers decide which product to buy. A common approach is to use discrete choice models to capture consumer demand for multiple products. Substitution and complementarity effects for multiple products. The second group examines the effect of inter-temporal substitution by customers. Customers may decide when to buy a particular product in response to dynamic pricing practices of the seller. Customers may decide to wait for price reductions. Other relevant issues include capacity allocations, pricing uncertainty, and consumer learning effects. These types of behavior mean that the dynamics of customer demand depend directly on the seller's dynamic pricing. This dependence is not captured in conventional models with exogenous demand arrival processes.

In the literature are formulated some specific models, methods and application areas of choice-based problems. The article (Strauss, 2018) provides a review of theory and methods of choice-based revenue management. The dissertation (Cao, 2020) consists of three studies on choice-based revenue management.in real-world business transportation settings. Formulation of buying a bundle of tickets for two or more events following the choice-based network revenue management approach is presented by (Baldin, 2017).

The paper presents models of network control with consumer demand for multiple products and intertemporal substitutions. The models are based on linear programming approximations with Data Envelopment Analysis methods.

2 Revenue management systems

A revenue management system is a specialized information and decision support system. The design of a revenue management system (RMS) includes the core modules, the information flows between modules and the information provided for RM decision-making and management, such as booking rates and prices. At the core of any RM system are 2 basic modules, a forecasting module and an optimization module.

The RM process follows 4 basic steps:

1. data collection and storage,
2. forecasting,
3. optimization,
4. control.

In the first step, real-time data is collected on demand and the factors that influence demand, data on bookings, cancellations, sales made, the proportion of unclaimed products (customers who fail to show up for service), etc. Available capacity for product provision is also monitored. All this data is stored as historical data, which is used in the forecasting and optimization modules.

In the second step, a demand model is created, its parameters are estimated and demand forecasts are generated based on the estimated parameters. Based on the real-time data, other important data such as cancellation rate, backorder rate, price sensitivity are estimated.

In the third step, the optimization module is used to optimize booking limits and suggested prices in each segment based on historical and real-time incoming data, using increasingly sophisticated models that try to capture as many influences as possible to approximate real-world conditions.

In the fourth step, decisions from the previous step are used to manage actual demand, set prices and adjust booking limits in each segment and product category.

These basic steps of the RM process are continuously repeated, forecasts are refined and the necessary decisions are dynamically re-optimized to improve the whole process. The structure of the revenue management system is shown in Figure 1.

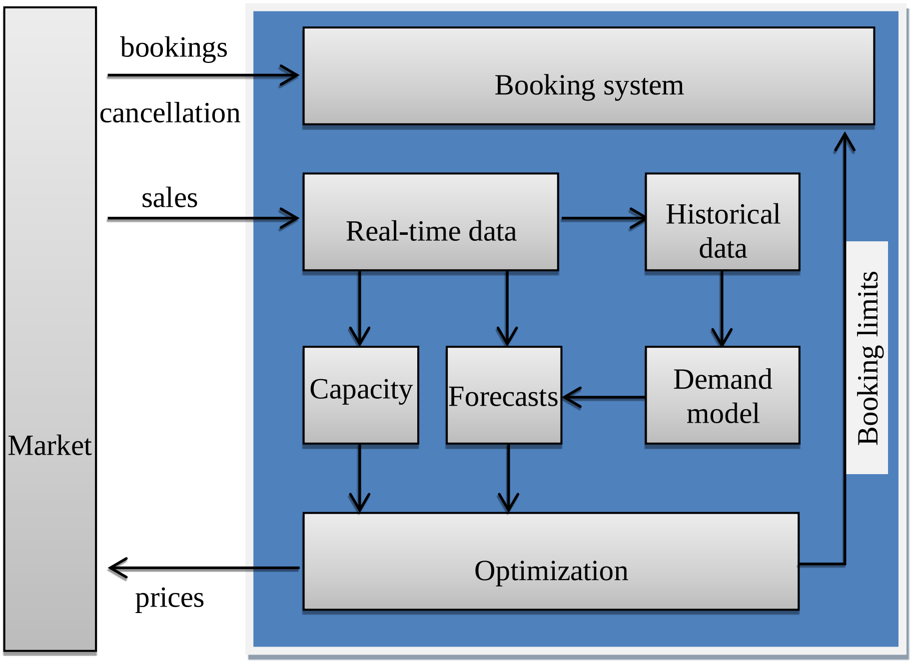

Figure 1 Structure of revenue management system [Authors]

3 Network revenue management

Network revenue management models seek to maximize revenue when customers purchase multiple resource packages. The interdependence of resources, commonly referred to as network effects, causes difficulties in solving this problem. A classic technique to approach this problem has been to use deterministic LP solutions to derive policies for the network capacity problem. The initial success of this method sparked extensive research into possible reformulations and extensions, and the method has become widely used in many industrial applications. A significant limitation on the applicability of these classical models is the assumption of independent demand. In response, there has been interest in incorporating customer choice into these models in recent years, further increasing their complexity. These developments have spurred current efforts to design powerful and practical heuristics that can still handle problems of practical scale.

The basic model of the network revenue management problem can be formulated as follows (see Talluri and van Ryzin, 2004a). A network has m resources which can be used to provide n products. We define an incidence matrix $A = [a_{ij}]$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, where

$a_{ij} = 1$, if resource i is used by product j, and

$a_{ij} = 0$, otherwise.

The j-th column of A, denoted a_j, is the incidence vector for product j. The notation $i \in a_j$ indicates that resource i is used by product j. The state of the network is described by the vector $x = (x_1, x_2, \ldots, x_m)$ of resource capacities. If product j is sold, the state of the network changes to $x - a_j$. Time is discrete, there are T periods and the index t represents the current time, $t = 1, 2, \ldots, T$. We assume that at most one request for a product can arrive in each time period t. The demand at time period t is modeled as the realization of a single random vector $r(t) = (r_1(t), r_2(t), \ldots, r_n(t))$. If $r_j(t) = r_j > 0$, this means that a request for product j occurred and that its associated revenue is r_j. If $r_j(t) = 0$, this indicates no request for product j occurred. The realization $r(t) = 0$ (all components equal to zero) means that there is no demand for any product at time t. The assumption that at most one arrival occurs in each time period implies that at most one component of $r(t)$ can be positive. The sequence $r(t)$, $t = 1, 2, \ldots, T$, is assumed to be indeterminate with a known joint distribution at each time period t. If the revenue associated with product j are fixed, we denote it by r_j and the revenue vector $r = (r_1, r_2, \ldots, r_n)$.

Given the current time t, the current remaining capacity x and the current request $r(t)$, a decision is made to accept or reject the current request. We define a decision vector $u(\mathrm{t}) = (u_1(t), u_2(t), \ldots, u_n(t))$ where

$u_j(t) = 1$, if the request for product j at time period t is accepted, and

$u_j(t) = 0$, otherwise.

The components of the decision vector $u(\mathrm{t})$ are functions of the remaining capacity components of vector x and the components of the revenue vector r, $u(\mathrm{t}) = u(t, x, r)$. The decision vector $u(t)$ is restricted to the set

$$U(x) = \{u \in \{0, 1\}^{\mathrm{n}},\ Au \le x\}.$$

The maximum expected revenue, given remaining capacity x in time period t, cannot be solved exactly for most real-size networks. The solutions are based on approximations of various types. Deterministic Linear Programming (DLP) was among the first models analyzed for network RM (see Talluri and van Ryzin, 2004a). The main advantage of the DLP model is that its solution is computationally very efficient. Its simplicity and speed make it popular in practice. The weakness of the DLP approximation is that it only considers mean demand and ignores all other distribution information. The performance of the DLP method depends on the type of network, the order in which fare products arrive, and the frequency of repeated optimization.

The DLP method uses the approximation

$$V_t^{LP}(x) = \max \quad r^T y$$

subject

$$Ay \le x \tag{1}$$

$$0 \le y \le E[D]$$

where $D = (D_1, D_2, \dots, D_n)$ is the demand for periods $t, t+1, \dots, T$, for product j, $j = 1, 2, \dots, n$, and $r = (r_1, r_2, \dots, r_n)$ is the revenue vector associated with n products. The decision vector $y = (y_1, y_2, \dots, y_n)$ represent the distributed capacity allocation for each of the n products. The approximation effectively treats demand as if it were deterministic and equal to its mean $E[D]$. The optimal dual variables, π^{LP}, associated with the constraints $Ay \le x$, are used as bid prices.

4 Modeling of strategic customer choice

Modeling customer behavior is gaining increasing attention in revenue management (see Shen and Su, 2007). Because customers will exhibit systematic responses to sales mechanisms, firms are responsible for anticipating these responses when making pricing decisions. The focus is on how customers decide which product to buy in a multi-product revenue management environment. A common approach is to use discrete choice models to capture consumer demand for multiple products. Substitution and complementarity effects for multiple products are also explored. Potential customers do not usually come with a preconceived notion of which product they will buy. Rather, they know only some specific characteristics that a product should have and compare several alternatives that share these characteristics before deciding whether or not to buy.

This issue of customer choice was first investigated by Talluri and van Ryzin (2004b), who studied the problem of revenue management within a discrete choice model of customer behavior. There are n tariff products, each associated with exogenous revenue r_j, $j = 1, 2, \dots, n$. At each point in time, the firm chooses to offer a subset of these tariff products. Given the subset of products offered, customers choose an option according to some discrete choice model. Gallego et al. (2004), van Ryzin and Liu (2008) extend this analysis to a network setting. Each product consists of a tariff class and a route that can use resources on multiple network segments. The dynamic program of finding optimal bidding sets becomes computationally intractable. The authors adopt a deterministic approximation by reinterpreting the purchase probability as a deterministic sale of a fixed quantity (less than one unit) of the product. Under this interpretation, the revenue management problem can be formulated as a linear program and the solution can be shown to be asymptotically optimal as demand and capacity increase. It is possible to design an implementation heuristic to convert the static LP solution into dynamic management policies.

4.1 Choice-Based Deterministic LP (CDLP)

The probability that the customer chooses product *j* given the set of offered tariffs *S* (conditional on customer arrivals) is denoted by $P_j(S)$. Time is discrete and is divided into *T* times periods that are small enough so that there is at most one customer arrival with probability λ and no arrival with probability $1-\lambda$. The network has *m* resources that can be used to provide *n* products. We use the incidence matrix $A = [a_{ij}]$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, introduced in network revenue management problems. The demand is assumed to be known and equal to its expected value. The problem then reduces to an allocation problem, where we need to decide for how many time periods a certain set of products *S*, denoted by $t(S)$, will be offered. Let us denote the expected total revenue from the offer *S* as

$$R(S) = \sum_{j \in S} P_j(S) r_j \tag{2}$$

and the expected total consumption of resource *i* from offering S by

$$Q_i(S) = \sum_{j \in S} P_j(S) a_{ij}, \ \forall i . \tag{3}$$

Then the choice-based deterministic linear program is given by

$$\begin{gathered} V^{\mathrm{CDLP}} = max \sum_{S \subseteq N} \lambda R(S) t(S), \\ \sum_{S \subseteq N} \lambda A P(S) t(S) \le x, \\ \sum_{S \subseteq N} t(S) \le T, \\ t(S) \ge 0, \forall S \subseteq N. \end{gathered} \tag{4}$$

The objective is to maximize total revenue subject to the constraints that consumption is less than capacity and the total number of time sets offered is less than the horizon length. The decision variables are the total offered time set $t(S)$. There are two basic ways to apply the CDLP solution. The first is to directly use the time variables $t^*(S)$ (Gallego et al., 2004). For some discrete choice models, column generation can be effectively used to optimally solve the CDLP model. It returns a vector with as many components as there are possible bid sets, and each component represents the number of time periods from a finite time horizon when the corresponding bid set should be available. The notion of efficient sets introduced by Talluri and van Ryzin (2004b) for the single-leg case is transferred to a network context, and the authors show that CDLP uses only efficient sets in its optimal solution. The second is the use of dual information in the decomposition heuristic (Liu and van Ryzin, 2007, van Ryzin and Liu, 2008). Dual variables of capacity constraints can be used to construct bid prices.

4.2 Searching the efficient frontier

Customer choice models can be extended to include multiple inputs (input sources, costs, choice probabilities, etc.) and multiple outputs (revenue, profit, output sources, etc.). Evaluation of alternatives can be done using DEA-based evaluation methods (see Cooper et al., 2000). The efficient frontier provides a systematic framework for comparing different policies and highlights the structure of optimal problem management. The search for an efficient frontier in a DEA model can be formulated as a multi-objective linear programming problem.

The set of effective decision units is called the reference set. The set that the reference set covers is called the efficient frontier. The search for an efficient frontier in a DEA model can be formulated as a multi-objective linear programming problem (see Korhonen, 1997). Suppose there are n decision making units, each consuming r inputs and producing s outputs and (r, n)-matrix X, (s, n)-matrix Y of observed input and output measures. The problem is defined as maximizing a linear combination of outputs and minimizing a linear combination of inputs.

$$\begin{gathered} Y\lambda \to \text{"max"} \\ X\lambda \to \text{"min"} \\ \lambda \geq 0 \end{gathered} \tag{5}$$

A solution λ_0 is efficient iff there does not exist another λ such that

$$Y\lambda \geq Y\lambda_0 ,\ X\lambda \leq X\lambda_0 \text{ and } (Y\lambda, X\lambda) \neq (Y\lambda_0, X\lambda_0). \tag{6}$$

Various methods of multi-objective linear programming can be used to solve this problem. We propose to use the Aspiration Level Oriented Procedure (see Fiala and Borovička, 2022).

4.3 Illustrative example

We will illustrate the approach for searching efficient subsets and for improving proposed price schemes on the following simple example. The seller offers nine basic subsets of products $P1$, $P2$, …., $P9$. Expected revenues are taken as output values, costs are taken as input ones (Input 1). Choice probabilities are considered according to consumer choice behavior. The probabilities of not-purchasing are taken as inputs (Input 2) (see Table 1).

Product	*P*1	*P*2	*P*3	*P*4	*P*5	*P*6	*P*7	*P*8	*P*9
Output	8	17	30	54	81	90	112	145	182
Input 1	3	8	15	25	35	47	59	72	86
Input 2	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Table 1 Inputs and outputs

The results of the DEA approach are summarized in Table 2. By solving the classical DEA model, we obtain score for products. The products $P1$, $P5$, and $P9$ are efficient. In comparison with ALOP procedure, the results are the same. For other products, the ALOP method proposes changes of aspiration levels for inputs and output which achieve efficient units.

Product	*P*1	*P*2	*P*3	*P*4	*P*5	*P*6	*P*7	*P*8	*P*9
Score	1.00	0.85	0.83	0.92	1.00	0.86	0,87	0.94	1.00
d^{+}	0.00	3.10	6.30	4.65	0.00	15.06	17.14	9.78	0.00
λ_1	1.00	1.50	1.50	0.75	0.00	0:00	0.00	0.00	0.00
λ_5	0.00	0.10	0.30	0.65	1.00	0.81	0.62	0.35	0.00
λ_9	0.00	0.00	0.00	0.00	0.00	0.22	0.43	0.70	1.00

Table 2 Results

The ALOP procedure is used for detailed analysis of efficient frontier and for searching for better price schemes. For example, we go out from the efficient unit $P5$ and search thorough the efficient frontier. Aspiration levels are stated as $y^{(1)} = 90$, $x_1^{(1)} = 40$, $x_2^{(1)} = 0.5$, but the model is infeasible for these aspiration levels . The ALOP proposes changes $\Delta x_1^{(1)} = 0.0218$ and the new aspiration levels as $y^{(2)} = 90$, $x_1^{(2)} = 40$, $x_2^{(2)} = 0.5218$ correspond to the efficient point on the efficient frontier.

5 Conclusion

Revenue management is the process of understanding, predicting and influencing customer behavior in order to maximize revenue. Revenue management systems are influenced by many factors. This paper proposes an approach to strategic customer behavior. Network revenue management models seek to maximize revenue when customers purchase multiple resource packages. The basic model of the network revenue management problem is formulated as a stochastic dynamic programming problem whose exact solution is computationally intractable.

In practice, the deterministic linear programming (DLP) method is popular. The DLP method assumes that demand is deterministic and static. Conventional modelling approaches assume that customers are passive and do not engage in any decision-making processes.

This simplification is often unrealistic for many practical problems. In response, in recent years there has been interest in incorporating customer choice into these models, further increasing their complexity. In this paper, the strategic behavior of customers has been analyzed. Customer choice depends crucially on the set of available products. A deterministic linear programming (CDLP) approach to modeling strategic customer behavior has been investigated. The paper presents a DEA-based model and methods for the generalized problem. The combination of efficient frontier search methods and dynamic sales process modeling approaches provides a powerful tool for capturing sales management problems with strategic customer behavior.

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Analysis of Risks in Order Processing Using WINGS Method for Decision-Making Support

Jiri Franek[1], František Zapletal[2]

Abstract. Risk analysis helps to identify and evaluate potential risks that could negatively impact their operations, finances, reputation, and customers. This allows businesses to develop strategies to mitigate or manage those risks, minimizing potential losses and maximizing opportunities for success.
In this paper we focused on analyzing risks related to order processing in a manufacturing company. Besides the classic risk analysis including identification and evaluation of risks, the company wanted to know which risks are the most important and play key role in the ordering process that runs throughout several departments. To add this dimension, we analyzed the interrelationships and importance of all involved departments using the WINGS method and combined this with the performed risk analysis. This helps to select the risks that have the highest risk number based on probability, impact and department involvement but also are those with more receptive or influencing role. Based on our results the company can better decide on which risk factor to focus and develop mitigation strategies.

Keywords: risk analysis, decision-making, WINGS, weighted influence non-linear gauge system, manufacturing.

JEL Classification: C49, M12, M51

1 Introduction

Effective risk management is crucial for businesses to identify, assess, prioritize, and mitigate risks that could impact their operations. Risk management involves steps such as risk identification, assessment, prioritization, treatment, and monitoring. However, there are limitations and challenges associated with risk prioritization and evaluation, including the lack of consensus among stakeholders, biased results due to subjective criteria, complex evaluations, overemphasis on probability, and inadequate consideration of interdependencies.

This paper focuses on the risk analysis of order processing in a manufacturing company that produces specialized vehicles customized to customers' demands. The company follows its own risk analysis procedure that includes identifying risks within each department, analyzing probability and impact, and selecting risks for developing mitigation strategies. However, the company is aware of the interdependencies among several departments involved in order processing, which have conflicting goals and varying levels of capacity.

To investigate these interrelationships, the Weighted Influence Non-linear Gauge System (WINGS) method, developed by Michnik (2013) based on the previously developed DEMATEL approach (Fontela and Gabus, 1974), is applied. This method aims to better identify

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the risks with the highest priority and influence by determining the involvement and role of company departments in the risks related to order processing.

The goal of this paper is to perform a risk analysis of the risks related to order processing in the company and investigate the interrelationships among the departments involved. The results will be presented in a ranking and chart, dividing the most important risks into influencing and influenced groups. The paper's structure includes a summary of relevant literature, a description of the methodological approach, application of the methodology, discussion of the results, and a conclusion.

To summarize, effective risk management is vital for businesses to avoid or minimize the negative impact of unexpected events and maximize opportunities for success. However, risk prioritization and evaluation are challenging, with limitations such as the lack of consensus among stakeholders, biased results, complex evaluations, overemphasis on probability, and inadequate consideration of interdependencies. The WINGS method provides a novel approach to better identify the risks with the highest priority and influence, especially in complex processes with interdependent departments. The paper's results will help the company prioritize and mitigate the risks related to order processing, ultimately improving efficiency, costs, deadlines, capacity overrun, competitiveness, quality, and customer satisfaction.

2 Literature summary

Given the nature of this paper we will elaborate on the most important and relevant literature regarding risk analysis using multi-criteria decision-making (MCDM) methods and the WINGS method applications.

To mitigate the problems involved in risk analysis and prioritization number of scholars applied different MCDM techniques. Based on visual bibliographic analysis of papers indexed in the Clarivate Web of Science (WoS) database using following query: *(TI=(risk assessment) OR TI=(risk management) OR TI=(risk prioritization) OR TI=(risk evaluation)) AND (AB=(MCDM))*. We have found 105 papers related to risk management, analysis or evaluation. They were mostly related to environmental sciences. Figure 1 shows cluster of keywords based on this sample. This diagram was developed using VOSviewer software. It is apparent that risk management and assessment are the key topics. Regarding the MCDM methods applied we can see occurrence of analytic hierarchy process (AHP), technique in order of preference by similarity to ideal solution (TOPSIS) and failure mode effects analysis (FMEA). Besides the analytical topics the selection occurs as an important issue as well. If we look up studies that are the most relevant to the problem solved in this paper, we can find some application focused on supply chain management and production Kahouadji and Belkaid (2022) utilized a simple and efficient technique for prioritizing preventive actions in a Failure Mode, Effects and Criticality Analysis (FMECA) based on the use of Multi Criteria Decision Methods (MCDM), namely TOPSIS and Multicriteria Optimization and Compromise Solution (VIKOR). Similarly, Nigam, Avikal and Ram (2021) Fuzzy COPRAS method on risk assessment of ERP projects. The result is more precise ranking and selection of risks for mitigation. Risk prioritization is an important issue in decision-making processes, especially in complex systems where uncertainties and vagueness are prevalent. Several recent studies have employed multiple-criteria decision-making (MCDM) methods to deal with risk prioritization issues. For instance, Gadekar, Sarkar, and Gadekar (2022) used Fuzzy DEMATEL and ARAS methods to mitigate uncertainties and vagueness in decision-making processes.

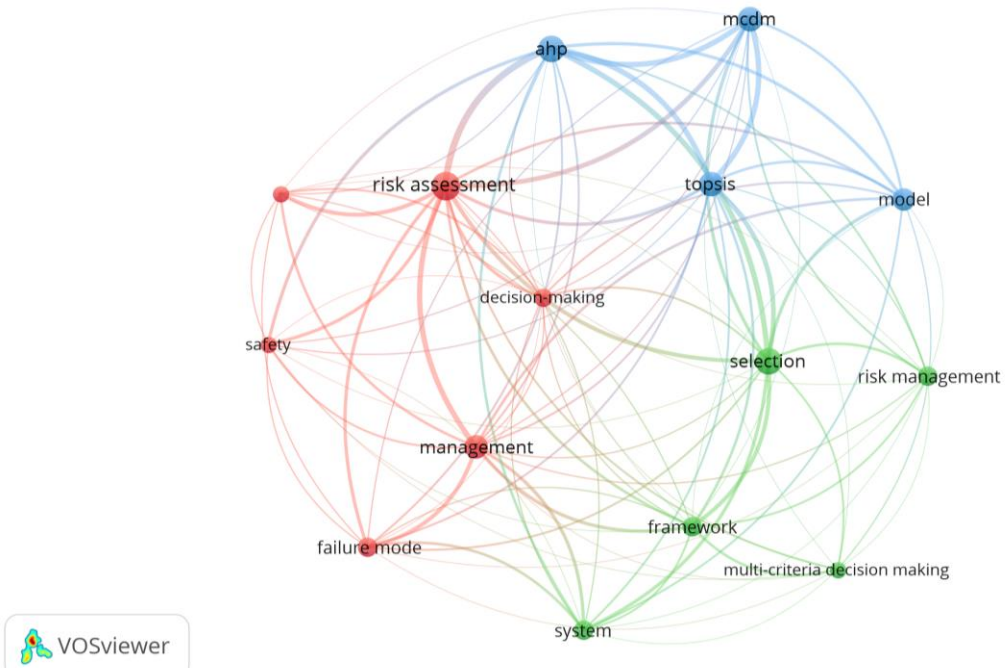

Figure 1 Network visualization of risk management, analysis and assessment with MCDM methods [own elaboration using VOSviewer and WoS database]

Guo, Xiang, and Lee (2022) employed DEMATEL and analytic network process (ANP) to identify and prioritize key risks in construction engineering projects. They also suggest that network-based MCDM methods can effectively reduce subjectivity and improve accuracy during expert risk evaluations.

To address the issue of risk prioritization in a system of criteria and alternatives, we applied the Weighted Influence Non-linear Gauge System (WINGS) method, which considers the feedback relationships among a system of criteria and alternatives. The WINGS method has been applied to various problems and has been further developed by several scholars, including Zhang and Xu (2022) in risk management in healthcare, Kashi (2017) and Kashi and Franek (2018) in human resources management, Radziszewska-Zielina and Śladowski (2017) in historical building adaptation, Michnik (2018) in innovation project selection, Banaś and Michnik (2019) in a combination of WINGS and a fuzzy cognitive map, Michnik and Grabowski (2020) using interval arithmetic, Kaviani et al. (2020) in a hybrid model with the best-worst method, Fedorczak-Cisak et al. (2020) in an addition to the method with fuzzy numbers (FWINGS), Wang et al. (2021) in a hybrid RBF-WINGS method for green building development, Tavana et al. (2021) in NASA applications, Tavana et al. (2022) in tourism project management, and Franek and Krestova (2023) in age management strategy. Our approach was also inspired by the study published by Zolfani et al. (2022) where the WINGS method was used on criteria evaluation only using rescaled OPA weights. The WINGS method has been widely applied in various fields, indicating its effectiveness and flexibility in dealing with complex decision-making problems.

3 Applied methods

The approach described in this section involves identifying sources of risk, evaluating their probability and impact, and using the WINGS method to assess relationships among departments in a company with regard to the flow of customer orders. The WINGS method is used to quantitatively assess the significance of components in a system and the strength with which they influence other components in the system.

3.1 Methodological approach

Our approach is based on typical risk analysis starting with identification of sources of risks, evaluation of their probability and impact. This enables to calculate the risk number (probability times impact). Probability was assessed based on occurrence and experience of company managers (in %). The impact was evaluated using scale from 1 to 44 (low to high respectively) based on the order of 44 risks evaluated in this study. The risk number was calculated as follows:

$$Risk\ number = \frac{(probability * impact)}{100}. \tag{1}$$

This procedure is used in the company where this study was performed, so this procedure was not changed and risk numbers were accepted as source data.

All identified risks are also related to separate departments within the company. Average impact of identified risks is used to estimate the weight of relevant department within the ordering process. After the initial risk analysis and estimation of their risk numbers, the managers of the company were asked to evaluate the relationships among departments with regard to the flow of the order throughout the company. This is where the WINGS method is used. Assessment of relationships is based on a following scale: *0 for no influence, 1 for low influence, 2 for medium influence, 3 for high influence, 4 for very high influence*. Weights are also recalculated to fit this scale. Then the result from WINGS is combined with the results of the risk analysis, where we combine the risk number and total engagement of the department in the ordering process. This gives us new ranking of risks and we can select those important ones using a Pareto rule 80/20. This rule is commonly used in the organization where this paper was applied. Then these selected risks are divided into influencing and influenced group base on their role.

3.2 Description of the WINGS method

The WINGS method is used to quantitatively assess the components involved in a system that is a model of a situation requiring analysis and decision-making. The method assesses two characteristics concerning the role of a component in the system: the strength (significance) of the component in the system and the strength with which it influences other components in the system. These characteristics are reflected in the method's acronym. Details of the WINGS procedure are as follows (Michnik, 2016).

At the outset, the user identifies the components that he or she believes are important in the problem being analyzed and the cause-and-effect relationships that exist between them. The user then selects a verbal scale to assess both characteristics: the familiarity and strength of the individual components of the system. Given that the scale represents the subjective assessments of the user, it does not seem sensible for it to contain much more than 10 points, although formally the method places no restrictions here. All evaluations are inserted into a square matrix **D** called the direct strength-influence matrix. This matrix is a $n \times n$ type with components d_{ij}. Values that represent the strength (importance) of components are inserted on the main diagonal where d_{ii} is the importance of the component i. Values representing influences are inserted into the matrix so that $i \neq j$, d_{ij} is influence of the component i on the component j. Matrix D is then calibrated according to the formula:

$$\mathrm{C}=\frac{1}{s}D, \tag{2}$$

where calibrating factor s is defined as a sum of all elements of matrix D

$$s = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}. \tag{3}$$

The calibration ensures the existence on total strength-influence matrix T defined in (3). As well as in the DEMATEL it will ensure that the results are stable according to homothetic transformation $d_{ij} \rightarrow d'_{ij} = \alpha d_{ij}\ \alpha > 0$, for $i, j = 1, \ldots, n$.. In the next step the total strength-influence matrix T is calculated:

$$T = C + C^2 + C^3 + \ldots = \frac{C}{I - C} \tag{4}$$

Then, for each element in the system the row sum r_i and column sum c_j of the matrix T are calculated:

$$r_i = \sum_{j=1}^{n} t_{ij}\, , c_j = \sum_{i=1}^{n} t_{ij}\, , \tag{5}$$

where t_{ij} are elements of the matrix T. The r_i and c_i represent the total impact and the total receptivity of component. Finally, for each element in the system $(r_i + c_i)$ and $(r_i - c_i)$ are calculated. The relation $(r_i + c_i)$, shows the total engagement of the component in the system; $(r_i - c_i)$ indicates the net position (role) of the component in the system: its positive sign means the component belongs to the influencing (cause) group, negative sign means that the component belongs to the influenced (result) group. Therefore, we can create a diagram (x, y) where x values are represented by $(r_i + c_i)$ and y values are represented by $(r_i - c_i)$, that it is called engagement-position map, that together with a numerical output helps with the analysis and discussion.

4 Results and discussion

This section is divided in to following sub-sections: risk analysis table, weighting of departments, application of WINGS and ranking of risks.

4.1 Risk analysis

Following table 1 is a result of an expert-based risk analysis of an order procession in a manufacturing company producing specialized equipment. In this company six departments (with one divided into three branches) share duties related to a customer order. They have identified sources or risks, their nature, probability, and impact. There are 44 risks. Probability was assessed based on occurrence and experience of company managers (in %). The impact was evaluated using scale from 1 to 44 (low to high respectively). Table 1 consists of 44 risk activities across the most relevant departments. The risk number was calculated using formula (1). As expected, the highest risk activities include late parts breakdown (risk no. 26), which prevents procurement from ordering critical items in advance. Surprisingly, the unavailability of documentation at the purchasing department (no. 23) ranked lower than that activity. This analysis also shows that offering non-standard solutions to customers (no. 8) creates bigger problem than previously thought, as this activity ranked second. Another problem is the removal of vehicles from production only at the end of the month (no. 40) and their incompleteness due mainly to missing parts (no. 37). The preparation of the technical solution (no. 9) in the sales department is also an important bottleneck in the processing of the order, as the sales department does not have sufficient capacity to prepare the technical solution for the customer, either on its own or with the help of the construction office. This causes late bid submission, missed deadlines and other delays and pressure within the company.

Department	No.	Source of risk	Impact of the risk	Probability in %	Impact	Risk number
Sales - Demand Processing	1	The sales rep. doesnt fulfill all cutosmer demands	Deadline, costs, capacity	6	7	0,42
Sales - Demand Processing	2	The customer does not know what he wants	Deadline, costs, capacity	11	12	1,32
Sales - Demand Processing	3	Legislation	Unfulfiled or unaware	10	11	1,10
Sales - Demand Processing	4	Customer deadline	Unfulfiled, paying penalties, reputational hazard	41	28	11,48
Sales - Demand Processing	5	Customer quality demands	Unfulfiled, paying penalties, reputational hazard	21	19	3,99
Sales - Demand Processing	6	Order economics	Uncompetitiveness, incorrrect cost structure	51	33	16,83
Sales - Demand Processing	7	Evaluation of quality, configuration and codification	Deadline, costs, capacity	8	9	0,72
Sales - Demand Processing	8	The sales representative offers unreasonable solution	Deadline, costs, capacity	61	43	26,23
Sales - Supply Process	9	Preparation of a technical solution	Capacity of construction department	55	37	20,35
Sales - Supply Process	10	Indetification of critical components	Overrun, supplier unavailiability	7	8	0,56
Sales - Supply Process	11	Inclusion of the product into a plan	Capacity, deadline	5	6	0,30
Sales - Supply Process	12	Mistake in supply	Deadline, costs, capacity	4	5	0,20
Sales - Order and contract	13	Difference in order and supply	Deadline, costs, capacity	12	13	1,56
Sales - Order and contract	14	Signing of a contract	Capacity of departments	15	16	2,40
Sales - Order and contract	15	Listing of the order	Capacity, deadline	3	4	0,12
Sales - Order and contract	16	Lincesing of the product	Rejection of the licence	9	10	0,90
Construction and R&D	17	Capacity planning	Deadline, costs	52	24	12,48
Construction and R&D	18	Checking of documentation, additional changes	Deadline, costs, capacity	15	16	2,40
Construction and R&D	19	Drawing of products	Deadline, costs, capacity	45	30	13,50
Construction and R&D	20	Order changes from other departments	Deadline, costs, capacity	31	25	7,75
Construction and R&D	21	Changes in legislation	Deadline, costs, capacity	16	17	2,72
Construction and R&D	22	Missing components	Deadline, costs, capacity	42	29	12,18
Construction and R&D	23	Unavailable documentation for parts list	Deadline, costs	60	42	25,20
Purchasing	24	Diversification of suppliers	Deadline, costs	47	31	14,57
Purchasing	25	Agreements with suppliers	Deadline, costs	59	41	24,19
Purchasing	26	Late parts breakup	Deadline, costs, capacity	62	44	27,28
Purchasing	27	Supplier contract termination	Deadline, costs, capacity	33	26	8,58
Purchasing	28	Late supply	Deadline, costs, capacity	53	35	18,55
Purchasing	29	Cost increase	Costs	54	36	19,44
Purchasing	30	Changes in legislation and geopolitics	Deadline, costs, capacity	14	15	2,10
Purchasing	31	Licences on specific parts and materials	Deadline, costs, capacity	7	8	0,56
Logistics	32	Noncompliance of order plan	Deadline, costs, capacity	23	20	4,60
Logistics	33	Conditional aproval of the order	Deadline, costs, capacity	19	18	3,42
Logistics	34	Acumulation of postponed orders	Deadline, costs, capacity	30	24	7,20
Production	35	Capacity planning of production	Deadline, costs, capacity	24	21	5,04
Production	36	Unfinished products	Deadline, costs, capacity	58	40	23,20
Production	37	Finishing of incoplete products	Deadline, costs, capacity	56	38	21,28
Production	38	Mistakes in assembly	Deadline, costs, capacity	13	14	1,82
Production	39	Changes in production plan	Deadline, costs, capacity	34	27	9,18
Production	40	End of the month production	Deadline, costs, capacity	57	39	22,23
Production	41	Acumulation of finished products	Deadline, costs, capacity	50	32	16,00
Quality	42	Aproval of incomplete product	Deadline, costs, capacity	28	22	6,16
Quality	43	Insufficient customer takeover	Deadline, costs, capacity	50	32	16,00
Quality	44	Complaints	Costs, capacity	29	23	6,67

Table 1 Risk table

4.2 Weighting of departmental importance

The weighting was based on the average risk impact of relevant departments (including sub-departments). Then those weighs were rescaled to scale from 1 to 4 to represent the importance of components in the WINGS matrix *D*. The procedure can be described as follows:

$$w_i = \frac{ARI_i}{\sum ARI_i}, \quad (6)$$

$$RW = \frac{w_i}{\max w_i} * 4, \text{ for } i = 1, \ldots, 8. \quad (7)$$

Resulting weights are in table 2.

Departments	**Average Risk Impact (*ARI*)**	**Weights (*w*)**	**Rescaled Weights (*RW*)**
Sales - Demand (DEP1)	20,250	11,058 %	2,282
Sales - Supply (DEP2)	14,000	7,645 %	1,577
Sales - Order and contract (DEP3)	10,750	5,870 %	1,211
Construction and R&D (DEP4)	26,143	14,276 %	2,946
Purchasing (DEP5)	35,500	19,386 %	4,000
Logistics (DEP6)	20,667	11,286 %	2,329
Production (DEP7)	30,143	16,461 %	3,396
Quality (DEP8)	25,667	14,016 %	2,892

Table 2 Importance of departments

4.3 Application of the WINGS method

Following table 3 shows the initial matrix *D* which includes all evaluations of relationships among departments regarding their influences on each other.

	DEP1	**DEP2**	**DEP3**	**DEP4**	**DEP5**	**DEP6**	**DEP7**	**DEP8**
Sales - Demand (DEP1)	2,282	3	2	4	3	3	3	2
Sales - Supply (DEP2)	2	1,577	2	4	3	3	3	1
Sales - Order and contract (DEP3)	1	2	1,211	4	3	3	3	2
Construction and R&D (DEP4)	2	2	2	2,946	4	3	4	3
Purchasing (DEP5)	2	2	2	3	4	4	4	2
Logistics (DEP6)	2	2	2	2	2	2,329	3	1
Production (DEP7)	2	2	2	2	3	3	3,396	3
Quality (DEP8)	1	1	1	1	1	1	1	2,892

Table 3 Initial matrix *D*

Following figure 2 shows the engagement-position map on which the most important risks related to the order processing.

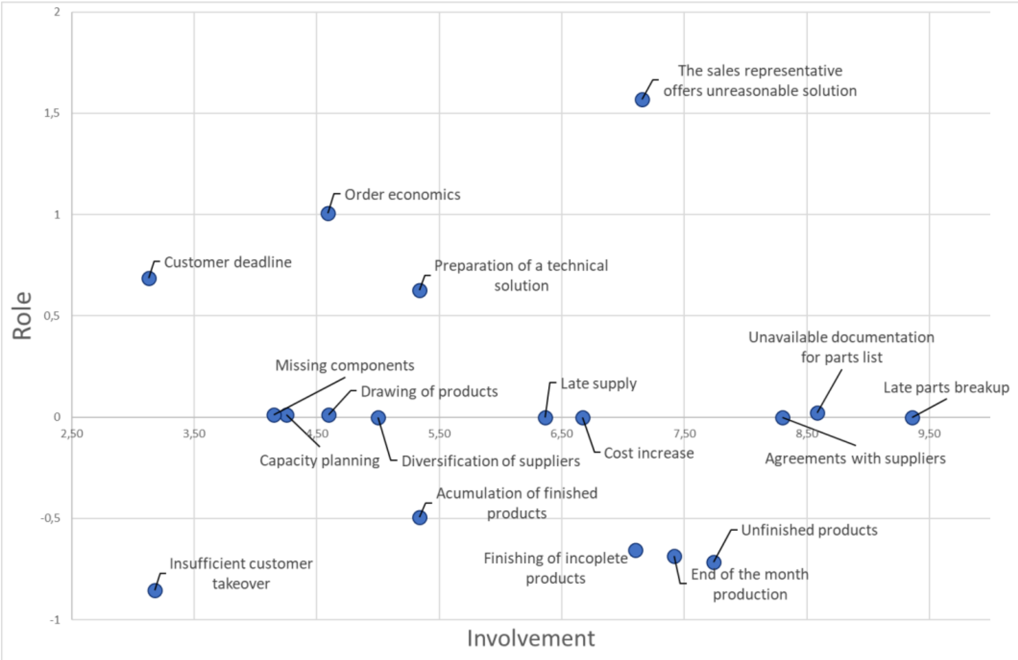

Figure 2 Engagement-position map showing different roles and involvement of the most important risks [own elaboration using MS Excel]

We can see that the unreasonable solutions are those that influence the other activities even if this is not the most critical risk on the involvement axis. On the other hand, unfinished and stacking up production at the end of the month is critical and also highly influenced risk. Thus, its mitigation may not be possible without decreasing the risk of influencing activities in the processing of the order.

4.4 Ranking of risks

Using the sum or rows r_i and columns c_i of the matrix T (see table 4) we can calculate total engagement of the component in the system $(r_i + c_i)$ and the $(r_i - c_i)$ which indicates the net position (role) of the component in the system: its positive sign means the component belongs to the influencing (cause) group, negative sign means that the component belongs to the influenced (result) group. By multiplying the *risk number* and the *total involvement* we can estimate the *risk involvement.* Then the risk involvement was analysed using a Pareto approach, where *risk involvement* was added up to cumulative number to find the most critical risks based on their position in the network of risks and their risk number. Table 5 shows only results with ranking up to the 82% most important risks based on their risk involvement.

Department	No.	Source of risk	Impact of the risk	Risk number	Total involvement	Total role	Risk involvement	Cumulative (Pareto)
Purchasing	26	Late parts breakup	Deadline, costs, capacity	27,28	0,343	0,000	9,359	7,07%
Construction and R&D	23	Unavailable documentation for parts list	Deadline, costs	25,2	0,341	0,001	8,584	13,55%
Purchasing	25	Agreements with suppliers	Deadline, costs	24,19	0,343	0,000	8,299	19,82%
Production	**36**	**Unfinished products**	**Deadline, costs, capacity**	**23,2**	**0,334**	**-0,031**	**7,740**	**25,67%**
Production	**40**	**End of the month production**	**Deadline, costs, capacity**	**22,23**	**0,334**	**-0,031**	**7,416**	**31,27%**
Sales - Demand Processing	**8**	**The sales representative offers unreasonable solutic**	**Deadline, costs, capacity**	**26,23**	**0,273**	**0,060**	**7,157**	**36,68%**
Production	**37**	**Finishing of incoplete products**	**Deadline, costs, capacity**	**21,28**	**0,334**	**-0,031**	**7,099**	**42,04%**
Purchasing	29	Cost increase	Costs	19,44	0,343	0,000	6,669	47,08%
Purchasing	28	Late supply	Deadline, costs, capacity	18,55	0,343	0,000	6,364	51,89%
Sales - Supply Process	**9**	**Preparation of a technical solution**	**Capacity of construction department**	**20,35**	**0,262**	**0,031**	**5,340**	**55,92%**
Production	**41**	**Acumulation of finished products**	**Deadline, costs, capacity**	**16**	**0,334**	**-0,031**	**5,338**	**59,95%**
Purchasing	24	Diversification of suppliers	Deadline, costs	14,57	0,343	0,000	4,998	63,73%
Construction and R&D	19	Drawing of products	Deadline, costs, capacity	13,5	0,341	0,001	4,599	67,20%
Sales - Demand Processing	**6**	**Order economics**	**Uncompetitiveness, incorrrect cost structure**	**16,83**	**0,273**	**0,060**	**4,592**	**70,67%**
Construction and R&D	17	Capacity planning	Deadline, costs	12,48	0,341	0,001	4,251	73,88%
Construction and R&D	22	Missing components	Deadline, costs, capacity	12,18	0,341	0,001	4,149	77,02%
Quality	**43**	**Insufficient customer takeover**	**Deadline, costs, capacity**	**16**	**0,199**	**-0,053**	**3,180**	**79,42%**
Sales - Demand Processing	**4**	**Customer deadline**	**Unfulfiled, paying penalties, reputational haza**	**11,48**	**0,273**	**0,060**	**3,132**	**81,79%**

Table 4 Ranking of risks based on the risk involvement

To better distinguish the risks, we can see that risks marked as red, are those that belong to the influencing group (their total role is positive) and those marked blue are belonging to the influenced group. That means that the company should firstly focus on those risks that are rather important and have an influence on the others from different departments. The mitigation strategy for the blue marked risks should go hand in hand with mitigation strategies for the red ones. The other risk cannot be precisely included in either group as they are intermediaries between the above mentioned two.

5 Conclusion

To conclude our approach has shown a potential how to enhance the insight a risk analysis can provide when considering relationships among risk factors or sources. The WINGS method has also several advantages against some more complex MCDM methods: ease of use, applicability on complex problems, possible combination with other MCDM methods, straightforward calculation and possible graphical representation. We limited the use of this method only on the interrelationships among departments to have little interference with the system of the risk analysis that the company regularly uses so that the enhancement using WINGS is less demanding in practice. The results also corresponded with the actual mitigation activities that were focused on the Sales departments hence the identified risks (no. 4, 6, 8, 9 see table 1 and 5) have and profound influence on the smoothness of the customer order processing and demands on other departments.

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Frameworks of strategic management in Industry 4.0

Bożena Gajdzik[1], Hana Štverková [2]

Abstract. Strategic management, at the level of companies' transformation to Industry 4.0, facilitates their smart processes. This work is based on a bibliometric analysis of scientific publications registered in the Scopus database. The aim of the study was to identify research areas of scientists in the topic of strategic management in the context of popularising the concept of Industry 4.0. An important element of the study, which forms the basis for identifying strategic areas for building Industry 4.0 and indicating the connections occurring between them, is a keyword map of scientific publications retrieved from the database for 'Strategic management' 'Industry 4.0'.

Keywords: strategic management, Industry 4.0, bibliometric analysis, digitalization, enterprise, supply chains.

JEL Classification: L23, L10

1 Introduction

The conditions of the modern global economy with the transformation of enterprises towards Industry 4.0 necessitate appropriate strategic actions. The implementation of the technologies of the Fourth Industrial Revolution into enterprises must take place in a systematic, coherent and time-framed form. The transformation of companies to Industry 4.0 must be subordinated to the adopted strategic objectives. The road to smart factory is an element of all activities aimed at realising the companies' goal of co-creating Industry 4.0. In accordance with the principles of strategic planning, the elements of the strategy are the mission, current and prospective goals, assessment of the enterprise's resources and its environment, selection of methods for the implementation of the adopted goals, organisation and management of the product manufacturing process and control of the progress of activities (David, 1979). Strategies are concrete plans that set businesses on a course of development based on the pillars of the Industry 4.0 development concept. The concept needs to integrate several tools, some newer than others, such as the Internet of Things, Robotics, Machine Learning, Big Data, Artificial Intelligence, Virtual and Augmented Reality, Additive Manufacturing (e.g. 3D printing), technologies of blockchain and Cyber-Physical Systems (Pereira and Romero, 2017).

The concept of Industry 4.0 (I 4.0) is constantly being expanded (Gajdzik, 2022a), with its technologies moving towards sustainability, human centricity (placing humans at the centre of cyber-physical systems) and building company resilience in a labile environment (Grabowska et al, 2022). The next evolution of industry is called Industry 5.0. In January 2021, the European Commission presented the principles of Industry 5.0 in the European document entitled *Industry 5.0 Towards a sustainable, human centric and resilient European industry*.

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Enterprises that want to co-create Industry 4.0 or Industry 5.0 are changing (improving) their existing operating strategies. In this study, the author assumed that Strategy 4.0 is a plan for building a smart enterprise. It is derived from the own resources and capabilities (financial, technical, organisational, human resources) of building a smart factory. Strategic management, in the Fourth Industrial Revolution, is the gradual adaptation of enterprises to the requirements of Industry 4.0. This paper presents clusters (segments) of strategic management focused on Industry 4.0 based on the analysis of scientific publications.

2 Materials and methods

Research subject: Strategic management and Industry 4.0 was realized based on bibliometric analysis of scientific papers recovered from database: Scopus. The time of analysis was established on the period from 2011 to 2022. The beginning of analysis was the year in which German government started to present the strategy of high-tech called the Industry 4.0. The analysis was finished on the end of 2022. In that period, 60 scientific papers were registered in the Scopus database. A collection of publications was created for the entry: "strategic management" "Industry 4.0". The search scope of the collection was: title, abstract and keywords (TITLE-ABS-KEY). The largest number of scientific publications on the topic analysed was in the last three years, i.e. from 2020 to 2022. In the first years of the analysis, from 2011 to 2014, no publications were found for the key used. The distribution of the dynamics of scientific publications, was narrowed down to the period 2015-2022, and the results are presented in Table 1.

2015	2016	2018	2019	2020	2021	2022
1	3	2	9	13	15	17

Table 1 Dynamics of publication for keywords: “strategic management” , “Industry 4.0” in TITLE-ABS-KEY of database Scopus [own elaboration]

In the literature section 3 were used the scientific publications with the highest citation rates (Top 10 list). A list of the scientific publications was presented in Table 2.

Figure 1 Keywords obtained records [own elaboration based on Scopus data for the keywords “strategic management” , “Industry 4.0” in TITLE-ABS-KEY]

Document title	Authors	Year	Source	Cited by
A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	Schumacher,A., Erol, S., Sihn, W.	2016	Procedia CIRP 52, pp. 161-166	734
External partnerships in employee education and development as the key to facing Industry 4.0 challenges	Stachová, K., Papula, J., Stacho, Z., Kohnová, L.	2019	Sustainability (Switzerland) 11(2),345	71
Building digitally-enabled process innovation in the process industries: A dynamic capabilities approach	Chirumalla, K.	2021	Technovation 105,102256	38
Design for product and service innovation in Industry 4.0 and emerging smart society	Gerlitz, L.	2015	Journal of Security and Sustainability Issues 5(2), pp. 181-198	23
Towards supply chain visibility using Internet of Things: A dyadic analysis review	Ahmed, S., Kalsoom, T., Ramzan, N., (...), Zeb, B., Ur Rehman, M.	2021	Sensors, 21 (12) 4158	21
Five Management Pillars for Digital Transformation Integrating the Lean Thinking Philosophy	Romero, D., Flores, M., Herrera, M., Resendez, H.	2019	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2019	20
A comprehensive insight into lean management: Literature review and trends	Sinha, N., Matharu, M.	2019	Journal of Industrial Engineering and Management 12(2), pp. 302-317	17
Designing Value Chains for Industry 4.0 and a Circular Economy: A Review of the Literature	Awan, U., Sroufe, R., Bozan, K.	2022	Sustainability (Switzerland) 14(12),7084	16
Digitalization business strategies in energy sector: Solving problems with uncertainty under Industry 4.0 conditions	Trzaska, R., Sulich, A., Organa, M., Niemczyk, J., Jasiński, B.	2021	Energies 14(23),7997	13
The Influence of Critical Factors on Business Model at a Smart Factory: A Case Study	Jerman, A., Erenda, I., Bertoncelj, A.	2019	Business Systems Research 10(1), pp. 42-52	10

Table 2 Scientific publications used in research the subject: “strategic management” , “Industry 4.0” in TITLE-ABS-KEY from database Scopus (12 Jan. 2023) [own elaboration]

Figure 1 shows the keyword analysis for 'strategic management' and 'Industry 4.0'. The base analysis was as follows: Industry 4.0: 37 results, strategic management: 25, digitisation: 6, digital transformation:5, innovation: 5, strategic planning: 5, competition: 4, dynamic capabilities: 4, industrial management: 4, sustainability: 4. On the basis of the analysis of the publications (Table 2), a new keyword picture was constructed, which is presented in Section 3.

3 Strategic management AND Industry 4.0: the concept of frameworks

In making the idea of Industry 4. 0, according to which, machines are automatised and individually controlled by computers and operate in systems in which they are able to collect and organise data collected from sensors installed in the machines and their peripheral devices on the production floor, including power and supply chain systems, in order to generate intelligent decisions in a fully automatic manner, representing a concept involving the integration of systems and agents with the common goal of improving the efficiency, flexibility and responsiveness of the production system, a strategy is needed that, on the one hand, sets a course of action and, on the other, facilitates the various organisational divisions and project teams to build cyber-physical systems.

Strategies are components of maturity models of companies transforming to Industry 4.0. The publication that had the most citations (734) in the Scopus database was about components of a maturity model of companies to I. 4.0 (Schumacher et al., 2016). The model consisted of 9 dimensions, including 4 core dimensions, and these were: "Products", "Customers", "Operations" and "Technology" and 5 additional dimensions, these dimensions were " "Strategy", "Leadership", "Governance", "Culture" and "People". Strategy at the organisational level of enterprises and starts them on the road to Industry 4.0. The key question used by the authors of the study: Do you use a road map for the planning of Industry 4.0 activities in your enterprise? Component strategy in their study is described as: compatibility of Industry 4.0 with company strategies, suitability of existing business models for Industry 4.0, existence of strategy for digital transformation, utilisation of an Industry 4.0 roadmap, availability of resources for Industry 4.0, communication and documentation of Industry 4.0 activities.

Based on research we see that companies have serious problems to grasp the overall idea of Industry 4.0 and particular pillars of Industry 4.0. On the one hand, they are unable to relate it to their specific field and specific business strategy. On the other hand, they find it difficult to define their state of development in relation to the Industry 4.0 vision, making them unable to identify specific areas of action, programmes and projects. In order to overcome the growing uncertainty and dissatisfaction in manufacturing companies with regard to the idea of Industry 4.0, new methods and tools are needed to provide guidance and support in adapting business strategies and operations to Industry 4.0 (Erol, Schumacher and Sihn, 2016).

A study (Stachová et al, 2019) (multiple case study a multiple case study design in two steel manufacturing firms) identified key challenges to process innovation, one of which is poor strategy (others: data readiness, lack of standardisation practices for change, competence and cultural gaps and ad hoc problem solving). In order for companies to realise their transformation strategies to Industry 4.0, process innovations must be integrated into the digital environment. Digitalisation needs process improvement infrastructure and methodologies, predictive and computer analytics, proactive management practices and digital maturity plans for each function and department (Stachová et al, 2019). The key critical factors influencing the building of a smart factory are top management and leadership orientations, employee motivation, collective wisdom, creativity and innovation (Jerman et al, 2019).

Strategic management in Industry 4.0 requires the digitisation of internal and external processes (Chirumalla, 2021). Digital transformation is a concept based on the use of digital technologies. The process of change towards a digital business requires a specific type of strategy, aimed at addressing the uncertainties caused by the implementation of Industry 4.0 (Trzaska et al, 2021). Digitalisation (digital transformation) at the workplace level can (and even should) apply the Lean philosophy (Romero et al, 2019). Among the pillars of Lean Thinking is (digital) strategic management, with the others being (re)process engineering management, (digital) technology management, (people) change management and (digital) risk management. The digital transformation of companies requires strategic management that structures the activities of companies moving towards Industry 4.0. Projects (innovations) that help companies create Industry 4.0, at the level of operational strategy, are embedded in Lean maturity (Sinha and Matharu, 2019). With the development of digitalisation and the interpenetration of cyber and physical dimensions connected by the Internet, companies need the IoT. The integration of design in smart production and services and in the process of generating value for a smart society is based on IoT. Gerlitz (2015) stated that integration (analysis using the example of design) in Industry 4.0 using the 'Internet of Things' from a strategic management perspective is still too narrow.

According to authors Pinto, Silva, Costa et al. (2019), stages of change are needed in the implementation of business development strategies, especially for small and medium-sized enterprises (SMEs) when building systems. Companies start with simple projects moving towards smart manufacturing and end with complex ones that create a smart factory. In describing the process of improving IT systems, the authors detailed the following eight steps. The first step is to analyse the company's processes and determine their complexity, as well as the links between processes. The individual processes must be defined, as well as named and labelled, so that tasks can be assigned to processes (step 2). In order to digitise processes, compatibility with the existing system (system structure and interfaces) must be established. Compatibility of IT systems takes time, the IT-computer systems supporting the different processes must work together to manage projects (Step 3). The proposed solutions (changes made) must improve the processes and the company must benefit, it must earn from the changes (Step 4 Evaluating earnings). Step 5 is to implement the changes. Changes in information systems are linked to changes in manufacturing technologies. The manufacturing process, through technological innovation, is becoming more and more independent of humans (full automation), with humans becoming the guardians of the processes and intervening when necessary (Jerman et al, 2019). The collected data from the machines is collected and processed in a centralised or decentralised systems, or a hybrid system (Meissner et al, 2017). Big Data needs IoT and cloud computing. IoT technology, which is one of the pillars of Industry 4.0, improves the ability of organisations to collect and evaluate information to balance strategy and objectives (Ivanov and Dolgui, 2021; Maghsoudi and Pazirandeh, 2016) in supply chains (SCs) (Ahmed et al., 2021). Improvements in companies and chains are continuously evaluated (Step 6 according to Pinto et al, 2019). After initial successes, companies embark on further projects, implementing new technologies in more processes, from adjacent processes where projects have been successful (Step 7) to very complex processes (Step 8) (Pinto et al., 2019). The cited staging, in the publication (Pinto et al, 2019), is a kind of conduct map that is embedded in the strategic development model of SMEs towards Industry 4.0. The usefulness of the map for building smart also works well in large and very companies belonging to strong capital groups.

The author Gajdzik (2022b, 2022c), in her research on the steel producer market, confirms the phased and clustered implementation of technologies that bring companies closer to smart manufacturing. Projects in large enterprises are implemented according to the transformation directions written in their strategies.

Strategic management in companies building Industry 4.0 is strongly linked to innovation management, which is based on all the pillars of Industry 4.0, as well as open innovation, including the design and perception of Industry 4.0. Strategic management in Industry 4.0 is integrating the design and implementation of a new framework of product development processes or processes leading to valuable innovations at corporate and society. Strategic management in Industry 4.0 combines different spaces (micro, meso and macro). Companies progress from internal projects to external projects, from smarter to smart processes, taking into account the needs of customers and suppliers as well as society with different players and stakeholders. Very large companies are seeking to invest in concurrent and coexisting technologies across their entire supply chains. In supply chains, companies' strategies are balanced with the logistics goals and values of different stakeholders. Ahmed et al. (2021) focused on increasing the visibility of supply chains and improving the delivery of strategic objectives, using IoT. IoT helps to streamline supply chains and create smart supply chains (SSCs). Strategic management focuses on value chain activities, which are based on the pillars of Industry 4.0. Industry 4.0 technologies provide customers with new aspects of added value within the framework of strong product personalisation, speed of delivery, personalized quality, new product usability, and other factors, breaking down various barriers, e.g. spatial, temporal, cultural.

Strategic management in Industry 4.0 integrates technological development with sustainability and circular economy policies. The relationship between circular economy and value chain activities in strategic management was discussed in the paper (Awan et al, 2021). The authors completed a literature review (79 papers) to identify strategic initiatives influencing the redesign of a company's value chain. Industry 4.0 technologies are enabling the development of smart manufacturing, as well as creating new logistics, marketing, sales and service opportunities. Industry 4.0 must be sustainable according to higher-level policies. Gajdzik et al. (2020) pointed out, on the basis of a bibliometric analysis, that the topic of sustainability entered slowly into scientific research on Industry 4.0. In the first years, after the initiation of the Industry 4.0 concept by the German government in 2011, scientific publications focused on new technologies, which were discussed and considered as pillars of Industry 4.0. Over time, practitioners and researchers began to discuss the usefulness of these technologies in the sustainability strategy of industries, economies, societies.

The analysis performed, although based on only 10 papers, enabled the development of a framework for strategic management in Industry 4.0. The framework is presented as a cloud of keywords, identified from the literature review (Figure 2). The strategic activity of companies in Industry 4.0 has been contextualised, starting with small projects and, over time, encompassing more complex projects that go beyond the company and are implemented in chains of business activity, taking into account the objectives of government policies.

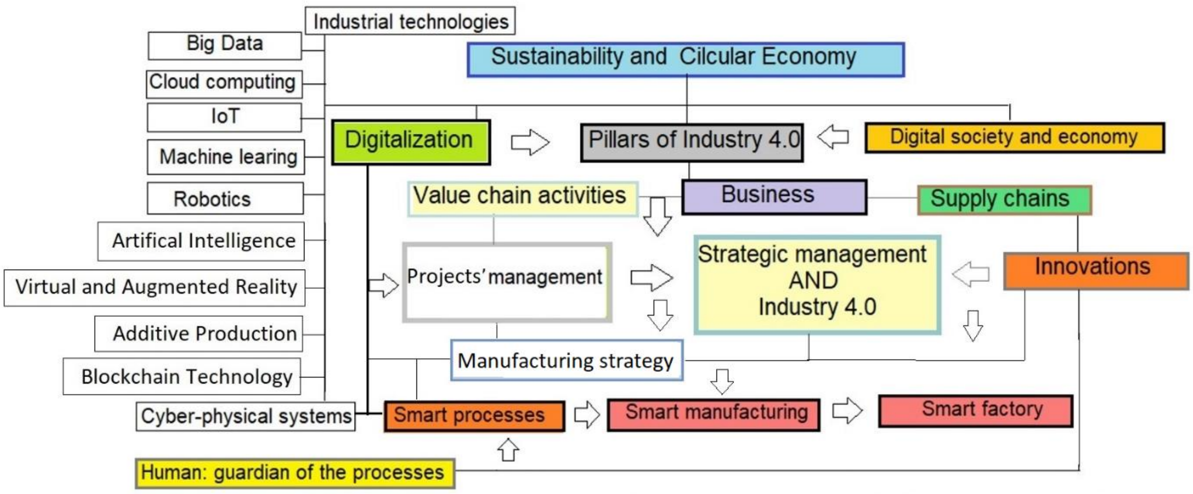

Figure 2 Framework of strategic management in Industry 4.0 [own elaboration]

4 Discussion

The digitalisation and technologies of Industry 4.0 promise to deliver many new opportunities and benefits for industrial companies, such as increased product quality and process reliability and operational flexibility. Although Industry 4.0 shows great potential from a technological perspective, many companies in the process industry still face challenges in using the next generation of technologies in their manufacturing processes. For companies to participate in the co-creation of Industry 4.0, they need to build smart manufacturing at home. Companies invest in new technologies in order to have the conditions and capabilities to realise smart management of production, marketing, logistics, etc. The process of creating smart manufacturing is complex and long-term. It cannot be realised without a good strategy of action at the level of the organisation and at its operations (from the provision of Industry 4.0 in the company strategy to the smart manufacturing strategy) (Ganzarain and Errasti, 2016, Das et al, 2022).

The implementation of projects to implement Industry 4.0 technologies in organisations is of interest to many companies, regardless of their size or the sector in which they operate. The holistic approach in this concept focuses on the smooth functioning of integrated processes, in the context of the organisation's goals and strategic objectives. Despite the use of many solutions and implementation methodologies, projects are not always successful, and many difficulties and constraints arise during implementation (Brzezinski and Bitkowska, 2022). Particular rationales for the use of projects in organisations are the increase in complexity, variability and dynamism of the environment and the individualisation of customer requirements (Nowosielski, 2017).

Companies need a strategy in order to reach Industry 4.0. There is no strategic management without a stratagem that is founded on a well-crafted situation analysis. Companies need to create images that answer three questions: What is the situation? What should the situation be? What might the situation be (Chirumalla, 2021). The juxtaposition of key challanges with key enablers is a construct of strategic management in the transformation of companies to Industry 4.0. The environment in which companies do business is increasingly difficult to predict, so it makes sense to create images of what was, what is and what will be (Kaurav and Gupta, 2022).

Strategic management is an important level of governance for organisations on their journey towards Industry 4.0. Strategic management in Industry 4.0 is inextricably linked to Industry 4.0 technologies (Big Data, Cloud Computing, AI, IoT, Machine Learning, Blockchain, robots, additive manufacturing e.g. 3D printing, virtual and augmented reality). Strategic management is a prerequisite for building a business maturity model (Çınar et al, 2021). A company that claims to be building smart manufacturing must have evidence that the organisation is investing in Industry 4.0 technologies and IT infrastructure (Kamble et al., 2020).

A manufacturing strategy should be an accessible and clear roadmap for a company transposing to Industry 4.0. Bibby and Dehe (2018) analysed Industry 4.0 technologies and ranked their impact on the maturity of a company. The authors distinguished three segments, the pathways of Industry 4.0, these segments are: business processes, people and organisational culture and organisational strategy. In the [Strategy] segment, the authors identified three sub-areas: technological investment, agility vision and manufacturing strategy. The authors concluded that "A solid and clear strategy, an ambitious and well thought out technology investment plan and an agility vision are important characteristics (features) of an organisation on its path to Industry 4.0".

The strategic management process must have a signpost, which is everything that can be described as smart (smart products, smart procedures and processes, and smart factories). Smart is the basis for the competitiveness of companies in Industry 4.0 (Porter and Heppelmann, 2014). The implementation of innovations described as smart in companies is a multi-stage process that involves the entire organisation and its collaborators (Zhong,et al, 2017). The co-creation of Industry 4.0 implies the integration of technologies, processes, products, etc. Johnsson and Brandl (2018) distinguished four levels of integration: (1) products, (2) processes (3) vertical integration, (4) horizontal integration. Vertically integrated production systems are when the systems involved in a company's value chain (from strategic management to the plant operational level) are integrated. There is a shift from strategic management within the company to chain management and horizontal integration in value chains (Mangla et al, 2022).

An important determinant of strategic management in Industry 4.0 is the agility vision of development. Any organisation (enterprise) that wants to participate in the co-creation of Industry 4.0 must have the ability to quickly and easily adapt processes, technologies, products, chains to customer requirements while maintaining high quality and productivity in production systems, distribution, etc. (Erol et al 2016a, 2016b). The vision of agility is viable when a company invests in fourth industrial revolution technologies that enable it to build a smart environment. Without smart manufacturing there is no agility and therefore no customisation and personalisation of products. Honglei et al (2022) identified levels of risk in flexibility strategies. Risks exist on the technology, organisational, innovation, management and financial sides. Strategic management needs flexible management capabilities, which the authors describe as open-mindedness. Low open-mindedness means that few employees, have a broad vision, open thinking and highly approve of the transformation of corporate strategy to Industry 4.0.

Chatha (2018) studied the impact of firms' technological and resource conditions on the implementation of smart manufacturing strategies. The areas of research were technology portfolio, enterprise resource planning and proactive manufacturing and modularity-based manufacturing practices. Chirumalla (2021), on the other hand, used a multiple case study method in his study and developed a framework for building digitally assisted process innovation using the dynamic capabilities of the organisation. The study found that poor strategy and lack of data readiness, as well as lack of standardisation practices for change, as well as competency and cultural gaps and ad hoc problem solving, are barriers to building smart manufacturing and smoothly transforming a company from traditional process innovation to digital process innovation.

In Industry 4.0, or rather in companies building smart manufacturing, people (employee teams) are important, who need to collaborate with next-generation technologies and benefit from access to Big Data as a collection of data useful for strategic management. Akhtar et al. (2019) highlighted the importance of multidisciplinary skills of employees using Big Data. Among these skills were computer science, mathematics, statistics, machine learning and business domain knowledge, which help managers transform traditional business operations into modern data-driven ones (e.g. knowledge of real-time price changes and customer preferences). The paper (Akhtar et al, 2019) highlights that strategic agility comes from big data-driven (BDD) activities that improve business performance.

At the core of building smart manufacturing are projects, so it is necessary to know their essence and relevance to the implementation of the company's strategy. Alkaraan (2020) formulated the question: are recently developed analysis techniques (i.e. those that aim to integrate strategic and financial analyses) being employed to evaluate strategic investment projects? The answer concerned Strategic Investment Decision-Making (SIDM) practices that are the art and science of steering and controlling organisational resources to achieve a desired strategy. Findings of this study reveal the influence of pre-decision control mechanisms on SIDM practices. Pre-decision proceedings are influenced by changes in internal and external contextual factors, including organisational culture, organisational strategies, financial considerations, including formal approval management mechanisms, regulatory and other compliance policies affect companies' internal control systems. Companies consider non-financial factors alongside quantitative analysis of strategic investment opportunities.

Project management is about descending from the level of strategy to the operations of workstations (Fuchs, 2018), which are already highly digitised in companies after the third industrial revolution (Dery, 2017). Digitisation of workstations facilitates (streamlines) companies to improve processes and products, and its understanding is broader than it was in the third industrial revolution because it very often means 'agility' (Verhoef, et al, 221, Vial, 2019). Companies' strategies should reinforce the symbiosis of digitality, technology and social expectations. Strategic management cannot be limited to the company alone but must enter supply chains and the business environment.

The strategic management of companies on their way to smart manufacturing needs to realise the tenets of sustainability. Green supply chain management (GSCM) have specific components, such as internal environmental management (IEM), green purchasing (GP), ecodesign (ED), eco-customer collaboration (CC) and environmental investment recovery (IR) (Alghababsheh, et al, 2022). The business strategy (i.e. cost leadership strategy and differentiation strategy) build a wide range of GSCM practices.

Ayan et al. (2022) analysed the relationship of blockchain technology (BT) with a sustainability orientation in supply chains and logistics. The authors used a systematic literature review method (publications from the Scopus and Web of Science databases, comprising 552 publications between 2017 and 2022) and built examples of strategic linkages. Two key segments of companies' transformation to Industry 4.0 are evident in the authors' research (Ayan et al, 2022): the first concerns environmental management and the second the application of innovative Industry 4.0 technologies such as IoT, Big Data and others.

Smart circular economies need circular strategies (Kristoffersen et al., 2020), and sustainability is a determinant of corporate social responsibility (Sharma et al., 2020, Rosa et al., 2020). In circular strategies, there are strategies for raw materials and sourcing (e.g. use of recyclable materials and sourcing of waste), production (e.g. reworking and cascading through industrial symbiosis), logistics and energy (e.g. optimised routing and renewable energy), product use and operation (e.g. operations (e.g. product longevity and use of unused capacity). Smart circular strategy is embedded in the end-of-life and end-of-life processes of many products (e.g. reuse and remanufacturing), materials (e.g. recycling and composting), technologies, etc. A useful technical mechanism in realising the smart circular strategy is virtualisation through new ways of delivering functions and/or value propositions of products.

Kumar et al. (2022) highlighted the importance of sustainability in strategic management, emphasising the importance of energy intensity, decarbonisation and other challenges of modern economies. Sustainable manufacturing incorporates sustainable activities at all production levels - product, process, and system. It is further broadened to include more R's, such as reducing, reusing, recovering, recycling, redesigning, repurposing, remanufacturing, and refurbishing (Javaid et al, 2022). Strategic management based on Industry 4.0 technologies should assume that the technologies implemented should support the desire of companies, industries and economies to preserve the environment for us and for future generations.

In conclusion, strategic management is changing with the development of companies and the dynamics of their environment. The innovations of Industry 4.0 are building new business models (Løbner and Goduscheit, 2022). In the new business models, smart innovation enters production technologies, market expansion, supply chain, product lifecycle, workplaces etc. Strategic management in the new conditions of Industry 4.0 must be more agile than before and more open to the environment.

5 Conclusion

The literature review attempted to identify the essence of strategic management in Industry 4.0. The segmented literature review performed established that: companies need to reorganise their existing growth strategies and initiate investments (innovations) in order to co-create Industry 4.0. The big strategy as well as the strategies at different levels of the organisation should fit into the principles of Industry 4.0. There is a long way from smart manufacturing to smart value chain, and it has to be well planned. On the road to Industry 4.0, companies must take into account overarching policies, including sustainability goals and the requirements of the circular economy. Industry 4.0 technology should serve to improve environmental quality.

This study is a first step in understanding strategic management in the face of challenges to the development of companies in Industry 4.0. The study provides a framework for the strategic business management of companies in their transformation to Industry 4.0.

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Modelling of aerodrome control processes based on coloured Petri net queueing model with priorities

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Abstract. Aerodrome control service provided by air traffic controllers to aerodrome traffic contains different kinds of clearances, instructions, and information with dissimilar levels of priorities. A special set of instructions issued to aircrew of departing aircraft on the apron before start-up is called clearance delivery. It has one of the lowest priorities in the controller's job and can be provided from a separate working position. The paper describes a priority queueing model representing these aerodrome control processes; the mode is based on coloured Petri nets. CPN tools were used to create the model. An experiment that was run with the model showed the controller capacity limit when the clearance delivery service shall be provided from a separate working position to increase control tower capacity.

Keywords: Air traffic control, Aerodrome control, Coloured Petri nets, CPN Tools, Tower capacity.

JEL Classification: C63

1 Introduction

The aerodrome control tower (TWR) is the unit established at the controlled airport to provide aerodrome control service to traffic. The tower controller (also referred to as "aerodrome controller") is responsible for the provision of air traffic services to aerodrome traffic. Aerodrome traffic includes the traffic in the manoeuvring area, i.e., runway(s) and taxiway(s), and traffic in the vicinity of the aerodrome, i.e., any landing and departing aircraft and any aircraft that is on, entering, or leaving an aerodrome traffic circuit. The TWR controller also communicates with aircraft on the apron(s), although this is not a part of the area of his/her responsibility.

There are three major types of traffic served by the TWR controller:

- Departures.
- Arrivals.
- Overflies, i.e., aircraft passing through the control zone (CTR). CTR is a controlled airspace extending from the surface of the earth to a specified upper limit designed around a controlled aerodrome to protect aerodrome traffic. These are a relatively small part of the total the TWR controller serves.

Each of the mentioned major types of traffic requires some typical actions and considerations related to the provision of aerodrome control service. For the departure flights the TWR controller issues information, air traffic control (ATC) clearance, clearance for the

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start-up of the engine(s), and provides aerodrome control during the taxi and the take-off phases of the flight. For the arrival flights the TWR controller provides control during the landing and taxi phases of the flight. The transit overlies include mainly low-flying VFR (Visual Flight Rules) flights and these flights need to obtain entry clearance into the CTR as well as related information.

Except for those three major types of flights, there can be special flights such as training flights (comprising multiple take-offs, landings, and flying the aerodrome traffic circuit) or calibration flights (inspecting if the aerodrome navigation aids are operating as expected). While they technically fall into one of the above-mentioned categories, the prolonged period they spend in the TWR's airspace justifies them being treated as a separate type of flight.

The last specific type of traffic that must be considered is mobile vehicles and personnel moving along the manoeuvring area. Each entry and activity at the manoeuvring area must be subject to TWR controller clearance to achieve one of the aims of aerodrome control service which is preventing collisions between aircraft and obstructions. Standalone frequency can be dedicated for this purpose, and it is served by the TWR controller.

The number of controller working positions set up on the control tower depends on the traffic demand and the aerodrome layout. Smaller aerodromes with one runway can have single-person operations, i.e., only one controller on duty at any given time. If necessary, another person may assist the controller with traffic planning and coordination with adjacent units and facilities, but they normally do not operate the radio. In the case of a large airport with busy traffic, it is necessary to form another one or more separate working positions.

One of them that can be formed is the ATC Clearance Delivery position operated by ATC Clearance Delivery Dispatcher (CDD). CDD communicates at standalone radio frequency where CDD provides actual weather and aerodrome information including runway in use, time check, actual CTOT (Calculated Take-Off Time), SSR (Secondary Radar) transponder setting, departure clearance, and start-up clearance.

To simplify the whole process of the provision of aerodrome control service, it can be seen as a queueing system. There is a flow of requests with different priorities, a specific time for serving individual requests, and a specific capacity available at a frequency where the service is provided. The paper describes how such a priority queueing system can be modelled using coloured Petri nets and a result of the experiment done with the model. The aim of the experiment was to find a controller capacity limit when the new separate working position for the ATC clearance delivery service must be activated to absorb more traffic. The maximum acceptable mean waiting time for the departing flights waiting for ATC clearance delivery was set to 4 minutes for the experiment purposes.

1.1 Literature review

This approach to the issue is limited by simplifying the decision-making process in ATC. It is not a simple queuing system with the first-in-first-out service discipline and there is no general rule on how to define the priority of incoming requests. Air traffic control is a very complex area moreover especially aerodrome control requires immediate actions and reactions. Each issued clearance must be evaluated and checked to assure safety. The complexity of the ATC workload is evident for example from Gómez et al (2016) where the authors describe an ATC decision-making process by using a Hybrid Kripke model. Similarly, Kontogiannis and Malakis (2013) discuss the development of a behavioural marker system to evaluate and provide feedback on the strategies that air traffic controllers use. It is allowed for the purpose of the presented issue of this paper to simplify the complexity of ATC work on the control tower since generally, ATC clearance delivery service has the lowest priority. The aircraft which request the ATC clearance is safely parked on the apron and immediate priority action from the controller is not necessary in this case.

Nosedal et al (2015) present an optimization model for airspace capacity-demand management. The same problem of airspace capacity is dealt with by Nosedal et al (2012) where Clustering and Interaction Causal Solver models are applied. In both articles, Petri nets are used. Petri nets were also used for analysing and solving capacity problems in the terminal manoeuvring area of TMA Warsaw – see Kwasiborska and Skorupski (2018), Kwasiborska and Skorupski (2021) and Skorupski and Florowski (2016).

The last area where Petri nets were used for modelling the processes in air traffic is the domain of aerodromes. Kovács, Németh, and Hangos (2005) presented a Petri net model of a single runway to analyse the effect of the availability of taxiways on the capacity of the runway and on the timing of a given schedule. Uehara, Hiraishi, and Kobayashi (2015) present a Petri net model of airport surface traffic. Skorupski and Wierzbicki (2017) analyse the way of braking during a landing roll using the landing roll simulator (named ACPENSIM) which is based on Petri nets. They showed that by using the proposed braking profiles the runway occupancy time can be reduced even by 50%.

But not only air traffic and aerodrome layout were modelled using Petri nets. Kozłowski, Skorupski, and Stelmach (2018) studied aerodrome Communications, Navigation, and Surveillance systems (CNS) reliability in relation to aerodrome traffic operations and ATC procedures. Skorupski (2015) created a Petri net model to estimate the probability of a collision at the intersection of runways – the model was implemented in conditions of Warsaw Chopin Airport. The last example of using Petri nets in aviation is a study by Skorupski (2016) where a Petri net model was used to assess the probability of aircraft collision.

2 Problem formulation

The model shall describe the TWR controller's workload process at Ostrava/Mošnov International Airport (LKMT). As it was described during low-level traffic is an ATC Clearance Delivery part of TWR controller's work. The whole workload of the TWR controller can be divided into three groups of activities for the model's purposes:

- The first group of activities has the highest priority. It contains the provision of aerodrome control. This includes all instructions and commands connected to all described types of traffic, excluding the ATC Clearance Delivery provision.
- The second group of activities has medium priority and contains the provision of ATC Clearance Delivery to IFR (Instrument Flight Rules) flights.

- The third group of activities has the lowest priority and contains the provision of ATC Clearance Delivery to VFR (Visual Flight Rules) flights.

At present, there is no precise data for the determination, what is the proportion between the period that the TWR controller devotes to the provision of aerodrome control and the period of the provision of ATC Clearance Delivery. Using professional presumption there is 70 % of the available time spent on the provision of aerodrome control service and the rest 30 % of the available time on the provision of ATC Clearance Delivery.

The proportion between the number of VFR flights and the number of IFR flights that request ATC Clearance Delivery service varies during the year and the daytime and it is also affected by the weather. There is a long-term ratio between departing VFR and IFR flights from LKMT airport, which comes from the internal statistics records of Air Navigation Services of the Czech Republic. Departing VFR flights create 60% of departing traffic and IFR flights create 40%. Based on this fact we will assume in the article that volumes of IFR and VFR flights requesting the ATC Clearance Delivery are the same.

3 Simulation model

Priority queues are among the complex queuing systems as they include various types of customers i.e., customers served based on their priority value than their arrival sequence. CPN tools enable to model such complex network queues and concurrent systems – see for example Valero et al (2022). The CPN priority queueing model is developed by assigning traffic for a different queue with their priority. Based on this idea a priority queuing model of the TWR controller's workload process at Ostrava/Mošnov International Airport using CPN tools in version 4.0.1(https://cpntools.org) was developed.

The Petri net model is constructed with 16 places, 9 transitions, arc inscription and colour sets. When we developed the model initially, we declare some standard colour sets such as *INTINFtm*, *INTINFlist*, *UNITtm* or *p* and variables like *aircraft* and *aircrafts* – see Figure 1. Moreover, as the model is a priority queuing model, low, normal and high priority standards as they are pre-defined in the CPN Tools were applied.

```
▼Declarations
  ▶Standard priorities
  ▼Standard declarations
    ▼colset UNITtm = unit timed;
    ▼colset INTINF = intinf;
    ▼colset INTINFtm = intinf timed;
    ▼colset INTINFlist = list INTINF;
    ▼var aircrafts :INTINFlist;
    ▼var aircraft: INTINF;
    ▼colset p = with  x;
    ▼fun ET(EX) = round (exponential(1.0/EX));
    ▼fun NT(n,v) = round (normal(n,v));
    ▼fun WT(l,k) = round (weibull(l,k));
    ▼colset UNIT = unit;
    ▶colset INT
    ▶colset BOOL
    ▶colset TIME
    ▶colset REAL
    ▶colset STRING
```

Figure 1 Declarations of the model

The model is designed to represent three classes of aircraft service – TWR, IFR, and VFR aircraft control service. TWR service has the highest priority; IFR service has the medium priority and VFR service has the lowest priority. An air traffic controller is modelled with a common place called "*Free server*" – the initial marking of the place is defined so that a token representing the air traffic controller is found in the place – and the rest of the transitions and places are assigned for each class of service. In the model, the places "*TWR rate*", "*IFR rate*" and "*VFR rate*" model the places via which an input stream of individual requests is modelled. By firing the transitions "*TWR*", "*IFR*" and "*VFR*" individual requests for service enter the corresponding queues modelled by places "*Queue A*", "*Queue B*" and "*Queue C*". The transitions "*TWR service start*", "*IFR service start*" and "*VFR service start*" model beginning of the service of individual customers' classes, a token found in the places "*TWR service*", "*IFR service*" or "*VFR service*" models serving the corresponding request for service and via firing the transition "*TWR service end*", "*IFR service end*" or "*VFR service end*" the service is finished – there is a server shared by all types of requests. The probability distributions we used to model inter-arrival and service times will be discussed in the following section.

The places "*TWR waiting for service*", "*IFR waiting for service*" and "VF*R waiting for service*" are designed to estimate the mean number of aircraft found in the corresponding queue and the places "*TWR arrived*", "*IFR arrived*" and "*VFR arrived*" are used to estimate the mean number of aircraft found in the whole system.

After the model was created, 15 monitoring functions were defined to obtain the desired outcome. It is possible to categorize them into the mean number of requests in the queue (*Eq*) and in the system (*EL*), the mean waiting time in the queue (*EW*), the mean time spent in the system (*ET*), and mean number of requests in the service (*ES*). For each type of request separate monitoring functions are defined.

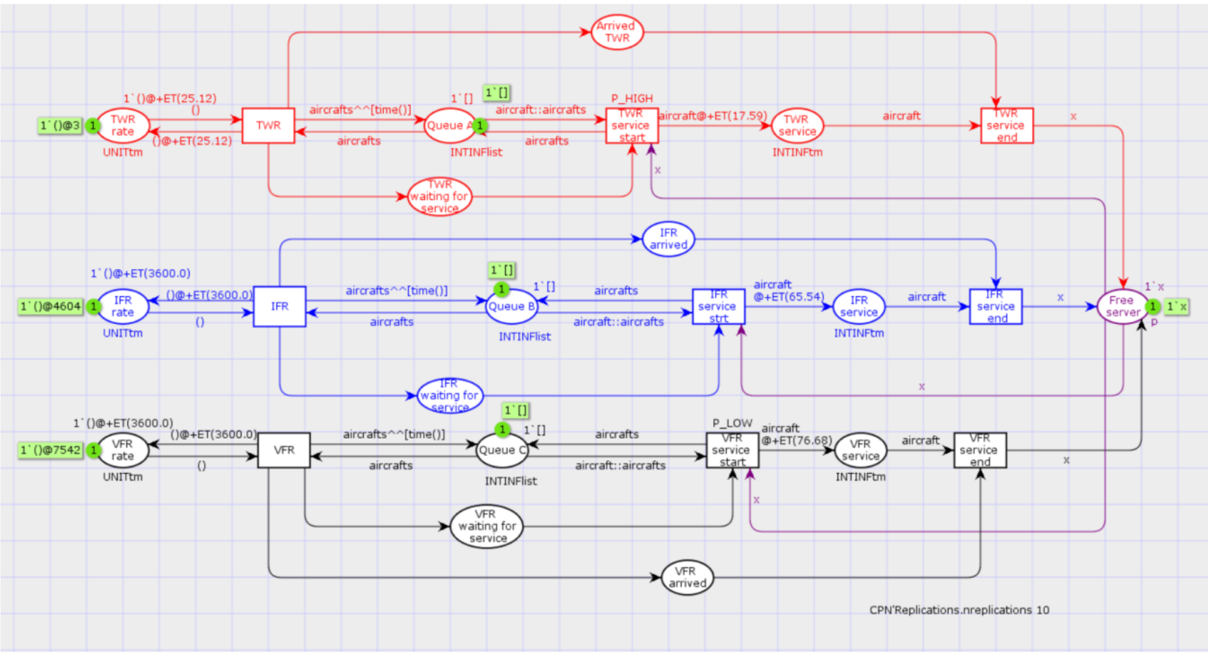

Figure 2 Priority queueing model using the CPN tools

Finally, to terminate a simulation run at a specific time we applied the standard CPN Tools breakpoint monitoring function with the predicate function "*fun pred () = IntInf.toInt(time()) >2592000*" which means each simulation run is terminated after reaching the simulation time 2 592 000 seconds which corresponds to 30 days. In addition to this to simulate the model 10 times the auxiliary text "*CPN'Replications.nreplications 10*" was used. The final Petri net model is shown in Figure 2.

4 Simulation experiments

Because this is a preliminary study, no precise data on probability distributions of arrival processes and service times of individual classes of requests are currently available. Therefore, the decision was made to experiment with three probability distributions – exponential, normal and Weibull distributions to compare the result – these probability distributions are used to model service times. To model inter-arrival times, the exponential distribution was used only.

The following assumptions for modelling inter-arrival times and service times were established:

- The inter-arrival times for TWR requests are modelled by the exponential distribution with the mean value 25.12 seconds. For TWR requests we further assume that for exponentially distributed service times the mean value is 17.58 seconds, for the normal distributed service times the mean value is 17.58 seconds with the dispersion 67.25 seconds^2 and for Weibull distributed service time the scale parameter is 19.91 seconds and the shape parameter 2.26. In all cases the service times are set up so that the utilization of the air traffic controller is 0.7 to satisfy the assumption that 70 % of the available time is reserved for the provision of aerodrome control service.
- 11 different values of mean inter-arrival times for IFR and VFR requests was used to study impact on the mean waiting times of these requests, namely 0, 3600, 1800, 1200, 900, 720, 600, 514.28, 450, 400 and 360 seconds. In all cases the inter-arrival times are modelled by the exponential distribution of probability.
- The mean service times for the exponential distribution of classes IFR and VFR are 65.54 and 76.67 seconds respectively. Classes IFR and VFR have the mean service times of 65.54 seconds and 76.67 seconds and the dispersions of 162.05 seconds^2 and 218.74 seconds^2 respectively for the normal distribution. For the Weibull distribution, the scale parameters are 70.84 seconds and 82.85 seconds, and the shape parameters are 5.37 and 5.37 respectively.

Table 1 indicates results – point estimations of the mean waiting times for IFR requests – and Table 2 presents results of the same meaning for VFR requests. We present only these results because they are the most important – they provide information how long must IFR and VFR requests wait to be serviced on average. As we can see from the results when the mean inter-arrival time increases the mean waiting times decreases. Moreover, we can see the results for individual service time probability distributions are comparable one another (for the corresponding values of inter-arrival times), the exponentially distributed service times yield the highest mean waiting times in most cases. We can see that the mean waiting times of VFR requests are essentially higher – this is because these requests have the lowest priority.

As stated earlier, the 4-minute average delay was set as the maximum acceptable limit of the mean waiting time of aircraft requesting the clearance delivery service. The experimental results showed that for given time service periods the limit is reached for 2 IFR flights and 2 VFR flights flow in an hour. From that moment it would be necessary to activate a separate working position for clearance delivery service to allow more flights expecting the service with an acceptable waiting time.

Mean inter-arrival time [s]	Mean waiting time [min] – exponential distribution	Mean waiting time [min] – normal distribution	Mean waiting time [min] – Weibull distribution
0.00	0.00	0.00	0.00
3600.00	2.93	2.94	2.93
1800.00	3.78	3.29	3.45
1200.00	4.78	3.80	3.82
900.00	5.79	4.36	4.46
720.00	7.00	5.11	5.22
600.00	8.45	5.81	6.09
514.29	10.54	6.81	6.99
450.00	11.99	7.79	7.96
400.00	14.78	8.63	8.91
360.00	16.51	9.68	10.09

Table 1 The mean waiting times for IFR requests

Mean inter-arrival time [s]	Mean waiting time [min] – exponential distribution	Mean waiting time [min] – normal distribution	Mean waiting time [min] – Weibull distribution
0.00	0.00	0.00	0.00
3600.00	3.50	3.35	3.54
1800.00	5.12	4.28	4.59
1200.00	8.22	5.84	5.99
900.00	12.37	8.27	9.06
720.00	20.86	13.33	14.82
600.00	38.94	24.72	30.55
514.29	112.76	77.81	148.30
450.00	2181.82	2347.84	3568.61
400.00	6350.68	6670.47	7875.02
360.00	9430.69	9887.04	10539.06

Table 2 The mean waiting times for VFR requests

5 Conclusions

This paper has shown how the processing of aerodrome traffic service can be modelled by coloured Petri nets with priorities of solving tasks. Except an emergency situation the real priority of each individual task is never clearly stated. Tasks are always subject to actual traffic situation, and it is the controller who is finally responsible for the proper, safe and expeditious solution. To be able to model the process the tasks were divided into groups where priorities among each group of tasks can be stated.

The capacity of the controller is limited by the available time that the controller must spend solving each task. The time period of the communication was used for the service time description and it is obvious that it varies for every group of tasks. At any given time, he can devote himself to the solution of only one task (communication) and this creates a delay and waiting for other incoming requests. With increasing traffic, a moment arises when the delay period is no longer acceptable, and action must be taken to continue the service – based on the experimental results we can say that the limit is reached for 2 IFR flights and 2 VFR flights flow in an hour. From that moment it would be necessary to activate a separate working position for clearance delivery service to allow more flights expecting the service with an acceptable waiting time.

The following work and study shall focus on the determination of probability distributions of arrival processes and service times of individual classes of requests. The determination of the proportion between the period that the TWR controller devotes to the provision of aerodrome control service and the period of the provision of ATC Clearance Delivery service as well as the determination of how the proportion is changing with an increasing flow of traffic is inevitable for more precise experiment results. It is also possible to experiment with more complex priority logic to lower the waiting times of VFR flights.

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Exploring the potential of using system dynamics to develop a regulatory policy for a plastic waste management system

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Abstract. The collection and recycling of plastic waste are very important for the prevention of environmental pollution and the fight against climate change. System dynamics confirms its important role as a tool for modelling the consequences of the application of various regulatory measures. Therefore, the paper deals with the application of simulation modeling of plastic packaging waste recycling based on system dynamics. The main goal of the paper is to find out whether it is appropriate to use simulation methods, including system dynamics, to develop regulatory policy in the area of plastic waste management. The authors used a systematic approach to understand the plastics market and its role in the economic system and the potential impact of simulation modelling on policy formulation in relation to sustainable development. The authors also used a big data approach whereby literature was identified using specialized databases.
The authors drew conclusions on the extent to which system dynamics can serve as a tool for long-term policy making in the field of plastic waste management.

Keywords: system dynamic, simulation modeling, plastic waste, plastic recycling, policy simulation.

JEL Classification: Q01, Q58, Y3

1 Introduction

With the recent increased attention being paid to the issue of environmental pollution, there have been major demands to limit or even ban the use of plastics in the production of packaging and various products. However, the fundamental problem is that plastic packaging has become an important part of the economic system of modern society.

The situation with regard to the recycling of plastic waste varies considerably from country to country. To address the problem of collection and treatment of polymer waste, governments of different countries have adopted measures over the past decades taking into account the specificities of consumption, the structure of the economy and other factors[6]. Bans on waste imports to China, Malaysia, Thailand and Vietnam have prompted many developed countries that traditionally export their waste to be more responsible in managing the plastic waste they produce. This matter is explained (Kerdlap et al, 2021). Governments of various countries are

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[6] Decision-making is influenced by factors such as the availability of its own hydrocarbon resources, the development of the chemical and petrochemical industries, the availability of capacities for processing and incineration of polymer waste, consumer behavior, the availability of substitute analogues for plastic products, etc.

developing and adopting Zero Waste plans. The European Union has adopted a European strategy for plastics in the circular economy. This situation is addressed (European Strategy).

The lack of a systematic approach can lead to decisions that have undesirable socio-economic consequences. For example, in 2016, California introduced a ban on single-use plastic bags in retail after a referendum. The behavior of the participants of the referendum was dictated by concern about the pollution of the seashore. Apparently, the consequences of such a ban have not been analyzed in sufficient detail. After the introduction of the ban on single-use plastic bags sales of small plastic garbage bags have increased dramatically. This is primarily due to the fact that earlier buyers used mainly packaging bags received in the store for garbage. In addition, the main demand from disposable plastic has shifted not to the segment of reusable bags, but to disposable paper bags. This is described (Taylor, 2019). Studies show that, if we analyze the full life cycle of a product, the negative impact of paper bags on the environment is no less than for plastic analogues.

The difficulties of finding quick and simple solutions to restrict or ban production are due to the fact that plastic packaging has become an important part of the economic system of modern society. The socio-economic context for making such decisions varies from country to country.

The waste management system, including polymer, is a complex socio-technical system, which is characterized by dynamism resulting from strong interactions between participants, feedbacks, nonlinearities, path dependencies, compromises and the distance between cause and effect in time and space. The problem is described (Sterman, 2000). Chang and Pires (2011) pointed out an important fact. In order to support decision-making in the field of solid waste management, the authors of publications have used various methods of system analysis, including system dynamics. This simulation technology allows you to visually conceptualize and simulate various aspects of the behavior of complex socio-economic systems. System dynamics makes it possible to develop a long-term policy in a specific field of activity. This application of the system dynamics approach was emphasized by its creator J. Forrester. He called politics the rules that determine decisions. Forrester (1998) believed that system dynamics was useful in developing policies that would lead to more favorable behavior of systems. In this context, the application of system dynamics can be useful for the development of long-term policies for the implementation of the principles of sustainable development, including in the field of plastic waste management.

This study is devoted to the application of simulation modeling of plastic packaging waste recycling based on system dynamics. In some industries, the collection and disposal of plastic waste is well established. The area of our analysis will be post-consumer polymer packaging waste, which is created by billions of people.

The premise of our research is that to develop a regulation policy in the field of plastic waste management, it is advisable to use simulation methods, including system dynamics.

The main goal of the paper is to find out whether it is appropriate to use simulation methods, including system dynamics, to develop regulatory policy in the area of plastic waste management.

2 Methodology

The analysis of how simulation modeling can help in the formulation of policies to increase the degree of recycling of polymer waste and the transition to Circular Economy is carried out in accordance with the following sequence of actions. At the first stage, we analyzed publications devoted to the study of the plastic waste market. Gatto et al (2023); Gothár and Schanz (2022); Freeman et al (2014); McKinnon et al (2018); Zhang and Wen (2014) used a systematic approach to understand the plastic market and its role in the economic system of countries. The purpose of the analysis was to identify the main participants in the process of collecting and processing plastic waste, the main problems existing methods of regulation.

At the second stage the big data approach was used to analyze publications, while specialized literature was determined using the databases Web of Science (Clarivate), ScienceDirect (Elsevier ScienceDirect) and the social scientific network ResearchGate.

The search with combinations of the words ‘system dynamics’ and ‘plastic waste’ gives us 25 publications from ScienceDirect. Some publications were devoted to technological issues, some publications do not contain explanations about the type of simulation model. Of the 15 publications that were found on this platform, 14 were in English and one was in Chinese. Two publications in English were found in the WoS database and two on the ResearchGate network. The lists of publications received on various platforms were analyzed for repetition. 17 publications with open access have been downloaded and systematized.

Year of publication	**Scopus**	**Web of Science, ReseargeGate**
2002		1
2004	1	
2010	2	
2012	1	
2014		1
2016	1	1
2019	3	
2020	2	
2021	1	1
2022	2	
2023	2	
Total	15	4

Table 1 Distribution of publications by year

One of the authors of our study participated in modeling the econometric parameters of various scenarios for the regulation of flexible polymer packaging in Russia. The results of the study have not been published because they are proprietary. Scenario modeling was based on the system dynamics approach. The experience gained in the course of this study will be taken into account when analyzing the collected publications.

At the next stage, the publications were analyzed in order to determine which processes within the plastic waste management system were the subject of the authors' research. They were also systematized by the countries for which the simulation was performed. The territorial scope of the research shows that system dynamics is used to study waste management systems in countries where the largest amount of plastic packaging is consumed. The analysis of the research objectives, the territorial coverage, the collected data, as well as the results obtained made it possible to compile a list of issues for which simulation models based on system dynamics were developed. This allowed us to draw conclusions to what extent system dynamics can serve as a means for developing a long-term policy in the field of plastic waste management.

3 Results and discussion

3.1 Plastic waste recycling system: key players and the main problems

Gothár and Schanz (2022); McKinnon et al (2018) state that the market for waste plastics is multifaceted and complex, with many actors and multiple inhomogeneous and highly differentiated waste streams, production processes and products.

Based on Freeman et al (2014); McKinnon et al (2018); Zhang and Wen (2014); Zimmermannová et al (2022), the authors of this paper have compiled Table 2, which shows the waste generation and management process in relation to the main actors and activities at different stages. Part of the polymer waste is incinerated (with or without energy recovery) or landfilled, as well as waste generated in all these phases that is not recyclable for various reasons.

Stage	Actors	Activities
Creating plastic waste	Consumers	Creation of post-consumer plastic waste Pre-sorting
Collection of plastic waste and preparation for recycling	Collectors: municipal, private (retail stores, buy-back centers, scrap dealers), informal (scavengers)	Collection of plastic waste using various methods and logistics
	Waste handler with low-value addition	Cleaning, sorting and separation, bulking
	Compounders with semi-processing – high value addition	Recycling plastic into granules, flakes, agglomerates
Remanufacturing	Recyclers	New products developments from recycled polymer materials

Table 2 Stage and actors in the process of collecting and recycling plastic waste

In order to represent the process organization, as well as material, financial and information flows between process participants, it is necessary to take into account the specifics of the organization of the plastic waste market in different countries. Ameir (2021); Freeman et al (2014); Zhang and Wen (2014) state that the level of centralization of the regulation of the plastic waste market also varies in different countries. Depending on the degree of centralization and legal regulation, the level of authority of special bodies designed to regulate relations between participants in this market varies. To coordinate the PET bottle recycling collection system of the United States, Japan, and Brazil were established a specialized organizations (i.e., NAPCOR in the US, CPBR in Japan, and ABIPET in Brazil). These agents are responsible for giving statistical reports of consumed and collected PET bottles. These agents study the PET bottle recycling collection system and give improving suggestions for the recycling collection system. This is described (Zhang and Wen, 2014). In Japan there is a special body that coordinates the process of collecting and processing PET. Council for PET Bottle Recycling (CPBR) established in Japan in 1993. The system is operated under The Containers and Packaging Recycling Law. The problem is described (Zhang and Wen, 2014). The presence of such a rigid system has contributed to the fact that Japan has a high percentage of PET waste collection.

Zhang and Wen (2014) state that in China, Brazil, Indonesia and some others countries the primary collection of PET waste is carried out by private scavengers. The publications note a high percentage of PET waste collection in China. At the same time, the authors of a number of publications believe that simulation contributes to the development of effective measures to regulate the waste market. This situation is addressed (Wäger and Hilty, 2002); (Zhang and Wen, 2014).

Polymer materials for the production of plastic packaging can be produced domestically or imported. Countries can export some of their plastic waste. For a long time, the largest importer of polymer waste was China, whose companies bought waste all over the world. But after the introduction of waste import ban in 2018, export flows have moved to other countries, where polymer waste is mainly incinerated or recycled with environmental damage. In the next years waste import ban was approved in Malaysia, Thailand and Vietnam.

The structure of material flows in waste markets is extremely heterogeneous. As a rule, there are leading products that provide the bulk of recyclable materials. So, among the waste paper and cardboard, the main product is corrugated cardboard. As a rule, more than 90% of corrugated cardboard is collected and processed in different countries. Such a product among polymer waste is PET. The bulk of PET packaging is collected and processed. There are processing technologies, the volumes of recycled materials are large and stable. PET can be recycled up to 6 times. There are special organizations that collected data on the material flows of PET waste and prices. This contributes to the fact that a considerable part of publications on polymer waste markets is devoted to PET. The analysis of the collected publications makes it possible to identify the main problems of the organization of the plastic waste market. We have identified separately the problems concerning consumers and organizations (business structures, government agencies, NGOs and others).

Based on Freeman et al (2014); Chlopecký et al (2020); McKinnon et al (2018); Wilson et al (2012), the authors of this paper have compiled the following list that summarizes the main problems and barriers to the development of plastic waste recycling by consumers:

1) consumerism
    a) the idea of consumerism, which encourages people to buy more of everything,

2) consumers' interest in collecting and sorting plastic waste
    a) separation of plastic waste, cleaning and sorting require efforts on the part of the consumer,
    b) the media and authorities mainly stimulate consumers by showing the threats that plastic waste poses to nature,
    c) there are economic incentives in different countries (deposit system, buy-back, and others),
3) knowledge gap
    a) many people have no knowledge of the complexity and cost of replacing some packaging materials with others (information is often given to the consumer in a simplified way, which can create a misconception, for example, that paper packaging waste is always less harmful to the environment),
    b) consumers may not be aware of the full cost of waste (for example, spent raw materials and labor costs embedded in products) or preventive measures that they could take to reduce it,
4) lack of design for recycling
    a) the lack of attention to the design of products containing polymers, including packaging design, leads to the fact that it is difficult for consumers to divide such a product into the same types of materials for subsequent recycling.

Based on Freeman et al (2014); Chlopecký et al (2020); McKinnon et al (2018); Wilson et al (2012); Wong (2010); Kerdlap et al (2021), the authors of this paper have compiled the following list that summarizes the main problems and barriers to the development of plastic waste recycling by organizations:

1) market fragmentation
    a) the plastics market is very fragmented and cannot be described as a "single market",
    b) market fragmentation depends on differences in technologies and commercial interests of the participants at different stages of collection and processing,
    c) the customer is not always sure of the quality and uniformity of the purchased waste,
    d) plastic waste comes from different waste collectors (“plastic" is a generic term for many chemical polymers that should preferably not be mixed in a recycling process),
2) lack of demand for recycled plastic waste
    a) demand strongly depends on the size and quality (uniformity) of the batch of secondary raw materials,
    b) the small volume of secondary raw materials makes its processing uneconomical,
    c) another part of the problems is related to the quality and price competitiveness of recycled plastic compared to primary plastic,
    d) these factors may be the result of a lack of cooperation in the value chain, lack of communication and coordination between the stages of the recycling process,
3) split incentives
    a) the beneficiaries of actions to increase the level of collection of plastic waste may differ from those who have the costs of these actions (for example, an extended

product life will benefit the consumer and the local authorities who have to collect waste, but not necessarily the manufacturer who invested in it),

4) informational
    a) consumers and businesses may not be aware of the full costs of waste (e.g. wasted raw materials and labor costs embedded in products) or preventative actions they could take to reduce it,
5) behavioural Short-termism
    a) decision makers in organizations often underestimate the value of long-term benefits versus short-term costs and/or overestimate the risks associated with such long-term investments,
6) Lack of consumer demand for recycled plastic products
    a) consumers rarely make specific requirements for reducing waste from enterprises,
    b) in recent years, the interest of consumers, especially young people, in the "Green Agenda" is beginning to encourage enterprises to improve overall environmental performance,
    c) in particular, consumers prefer more environmentally friendly types of packaging,
7) corporate culture
    a) the business culture of a number of companies does not support efforts to reduce waste from polymer materials due to the lack of commitment of the management to the principles of the ESG and the inability to integrate this activity within the business,
    b) many countries have implemented Extended producer responsibility (EPR) strategies in terms of packaging waste management,
8) competing goals
    a) the widespread practice of recycling and disposal of waste to landfills can prevent the conversion of waste into a source of secondary raw materials,
    b) the sale of polymer waste to other countries creates the appearance of an easy solution and the success of existing waste management practices,
9) lack of infrastructure
    a) there are technological barriers to increasing plastics recycling, and there is often a chicken/egg problem related to the market and technology,
    b) investments in waste management infrastructure and technical innovations contribute to overcoming some of the technical and logistical barriers that the market is currently facing,
10) life cycle assessment (LCA) approach
    a) recycling plastic waste is generally perceived as an environmentally sound practice, as it saves energy, reduces the extraction of raw materials and tackles climate change,
    b) research using the LCA approach has shown that plastic recycling supply chains can be logistically inefficient, sprawling, fragile and even harmful to the environment,
    c) transporting plastic waste between the various parties involved in collection, trade, transportation, sorting, storage and recycling can lead to excessive emissions from vehicles that exceed the harm from landfilling of plastic,

11) informal sector
    a) in developing countries and countries with economies in transition the informal sector (scavengers) plays an important role in the chain of plastic packaging collection.

Authorities at various levels (state, regional, municipal) can take measures to regulate the plastic waste management system in a certain territory. Such measures may take the form of bans on the use of certain types of plastic, subsidizing collection and recycling processes, creating special bodies to coordinate processes, etc. Only market mechanisms of supply and demand cannot cope with the growing volume of plastic waste. As we can see from Table 4, the plastic waste market is highly fragmented. Stable flows exist only for products such as PET packaging. The high cost of recycling other plastic waste and the low profitability of processing low-value secondary raw materials require the introduction of subsidy mechanisms and responsibility of the business that produces plastic packaging. Thus, Sun et al (2021) summarizes the experience of applying various subsidy strategies. The authors conclude that the coordination of the activities of many agents and the management of the market mechanism are important priorities in the development of a subsidy-based policy. System dynamics was applied to assess regulation scenarios with the help of subsidies.

3.2 Simulation modeling of polymer waste recycling processes

System analysis is the most general approach that is used in system modeling. Report prepared for the British Department for Environment, Food and Rural Affairs (Defra) demonstrates the advantages of applying a systematic approach and system dynamics. The problem is described (Freeman et al, 2014). Pires and Chang (2011) state that the use of system analysis methods to support decision-making in the field of solid waste management in recent decades has been associated with the use of various modeling methods. Pires and Chang (2011) illustrate the relationship between the five models of system analysis and other tools. At the same time, they note that cost-benefit analysis (CBA) can be used as a common platform for decision support, and the use of simulation modeling (SM) and FM (forecasting models) together with this approach provides the necessary basis for system analysis.

The three most prominent simulation modeling methods are discrete-event simulation (DES), system dynamics (SD), and agent-based modeling (ABM). DES describes the system as sequences of processes and queues and is suitable for systems with a step-by-step process, for example for modeling the industrial processes. SD can be utilized for either qualitative or quantitative modeling. The qualitative aspect is often represented as a causal loop diagram that shows the cause-and-effect relationship between different elements of the system. The quantitative aspect is often referred to as a stock and flow diagram. This issue is explained (Kerdlap et al, 2021). System dynamics is most commonly used for modeling strategic management, marketing and macroeconomic issues, ecological and social systems. ABM simulates a system that is formed by the behavior of individual agents and their interactions with other agents. In ABM, the agents are autonomously making decisions based on the defined rules. The system behavior arises from a bottom-up approach, namely the sum of individual actions and the interactions (AnyLogic, 2020). Hence, this method is suitable to analyze a system with complex interactions between entities.

The grouping of publications by years and territories for which modeling was carried out is given in Table 3.

Territory	Scopus	Web of Science, ResearchGate
Belgium	2016	Inghels et al., 2016;
China	2010 (2), 2012, 2020, 2021, 2022	Long, 2010; Long, 2010a; Long, 2012; Wang et al., 2020; Sun et al., 2021; Xiao et al., 2022
Egypt	2016	Jaligot et al., 2016
India	2021	Dhanshyam & Srivastava, 2021
Indonesia	2019, 2020	Destyanto et al., 2019; Jati & Ardi, 2020
Mexico	2019	Lagarda-Leyva et al., 2019
Singapore	2021	Kerdlap et al., 2021
Switzerland	2002, 2004	Wäger et al., 2002; Krivtsov et al., 2004
UK	2004, 2014	Krivtsov et al., 2004; Freeman et al., 2014
USA	2023	Ghosh et al., 2023
Oceans	2019	Cordier & Uehara, 2019

Table 3 Distribution of publications by the territory for which the analysis was carried out

These data clearly demonstrate that in the early 2000s, studies based on system dynamics were conducted in developed countries rather in order to show the potential of this approach. This is described (Wäger and Hilty, 2002). In recent years, modeling of plastic waste collection and recycling processes using the system dynamics method has been carried out in developing countries and countries with economies in transition. Dhanshyam (2021); Jati and Ardi (2020); Lagarda-Leyva (2019); Long and Song (2012); Wang et al (2020) justify the need for simulation modeling by the fact that in their countries there is no comprehensive policy in the field of plastic waste management, despite the large volumes of plastic packaging consumption and the formation of post-consumer waste. In their opinion, the introduction of such a system requires the study of various scenarios. The largest consumers of plastic packaging, including PET containers, are countries such as China, Brazil, Indonesia. China is the largest producer of plastics, followed by Europe (Plastics – the Facts, 2018). One of the found publications is devoted to modeling various scenarios aimed at combating plastic garbage entering the world ocean. Cordier and Uehara (2019) conclude that technological solutions alone are not enough to solve the problems of plastic pollution of the ocean.

The main factors that were the subject of modeling

1) Plastic waste generation
    a) factors influencing the behavior of consumers of plastic packaging (Freeman et al, 2014),

   b) relationships between real income per capita and the demand for packaged drinking water, the impact of internet penetration on e-commerce demand, the impact of the increase in real income per capita on the e-commerce, and real income per capita and aggregate consumption have been estimated (Dhanshyam and Srivastava, 2021),
   c) collection is related to consumer behavior, consumers' basic income, as well as the impact of subsidy and collection prices on consumers (Wang et al, 2020),
   d) simulate and forecast the municipal plastic waste generations of four functional areas of Beijing (Long et al, 2012),
   e) the structure of plastic waste (Long et al, 2010),
   f) waste bins (Kerdlap et al, 2021),
2) Informal sector
   a) value chain analysis (VCA) to the informal recycling sector (Jaligot et al, 2016),
   b) informal plastic waste management systems (Jati and Ardi, 2020),
3) Comprehensiveness of the model
   a) complex plastics packaging recycling model (Freeman et al, 2014),
   b) causal loop diagram for plastic waste generation, accumulation and externalities (Dhanshyam and Srivastava, 2021),
   c) a dynamic recycling system of waste PET bottles for the production-consumption, consumption-collection, and collection-recycling subsystems (Wang et al, 2020),
   d) explorative learning about socio-technical systems (Wäger and Hilty, 2002),
4) LCA
   a) five impact categories were used in this LCA which were climate change, cumulative energy use, water depletion, terrestrial ecotoxicity, and land use (Kerdlap et al, 2021),
5) Policy mix simulation
   a) the project was conceived as a research project to evaluate the use of Systems Thinking and System Dynamics to support policy making (Freeman et al, 2014),
   b) charging disposal fee, provision of recycling subsidies, provision of kerbside recycling facilities and a new intervention - imposing a plastic ban (Dhanshyam and Srivastava, 2021),
   c) deposit-refund system, mandatory policy and tax refund system were used as the standard recycling policy in a simulation (Wang et al, 2020),
   d) integrates EPR strategy schemes into the current plastic waste management policy in Indonesia (Destyanto et al, 2019),
   e) development of SD model for evaluating informal plastic waste management policies (Jati and Ardi, 2020),
6) Extended producer responsibility
   a) conceptual model of system dynamics, which integrates Extended producer responsibility (EPR) strategy schemes into the current plastic waste management policy in Indonesia (Destyanto et al, 2019),
7) Scenarios
   a) simulate different scenarios aimed at controlling plastic debris entering the global ocean (Cordier and Uehara, 2019),
   b) scenarios simulation on municipal plastic waste generation (Long et al, 2012),

c) different implementation scenarios and combinations (Dhanshyam and Srivastava, 2021).

Since the model in system dynamics is represented by a set of stocks and flows between them, it is believed that such models are most suitable for modeling flows - material, financial and others. The authors of the analyzed publications use these capabilities of system dynamics, but are not limited to modeling material flows. As a rule, Freeman et al (2014); Dhanshyam and Srivastava (2021); Wang et al (2020); Wäger and Hilty (2002) tend to build a model of the entire cycle from the formation of plastic waste to its processing into a new product. Destyanto et al (2019); Dhanshyam and Srivastava (2021); Jati and Ardi (2020); Freeman et al (2014); Wang et al (2020) state the absence or imperfection of existing regulatory measures and aim to model scenarios for the application of various policies and methods of regulating the system of collection and processing of plastic waste. At the same time, the models allow us to analyze different scenarios, different combinations of regulatory measures. The problem is described (Cordier and Uehara, 2019); (Dhanshyam and Srivastava, 2021); (Long et al, 2012). A separate study was devoted to building a strategy of extended producer responsibility in the plastic waste management system. This situation is addressed (Destyanto et al, 2019); (Gatto et al, 2023). Ebner and Iacovidou (2021) state that the COVID-19 pandemic has exposed the plastic recycling sector's vulnerability to macroeconomic shocks.

Kerdlap et al (2021) pointed out an important fact that the completeness of the model, taking into account various factors of the impact of the plastic waste recycling system on the economy and the environment are also determined by the application of a LCA approach. The authors compare five different centralized and distributed scenarios and conclude that the LCA approach shows the advantage of a centralized scenario. Although distributed scenarios had smaller overall travel distances, the use of traditional commercial vans would result in a higher environmental impact than centralized scenarios.

Various approaches are used in publications to model the process of creating post-consumer plastic waste. Many authors use population indicators, per capita income (Freeman et al, 2014), the need for packaged drinking water (Dhanshyam and Srivastava, 2021), consumer behavior, the specifics of the population in various territories (Long and Song, 2012), impact of subsidy and collection prices on consumers (Wang et al, 2020) and others. Zhang & Wen (2014) show that the consumption of beverages in PET bottles largely depends on age, profession, gender and education, while income was not a significant factor. Such different conclusions confirm the need for a deeper understanding of consumer behavior in various countries in relation to drinks in PET bottles. This direction deserves the development of separate models. It should be noted that various agents operate in the field of waste generation and collection, and to adequately reflect their behavior in the model, it is advisable to use agent-based modeling, as suggested in (Wäger and Hilty, 2002). So Sun et al (2021) argues that the coordination of the various agents operating in the waste management sector as well as the management of the market mechanism are important priorities in the formulation of subsidy-based policies. Also was found that token-based incentives for social purposes are most suitable for stimulating end-consumers for proper plastic bottle recycling. This situation is addressed (Wankmüller et al, 2023).

It should be noted that since a significant part of the analyzed publications is devoted to the need to solve the problems of plastic waste in developing countries and countries with economies in transition, in which a large number of low-income people live, in these countries the informal sector - scavengers - plays an important role in the chain of plastic packaging collection. This issue is explained (Jaligot et al, 2016); (Jati and Ardi, 2020); (Wang et al, 2020). The regulatory measures of the plastic waste management system in some countries ignore this fact. But researchers include these participants in the value chain, because this corresponds to the real situation and requires consideration when setting up an economic mechanism in the waste management system. Jaligot et al (2016); Jati and Ardi (2020); Wang et al (2020) conclude that support for the informal sector should include access to financial and technical knowledge.

Along with modeling various scenarios that allow us to identify which combination of regulatory measures gives the greatest effect, the publications formulate proposals and roadmap for the implementation of these policies. The problem is described. (Destyanto et al, 2019); (Dhanshyam and Srivastava, 2021); (Wang et al, 2020). The most systematic approaches to creating a model for the collection and processing of plastic waste, which most accurately reflects the real state of affairs, existing relationships and interdependencies, are reflected in the report for the British Department for Environment, Food and Rural Affairs. This issue is explained. (Freeman et al, 2014). The authors show a complex process of organizing interaction with experts and implementing modeling results. Since the collection and recycling of plastic waste involves many different processes, it is difficult to find experts who would thoroughly know the details of the entire system. To identify the main components of the system and the relationships between them, as a rule, it is necessary to organize a series of meetings and workshops with experts, politicians and entrepreneurs who have experience and knowledge about individual parts of the system. For example, at the start phase of building waste prevention model for Defra two workshops were held for problem structuring and to develop causal loop diagrams of the system of interest. Participants were a mixture of academics, government policy makers and evidence analysts, and experts from industry, trade bodies, research institutes, and local government. The model building process for the plastics packaging recycling model also involved several model review sessions with recycling policy experts and stakeholders. This is described (Freeman et al, 2014).

In order to build the trust of stakeholders on whom the development and improvement of the regulatory system depends, it is necessary to continue to support mutual interaction in the process of developing a simulation model of the waste collection and recycling process. Such sessions and workshops may include providing stakeholders with the obtained modeling results, as well as involving them in the process of interacting with the model using special software. The description of the process of interaction with experts and stakeholders is very important because the purpose of our study is to analyze the appropriateness of applying the system dynamics approach to the preparation of plastic waste management policy by the authorities.

The authors of the analyzed publications note that there are certain difficulties with collecting data for modeling scenarios for the implementation of regulatory measures. This is often due to the fact that there is no single body in the country that coordinates the functioning of the system for collecting and processing plastic waste. Another problem is the existence of a significant informal sector in the countries considered. To study consumer behavior, the authors of a number of studies conducted a questionnaire. This situation is addressed (Wang et al, 2020). In order to more fully take into account the specifics of the area under study, a hybrid model was created in one of the publications using various approaches of simulation modeling: system dynamics, agent-based and discrete-event modeling. This issue is explained (Kerdlap et al, 2021).

4 Conclusions

The problem of the growth of plastic waste is relevant for most countries of the world. In most developed countries, there is a management system for the collection and processing of such waste. Such a system includes legal regulation, as well as organizations that are responsible for coordinating the collection and processing of plastic waste. At the same time, a significant part of plastic waste is exported or incinerated. The amount of post-consumer plastic waste in a certain territory largely depends on the population living there. Most of the world's population lives in developing countries and countries with economies in transition. In these countries, there is no management system for the collection and processing of plastic waste or regulates only part of the processes. Due to the need to take measures to combat climate change, many countries set themselves the task of developing a new policy - a policy of transition to zero waste, the creation of a circular economy of plastic. The complexity of such a task is due to the fact that the plastic waste market is very fragmented and different players operate on it, as well as the presence of certain problems. We conducted an analysis of publications devoted to the study of the plastic waste market in different countries and identified the main problems that should be taken into account when developing a regulatory policy. One of the methods of system analysis of such complex tasks is system dynamics. The main goal of the paper was to investigate whether it is appropriate to use simulation methods, including system dynamics, in the development of regulatory policy for plastic waste management. To meet this goal, the authors found publications dedicated to the use of simulation methods based on system dynamics for modelling the plastic waste collection and treatment system. The search for publications was carried out using the Web of Science and Scopus platforms, as well as the ResearchGate social scientific network.

The analysis of publications showed that most of them are aimed at developing policies and recommendations for regulating the system of collection and processing of plastic waste. The authors sought to cover all stages of the system, including the process of creating post-consumer plastic waste, collection, sorting and recycling. The application of the life cycle assessment approach made it possible to assess transportation taking into account the impact of transport on the environment. Since the informal sector plays an important role in the collection and primary sorting process in most of the countries studied, the researchers modeled scenarios taking this factor into account.

The results of modeling scenarios for the implementation of various sets of measures to regulate the collection and processing of plastic waste confirm that system dynamics can be an effective tool for working with such systems, since it allows you to reflect numerous interactions, as well as complex forward and backward links in the plastic waste management system. Future research should focus on the creation of hybrid models based on various simulation approaches. Agent modeling will make it possible to better take into account the behavior of various agents in the plastic waste management system.

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Metaoptimization Approach to Designing Optimal Transportation System with Multiple Criteria

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Abstract. We consider the traditional transportation problem of Hitchcock and Koopmans and with multiple objective functions. Furthermore, we assume that on the supplier's side, the supplier's capacities are not fixed. Knowing the costs for maintaining the supplier's capacities, we propose an approach to designing the optimal constellation of source capacities with respect to all objective functions in the optimization problem. We utilize the concept of DeNovo optimization to achieve the goal and discuss the specific unbalanced version of the problem. A numerical example follows after the proposed methodology. It occurs that the original costs for maintaining the supplier's transportation sources can be decreased by rearranging the capacities of the sources in the optimal sense.

Keywords: DeNovo Optimization, Metaoptimization, Multiobjective Linear Programming, Transportation Problem.

JEL Classification: C61, R41

1 Introduction

The traditional transportation problem is an old optimization concept whose original investigation and formulation are credited to Hitchcock (1941) and Koopmans (1947). Despite being this old, it stood at the beginning of the entire mathematical programming era and was one of the first practical applications to be tackled by Dantzig (1951), who demonstrated the application of the simplex method to this specific problem. Ever since scientists have developed countless applications based on this original concept. A simple search of the keywords *transportation problem optimization* in the scientific knowledge base, providing over 180 000 results[3], gives a hint on the importance of this concept until these days. There is indeed a reason to keep returning to this concept since it provides a simple yet efficient perspective on the optimal cost of the relationship between the suppliers and customers who all together form a *transportation system*. And there is still room for thinking about this problem from different viewpoints, like in this contribution in which we provide different perspectives on the transportation system.

The problem statement for the transportation problem is to find an optimal transportation plan that minimizes transportation costs while satisfying the constraints of the limited supply of the sources and the demand of the destinations. In our contribution, we present a different point of view on the problem. Rather than optimizing the transportation plan, we focus on designing an optimal transportation system under the given conditions. More specifically, we consider the transportation system in which the supplier's capacities are not fixed values, as in

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[3] in the *sciencedirect* database by February 2023

the traditional transportation problem. Instead, we assume that there is a possibility to set these capacities in the optimal arrangement, provided that the maintaining unit costs of these capacities are known and must fit in the total budget, which is given *a priori*. In order to make such rearrangement possible, we make use of the methodology originally called the *De Novo* approach developed by Zeleny (1986). Zeleny's approach focuses on redesigning the general linear system to make it optimal in the sense of using limited resources. The method is based on optimizing the original (linear programming) problem while optimizing the right-hand sides of the constraints in a way that the unit costs for maintaining the right-hand sides fit into the given budget. This is secured by additional constraints resembling the *continuous knapsack problem*. Moreover, the problem is considered with multiple criteria, and through ideal solutions of single criteria, an efficient (Pareto-optimal) solution is found, with respect to the original constraints, while setting the optimal right-hand sides, which would efficiently use the available budget.

Zeleny's approach was later developed by multiple authors in the theoretical sense and applied in practical situations as well. We do not present here the complete overview of Zeleny's followers and rather focus only on the theoretical results related to this paper. Among the multitude of papers of Shi related to the *De Novo* approach, we mention one from 1995 which extends the original concept by adding *optimum-path ratios* (Shi, 1995) that allows one to work with multiple budgets that may be different from the original budget (for maintaining the resources). Shi (1994) also suggests that the *De Novo* approach can be applied in the case of transportation problem, but to our knowledge, there has not been any attempt in the form of a paper to do so.

Further significant results about the *De Novo* system design are presented by Brožová and Vlach (2018, 2019). The first paper (Brožová and Vlach, 2018) discusses the prerequisites and pitfalls of the *De Novo* approach, and the latter one (Brožová and Vlach, 2019) summarizes the concept as a whole, with the addition of the metaoptimization phase based on the *STEM* method. The *STEM* method was originally developed by Benayoun et al. (1971) to find efficient solutions to multicriteria optimization problems. Since the very development of the *De Novo* methodology, a multitude of practically oriented papers has been published, pointing out the usefulness of the approach in various fields of practice. Babic and Pavic (1995) use it for production planning, Zhang, Huang and Zhuang (2009) for water resource system planning, and Chen (2014) for the purposes of ICT design in the semiconductor industry. The overall future perspectives of the *De Novo* approach are captured by Fiala (2011).

In the following chapters, we first introduce the essentials of the traditional transportation problem with multiple criteria (MC) and the general *De Novo* framework. Then we explain the implementation of *De Novo* in the transportation problem and extend it by an illustrative artificial example. We discuss briefly the algorithmic aspect of the problem and further outlooks of the approach, which seem to be plenty at the end of the paper.

2 Methods

Although the transportation problem is known well, we formally introduce it first in this chapter to clarify the notation that will be further used in our results. Then, the same will be done for the *De Novo* approach. We notify the reader that in the description of the *De Novo* concept in section (2.2), we do not provide any proofs and justifications for the procedure as this has been shown, for example, by Brožová and Vlach (2019).

2.1 Linear programming formulation of the transportation problem with MC

We consider the traditional transportation problem with multiple criteria (MC) and will need its linear programming form for our purposes. We assume the transportation system where a homogenous product is to be transported between the set of m suppliers and n destinations while minimizing the transportation costs and satisfying the demand on the destinations side. Further, we denote $a_i, i = 1, \dots, m$ the supply of i-th supplier and $b_j, j = 1, \dots, n+1$ is the demand of j-th destination. Note that we have m real suppliers, n real destinations, and one additional artificial destination to absorb the imbalance between the supply and demand. This is because, in our paper, we will specifically assume the case in which $\sum_{i=1}^{m} a_i \geq \sum_{j=1}^{n} b_j$, meaning that on the supplier's side, which will be subject to our modelling, there is enough capacity to satisfy the demand of all destinations. This needs, however, an additional dummy destination to balance the problem. Note that this assumption is laid just to focus this paper on one particular case, but generally, our approach described further in the text would also work without this assumption, with some specifics.

The linear optimization model of the MC transportation problem is formulated as follows:

$$\max \sum_{i=1}^{m} \sum_{j=1}^{n+1} c_{ijk} x_{ij}, k \in K^{Max}$$
$$\min \sum_{i=1}^{m} \sum_{j=1}^{n+1} c_{ijk} x_{ij}, k \in K^{Min}$$
$$\text{s.t.} \tag{1}$$
$$\sum_{j=1}^{n+1} x_{ij} = a_i, i = 1, \dots, m$$
$$\sum_{i=1}^{m} x_{ij} = b_j, j = 1, \dots, n+1$$
$$x_{ij} \geq 0, \forall i, j$$

We seek the solution $w^T = \left(w^{Max}, w^{Min}\right) = \left(w_1, \dots, w_p\right)$ over p objectives determined by the individual cost coefficients c_{ijk} over all transportation routes for which the transported amount is expressed by x_{ij}.

2.2 De Novo optimization concept

The *De Novo* is the general framework for working with the MC linear optimization model developed by Zeleny (1986), which generalization form can be expressed in the following form (2) that respects the different objective directions and different constraint types (Brožová and Vlach, 2018):

$$
\begin{gathered}
\max(C^{Max}x) \\
\min\left(C^{Min}x\right) \\
\text{s.t.} \\
A^{\leq}x \leq b^{\leq} \\
A^{=}x = b^{=} \\
A^{\geq}x \geq b^{\geq} \\
x \geq 0
\end{gathered}
\tag{2}
$$

In the *De Novo* concept, we seek to design an optimal constellation of $b^T = (b^{\leq}, b^{=}, b^{\geq})$ under the given budget B with the technical coefficients $A^T = (A^{\leq}, A^{=}, A^{\geq})$. Let us now assume that all (wlog) components of b do not attain predefined values and become unknown variables in the problem expressed as y and $y \coloneqq b$ componentwise. We introduce the new set of parameters q that represents the unit costs for maintaining the individual components of b. Given the budget B, the feasible distribution of costs between the right-hand sides of the problem is expressed by the following inequality:

$$
q^T y \leq B \tag{3}
$$

This leads to a new formulation of the MCLP problem with the allocation of b components with respect to the costs q:

$$
\begin{gathered}
\max(C^{Max}x) \\
\min\left(C^{Min}x\right) \\
\text{s.t.} \\
Ax - y = 0 \\
q^T y \leq B \\
x, y \geq 0
\end{gathered}
\tag{4}
$$

At this point, problem (4) expresses to optimization problem under the constrained budget. Since we deal with p objectives, it is now necessary to propose a solution method that would lead to finding an efficient solution with respect to all objectives. First, we solve the problem (4) p times with each objective separately and find the set of ideal solutions for all maximization and minimization objectives:

$$
z^T = \left(z^{Max}, z^{Min}\right) = \left(z_1, \dots, z_p\right) \tag{5}
$$

The optimal system design is now finding the optimal constellation of components of b under the constrained budget B such that all objectives are achieved at least on their ideal values given by z, and this is achieved through the following optimization model based on (Zhuang and Hocine, 2018):

$$
\begin{gathered}
\min(q^T y) \\
\text{s.t.} \\
Ax - y = 0 \\
C^{Max}x \geq z^{Max} \\
C^{Min}x \leq z^{Min} \\
x, y \geq 0
\end{gathered}
\tag{6}
$$

By solving the model (6), we obtain the optimal solution (x^*, y^*) for a minimum budget $B^* = q^T y^*$ necessary for achieving ideal values z in all objectives. Unfortunately, it is not guaranteed that such an optimal solution (x^*, y^*) exists for any instance of the problem (6). This is caused by the constraints for achieving the ideal solutions overall objectives:

$$\begin{gathered} C^{Max}x \geq z^{Max} \\ C^{Min}x \leq z^{Min} \end{gathered} \tag{7}$$

Therefore, instead of trying to accomplish the ideal values in all objectives, we introduce a vector of achievable objectives $\bar{z}$ for which it is guaranteed that the system (6) has a feasible solution. In order to construct $\bar{z}$, we use the principles *STEM* method (Benayoun et al., 1971), which is primarily used for finding an efficient solution to the MCLP problem by minimizing the distance of the solution vector from the ideal vector through weighted deviations. In our particular case, the *STEM* method will be applied through the following model:

$$\begin{gathered} \min(d) \\ \text{s.t.} \\ Ax - y \leq 0 \\ (z_k^{Max} - C_k^{Max}x)\lambda_k = d, k \in K^{Max} \\ \left(C_k^{Min}x - z_k^{Min}\right)\lambda_k = d, k \in K^{Min} \\ x, y, d \geq 0 \end{gathered} \tag{8}$$

where k denotes k-th objective from the set K^{Max} of maximizing objectives or from the set K^{Min} of minimizing objectives. The individual normalized weights λ_k are obtained through the following formula:

$$\lambda_k = \frac{\max\limits_{l=1,\dots,p} z_k(x_l^*) - z_k}{z_k \|C_k\|} \tag{9}$$

where x_l^* are the individual minima for each objective $l \neq k$ and $\|C_k\|$ is the Euclidean norm of k-th objective. Note that we only find the initial weights λ_k and do not change them by additional iterations. The model (8) yields the optimal solution $\left(\hat{x}, \hat{y}, \hat{d}\right)$. Based on the optimal solution of (8), we obtain the achievable objectives $\bar{z}^T = \left(\bar{z}^{Max}, \bar{z}^{Min}\right) = \left(C_1\hat{x}, \dots, C_p\hat{x}\right)$. Finally, it is possible to formulate the metaoptimization model, which attains the form of (6) but now with the achievable objective values instead of ideal values:

$$\begin{gathered} \min(q^T y) \\ \text{s.t.} \\ Ax - y \leq 0 \\ C^{Max}x \geq \bar{z}^{Max} \\ C^{Min}x \leq \bar{z}^{Min} \\ x, y \geq 0 \end{gathered} \tag{10}$$

By solving (10), we obtain the optimal solution (x^{**}, y^{**}) and the minimal necessary budget $B^{**} = q^T y^{**}$. If the budget B^{**} is available to the decision-maker, then y^{**} is the optimal design of the right-hand sides of the problem with the optimal solution x^{**} and the optimal objective values Cx^{**}. It may as well occur that such a necessary optimal budget is not the same as the actual budget, i.e. $B^{**} \neq B$. In such case, it is possible to carry out the linear transformation of the results according to Shi (1995) through *optimum-path ratio* $r = \frac{B}{B^{**}}$ and the optimal design of the right-hand sides is then $ry^{**}$and the optimal solution to the problem is rx^{**} with the objective values rCx^{**}.

3 Results

We aim to apply the *De Novo* framework described in (2.2) to problem (1). Specifically, for problem (11a), we seek the optimal design described in (11b).

$$\begin{gathered}\min \sum_{i=1}^{m}\sum_{j=1}^{n+1} c_{ijk}x_{ij}\,, k = 1, \dots, p \\ \text{s.t.} \\ \sum_{j=1}^{n+1} x_{ij} = a_i\,, i = 1, \dots, m \\ \sum_{i=1}^{m} x_{ij} = b_j\,, j = 1, \dots, n+1 \\ x_{ij} \geq 0, \forall i, j\end{gathered} \tag{11a}$$

$$\begin{gathered}\min q_i^T y_i\,, i = 1, \dots, m \\ \text{s.t.} \\ \sum_{j=1}^{n+1} x_{ij} = y_i\,, i = 1, \dots, m \\ \sum_{i=1}^{m} x_{ij} = b_j\,, j = 1, \dots, n+1 \\ \sum_{i=1}^{m}\sum_{j=1}^{n+1} c_{ijk}x_{ij} \leq \bar{z}_k, k \in K^{Min} \\ \sum_{i=1}^{m}\sum_{j=1}^{n+1} c_{ijk}x_{ij} \geq \bar{z}_k, k \in K^{Max} \\ x_{ij} \geq 0, \forall i, j\end{gathered} \tag{11b}$$

In the practical sense, in the original problem (11a), we seek an efficient solution over k objectives such that the limited resources a_i of suppliers satisfy the demands b_j of destinations, and we assume that $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n+1} b_j$ which means that the problem is balanced through the addition of $(n+1)$-st destination in the problem. In (11b), we seek the efficient solution to the problem over k objectives under the constrained budget B which is used for maintaining the resources $y_i \coloneqq a_i$ and under the optimal design of the transportation system that would minimize the budget while achieving the desired objective levels $\bar{z}_k$. Problem (11b) is a specific form of the general problem (10).

3.1 Example

To illustrate the general results above, we present a simple transportation system for the unspecified product with three suppliers and three destinations with one additional destination that balances the problem. Clearly, the supply exceeds the demand. We assume two objectives $w_1^{Min} = c_1^T x$ that minimizes the total distance and $w_2^{Max} = c_2^T x$ that maximizes the prices for which the product is sold in the different destinations. All units are dimensionless. The objectives in the table are denoted in the upper-right corners as c_1 (c_2). Rather than presenting the problem in equation form, we present a traditional transportation table that is more comprehensive:

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	5 (6)	4 (12)	1 (7)	0	9
Supplier 2	3 (8)	2 (14)	2 (9)	0	16
Supplier 3	3 (7)	5 (13)	8 (8)	0	18
Demand	10	15	12	6	

Figure 1 The original problem in the transportation table

The optimal solutions for single objectives of the transportation system (Figure 1) are in Figure 2:

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	5	4	1 9	0	9
Supplier 2	3	2 13	2 3	0	16
Supplier 3	3 10	5 2	8	0 6	18
Demand	10	15	12	6	

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	6 9	12	7	0	9
Supplier 2	8	14	9 10	0 6	16
Supplier 3	7 1	13 15	8 2	0	18
Demand	10	15	12	6	

Figure 2 The optimal solutions for single objective functions w_1 (left) and w_2 (right)

The optimal values of single objectives are $w_1 = 81$ and $w_2 = 362$. Now assume that the supplier capacities can be rearranged freely and the maintaining costs are given for each supplier as $q^T = (11,17,21)$. We also set our available budget according to the current state of the system, which is $B = q^T a = 749$. We now solve the problem in the form (Figure 4) for each objective separately to receive ideal values of the single objectives under the constraint budget as expressed in the following figure:

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	5	4	1 12	0	12
Supplier 2	3 10	2 15	2	0	25
Supplier 3	3	5	8	0	0
Demand	10	15	12	6	

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	6	12	7	0	0
Supplier 2	8 10	14 15	9 12	0	37
Supplier 3	7	13	8	0	0
Demand	10	15	12	6	

Figure 3 The optimal solutions for single objective functions z_1 (left) and z_2 (right) under the constraint budget

This yields ideal solutions $z_1 = 72$ and $z_2 = 398$. Note that the ideal solutions under the constraint budget are better than the standard optimal solutions, i.e. $z_1 < w_1, z_2 > w_2$. This is possible thanks to the changes in the supplier capacities that allow the transport in the routes with better coefficients. Knowing the ideal solutions, we attempt to solve the problem in the form of (6), and it occurs that such a solution is infeasible. As discussed in the methods, this is caused by the constraints (7) in the problem (6). Practically speaking, it means it is impossible to achieve such a solution under any available budget. Therefore, it is necessary to seek the achievable objectives $\bar{z}_1$ and $\bar{z}_2$ through the model (8). Solving the model (8) with the objective weights $\lambda_1 = 0.866$ and $\lambda_2 = 0{,}134$ obtained through the STEM method, the achievable objectives are $\bar{z}_1 = 74.844$ and $\bar{z}_2 = 379{,}6882$. These values are achievable thanks to applying the STEM method, which finds these values on the Pareto-front of the multiple-objective optimization problem (4). Finally, it is possible to calculate the optimal budget $B^{**} = 574.065$ by solving the problem (10), which yields the corresponding transportation table in Figure 4:

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	5 (6)	4 (12)	1 (7) 9.156	0	9.156
Supplier 2	3 (8) 10	2 (14) 15	2 (9) 2.844	0	27.844
Supplier 3	3 (7)	5 (13)	8 (8)	0	0
Demand	10	15	12	0	

Figure 4 The optimal system design under the minimum budget B^{**}

Figure 4 shows the optimal transportation system arrangement under the minimum budget, which achieves the efficient objective values $\bar{z}_1, \bar{z}_2$. Note that the solution in figure 4 still redistributes the same minimum necessary amount of the product from the suppliers to the destinations to satisfy their demand (an amount of 37) but in a different arrangement: instead of supplier capacities in the original system $b^T = (9,16,18)$, we now have the new capacities $y^{**T} = (9.156, 27.844, 0)$. The new solution yields supplier 3 as unnecessary with respect to both objectives of the problem and the given budget. The budget needed for the realization of the transportation system in figure 4 is $B^{**} = 574.065$. Suppose we expect that the original budget is still available to the decision-maker. In that case, it is possible to construct an equivalent solution to the one in figure 4 with the original budget using the optimum-path ratio described in chapter 2. The *optimum-path ratio* is $r = \frac{B}{B**} = 1.305$. The *optimum-path ratio* serves as a multiplier for determining the optimal system design under the available budget. If the original budget $B = 749$ is available, then the optimal system design is in Figure 5:

	Destination 1	Destination 2	Destination 3	Dummy	Supply
Supplier 1	5 (6)	4 (12)	1 (7) 11.946	0	11.946
Supplier 2	3 (8) 13.047	2 (14) 19.571	2 (9) 3.711	0	36.329
Supplier 3	3 (7)	5 (13)	8 (8)	0	0
Demand	13.047	19.571	15.657	0	

Figure 5 The optimal system design under the original budget B

3.2 Discussion

We have demonstrated the possible use of the *De Novo* methodology for designing the optimal transportation system under the given budget, and we assumed the case in which the supplier's capacities are budget-controlled, and the capacities exceed the demand of the customers. The other cases may be considered, where the problem is balanced in the beginning and supply equals the demand, or if the supply is lower than demand and we seek the optimal distribution of the insufficient resources. Our preliminary calculations show the usability of our approach, but additional aspects must be considered. We do not use the STEM method to its full extent in this paper but we only use its principle to find some achievable solution. The STEM method used for determining the achievable objectives is not the only possible approach, and other ways are known, as the one recently presented by Banik and Bhattacharya (2022). This phase of the methodology deserves further research on how the choice of the method influences the final solution.

In this contribution, we have only assumed the case where all parameter values attain some predefined values, which may not be sufficient for real uses. In practice, the supply and demand may vary as well as the other coefficients in the problem, and the problem has to be solved under a certain degree of uncertainty. The *De Novo* approach based on fuzzy evaluation has already been studied by Liu and Shi (1994) or Chen and Hsieh (2006).

4 Conclusions

In our contribution, we have studied how the transportation system can be redesigned using the *De Novo* methodology, and the specific case is shown. It turns out that by applying the described methodology to the transportation problem, significant cost reduction may be achieved, and a more efficient system design is obtained that respects the multiple objectives. In our future work, we will investigate and describe the other transportation cases, apply a different perspective on the possible uncertainty in the model input, and test it on a real case with a large dataset.

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Mathematical models for solving the efficiency of the storage space utilization with a link to the amount of bound capital in stocks

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Abstract. Storage is one of the many processes that take place within logistics chains. It is a process that primarily generates costs, which is why is important to monitor its going regularly and optimize it if necessary. During optimization, various tasks formulated by one or more optimization criteria are pursued. In the presented paper, two parallel tasks are pursued, which do not occur so often, but which are significant from the point of view of practical applications. The first task is the most efficient utilization of storage space capacity. The second task is to consider the amount of bound capital in the stocks. Based on the defined inputs, three optimization approaches based on mathematical programming suitable for solving the formulated problem are presented in this paper. At the end of this paper, the results of each individual optimization approach are compared with each other, and recommendations for the client are formulated.

Keywords: Bound capital, Goal programming, Linear programming, Logistics, Warehouse stocks.

JEL Classification: C61

1 Introduction – motivation to deal with the problem

The issue of optimizing storage from the point of view of costs is one of the important decision-making processes. The efficiency of the storage process can be assessed from different perspectives. In the case of some types of warehousing processes, the subject of optimization is the cost of storage supplemented by the cost of delivering the stored stock. However, there are also cases that can be considered non-standard. Such a case can be, for example, a storage system in which the highest possible utilization of available storage space is simultaneously required and at the same time the lowest possible amount of bound capital in stocks, which is one of the indicators monitored and periodically evaluated in various types of business companies. The task is therefore to decide on the optimal combination of stored boxes in such a way that both objectives are considered at the same time from the point of view of the client.

Various optimization approaches and criteria can be used to solve the problem of optimizing of the storage space utilization. E.g., Manoharan et al. (2022) solve the problem of determining the optimal number of stored products and then focus on the placement of products in the

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warehouse in such a way that the storage space is used to the maximum and at the same time there are minimal movements using integration of linear programming and decision-making models. Kantasa-ard (2017) uses linear model for maximizing warehouse space utilization while maximizing the number of relocated automotive spare-part pallets and not exceeding available number of the pallets. Fumi, Scarabotti and Schiraldi (2013) use linear models for increasing space utilization by minimizing the required storage space while determining the correct slot allocation to reduce handling times and distances. Sarudin and Shuib (2015) maximize warehouse storage volume while minimizing travel distances using a mixed integer goal programming mathematical model. Kordos et al. (2020) place products in the warehouse to minimize order picking time using genetic algorithms. The same problem is dealt with by Dijkstra and Roodbergen (2017), with the use of dynamic programming. Van der Heide, Van Foreest and Roodbergen (2018) model rental system with several local warehouses and expedited shipments from a support warehouse as a continuous time Markov chain and derive its steady-state costs and define optimal base stock policy for a serial system. All mentioned papers ignore the value of the bound capital in the stocks when optimizing the utilization of available storage space.

Based on the conducted research, the paper considers three optimization approaches based on mathematical programming. Specifically, these are multi-criteria linear programming, single-criteria linear programming and goal programming.

2 Problem formulation and mathematical programming approaches

In this chapter, the solved problem and the mathematical models that are used to perform the computational experiments described in the following chapter are presented.

2.1 Formulation of optimization problem

Consider a set of heterogeneous stocks handling units I, where $|I| = m$, which need to be placed in the warehouse. For each stock handling unit of type $i \in I$, the minimum stored number p_i, the value of bound capital in one stored handling unit n_i and the width of the handling unit w_i are defined (the width of each unit contains a space reserve of 5 cm, this dimension is used in practical applications for the sake of convenience and safe handling). Let's further assume that handling units cannot be stacked behind each other, but only next to each other. The weight of the stock handling units does not affect the load capacity of the racks, therefore it is neglected. All storage racks are identical in length L. The number of racks in the warehouse is marked P.

The task is to determine how many stock handling units of type $i \in I$ will be placed in the warehouse, if the company requires compliance with the minimum number of stored handling units of individual types, maximum utilization of warehouse capacity and efficient allocation of bound capital in stocks.

2.2 Design of optimization models

This issue is solved in the paper by selected methods of mathematical optimization. First, the optimization criterion needs to be specified. Neither the criterion nor the method were specified, so several approaches were considered by the authors with the criteria listed in parentheses:

- Goal programming without additional constraints (deviations from full utilization of warehouse and bound capital in stored handling units beyond the minimum stored number)
- Linear programming (maximize the minimum value of bound capital in stored handling units beyond the minimum stored number)
- Goal programming with additional constraints (deviations from full utilization of warehouse and bound capital in stored handling units beyond the minimum stored number)

2.3 Goal programming without additional constraints

The possibility of multi-criteria linear programming is considered at first. The task of optimization is to maximize the utilization of the warehouse capacity and minimize the value of the total bound capital in the stored handling units. In this approach, the result would vary according to the determination of the weights for the given criteria. Since the client wants to prioritize the maximum utilization of the storage area, it can be assumed that the mathematical model would fill all the free areas with the material that has the minimum value of bound capital in the stocks of one stored handling unit per storage unit. In some cases, this handling unit could be supplemented with another type of unit to fill any remaining storage space. However, this solution is not useful in practical applications, because there would be no timely turnover of stored products and then they would become obsolete. Another reason is the long reaction time required for the eventual release of warehouse positions (it would take a long time to dispatch a large amount of one or two types of products). In both mentioned cases, a situation could arise where the owner of the warehouse would be forced to sell or dispose of excess products.

For validating the assumption of the authors of the paper about the outputs of multi-criteria linear programming, the task of multi-criteria linear programming was solved by transformation to goal programming. A multi-criteria linear programming problem can be transformed into a goal programming problem by expressing deviations from ideal values. In the solved problem, it represents the ideal values of the maximum utilization of the warehouse capacity (thus number of storage racks in the warehouse multiplied by length of storage rack - $P \cdot L$) and the value of the bound capital in the storage of the minimum number of stored handling units (thus $\sum_{i=1}^{m} p_i n_i$). Due to the way the storage space is defined, it may happen that a couple of handling units cannot be stored in the rack (there will not be enough space for them). For these cases, the warehouse includes a so-called overflow zone where these units can be stored.

Recapitulation of quantities used in the model

I Set of handling units

m Number of handling units

p_i The minimum number of stored handling unit $i \in I$

n_i Bound capital in one stored handling unit $i \in I$

w_i Width of handling unit $i \in I$

L Length of storage rack

P Number of storage racks in the warehouse

h_i^+ Deviation above the value of bound capital in storage of the minimum number of stored handling units $i \in I$

h^- Deviation below the value of full storage capacity utilization

M Prohibitive constant

List of the variables used in the model

x_i Placed amount of the handling unit of type $i \in I$ in the warehouse

The mathematical model of goal programming without additional constraints for solving the problem of multi-criteria linear programming has the following form:

$$\sum_{i \in I} h_i^+ + M \cdot h^- \rightarrow min \tag{1}$$

subject to:

$$x_i \geq p_i \qquad for\ i \in I \tag{2}$$

$$\sum_{i \in I} x_i w_i \leq L \cdot P \tag{3}$$

$$h^- = (L \cdot P) - \sum_{i \in I} x_i w_i \tag{4}$$

$$h_i^+ = n_i(x_i - p_i) \qquad for\ i \in I \tag{5}$$

$$x_i \geq 0 \qquad for\ i \in I \tag{6}$$

The objective function (1) minimizes the value of bound capital in inventories held beyond their minimum stored quantity while minimizing deviations from full warehouse capacity utilization. The prohibitive constant M ensures that priority will be given to minimizing the deviation from maximum storage capacity utilization. The group of constraints (2) ensures that the requirement of the minimum stored amount of the handling unit $i \in I$ in the warehouse is respected. The constraint (3) ensures that the storage capacity is not exceeded. The constraint (4) defines the deviation from the full utilization of the warehouse capacity. The group of constraints (5) defines the deviation from the bound capital in the storage of the minimum number of stored handling units $i \in I$. The group of constraints (6) define domains of the variable in the model.

2.4 Linear programming

Linear programming with the max criterion is chosen as another suitable method for solving the problem. The model maximizes while the parameters of the bound capital and space utilization are set to its minimal value. This type of criterion is used for the uniform distribution of the required quantity. In this case, it is an even distribution of bound capital in stored handling units that are placed beyond the minimum stored number.

The quantity d is newly added, which is explained below this text. Apart from the newly introduced quantity, the meaning of the other quantities is identical to the previous model.

d Optimization criterion – minimum value of bound capital in handling units stored beyond the minimum number stored.

The mathematical model of linear programming has the form:

$$d \rightarrow max \tag{7}$$

subject to:

$$x_i \geq p_i \qquad for\ i \in I \tag{2}$$

$$\sum_{i \in I} x_i w_i \leq L \cdot P \tag{3}$$

$$d \leq (x_i - p_i) n_i \qquad for\ i \in I \tag{8}$$

$$x_i \geq 0 \qquad for\ i \in I \tag{6}$$

The objective function (7) ensures the maximization of the minimum value of the bound capital in handling units stored beyond the minimum stored number. The group of constraints (8) determines the value of the objective function, i.e. the lower limit of the bound capital in stored handling units. The groups of constraints (2), (3) and (6) have the same meaning as in the previous model.

2.5 Goal programming with additional constraints

The principle of using goal programming is based on the expression of the deviation from the set goal value, which is usually minimized. In the following model, it is minimizing the deviation from the full utilization of the storage capacity h^- and minimizing the bound capital in stored handling units beyond the minimum stored number h^+. The value h^- is additionally multiplied by the prohibitive constant M, since its minimization has priority over the value h^+.

As previously mentioned, in the Goal programming without additional constraints approach, a situation would arise where the utilization of the available storage space is dominated by one type of handling unit $i \in I$. To prevent this situation from occurring in the following model, constraints are also introduced that set an upper limit for the amount of handling unit $i \in I$ that can be stored beyond the minimum stored amount.

For clarity, quantities that did not appear in previous models are summarized below. The meaning of other quantities and variables is identical to the previous models.

- $\bar{S}$ Average value of bound capital in inventory of one handling unit per one storage unit
- K Coefficient to control the flexibility of placement of handling units beyond the minimum number stored

The mathematical model of goal programming with additional constraints for solving the problem of multi-criteria linear programming s has the following form:

$$\sum_{i \in I} h_i^+ + M \cdot h^- \rightarrow min \tag{1}$$

subject to:

$$x_i \geq p_i \qquad for\ i \in I \tag{2}$$

$$\sum_{i \in I} x_i w_i \leq L \cdot P \tag{3}$$

$$h^- = (L \cdot P) - \sum_{i \in I} x_i w_i \tag{4}$$

$$h_i^+ = n_i(x_i - p_i) \qquad for\ i \in I \tag{5}$$

$$\bar{S} = \frac{\sum_{i \in I} \frac{n_i}{w_i}}{m} \tag{9}$$

$$x_i - p_i \leq K \cdot \bar{S} \cdot p_i \frac{w_i}{n_i} \qquad for\ i \in I \tag{10}$$

$$x_i \geq 0 \qquad for\ i \in I \tag{6}$$

The objective function (1), the constraints (3) and (4) and the groups of constraints (2), (5) and (6) have the same meaning as in the previous models. Constraint (9) determines the average rate per rack storage unit. The group of constraints (10) creates a limit for the amount of handling unit $i \in I$ placed moreover above its minimum stored number. The constant K is introduced for the purpose of adjusting the restriction rate setting. By default, the value $K = 1$ can be set, if the value of K was to be reduced, the model would have more flexibility in terms of storage variation of different handling units $i \in I$. If, on the other hand, the value of K was increased, the model would be able to place a larger number of individual handling units $i \in I$ and the value of the total bound capital in the stocks would decrease.

3 Calculation experiments with the mathematical models

In this chapter, the results of the presented methods for the proposed mathematical models are presented and commented. The width of the units is based on real data, the other data was randomly generated.

Input data of the models:

Handling Unit ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
$w_i(m)$	0,8	0,8	0,8	1	1	0,8	1,6	0,8	1,2	1,6	1,2	1,2	1,6	1,6	1,6	1,2	1,2	1,2	1	1
p_i	37	49	12	33	38	19	48	30	13	10	25	12	41	16	20	16	27	17	13	34
$n_i(1000\ CZK)$	14	5	4	5	10	1	8	1	12	2	10	8	15	4	2	1	2	14	13	4

Table 1 An overview of input data of models

3.1 Output of the Goal programming without additional constraints

Using the outputs of multi-criteria linear programming, the authors verified their input assumptions about the nature of the model's outputs. For reasons of space saving, the outputs are given in abbreviated form, in contrast to the outputs of the other two optimization approaches.

The storage space was used to the maximum possible (1050 m out of 1050 m was used). The value of bound capital in stocks was 40.32 million. One handling unit with ID 6 and 388 handling units with ID 16 were placed beyond the minimum stored number.

3.2 Output of the linear programming model

An overview of the outputs of the linear model is shown in Table 2. The ID of the handling unit (HU) is in the first column. In the second column, the total stored quantity (resulting value of variable x_i). The third column shows the number of handling units $i \in I$ stored beyond the minimum stored number $(x_i - p_i)$. The fourth column shows the value of bound capital in stored handling units $i \in I$ $(x_i n_i)$. The last column shows the bound capital in stored handling units $i \in I$ located beyond the minimum stored number $(n_i(x_i - p_i))$.

HU ID	Total stored quantity HU	HU Stored beyond minimum	Bound capital	Bound capital beyond minimum
1	42	5	588 000	70 000
2	62	13	310 000	65 000
3	28	16	112 000	64 000
4	46	13	230 000	65 000
5	45	7	450 000	70 000
6	83	64	83 000	64 000
7	56	8	448 000	64 000
8	94	64	94 000	64 000
9	19	6	228 000	72 000
10	42	32	84 000	64 000
11	32	7	320 000	70 000
12	20	8	160 000	64 000
13	46	5	690 000	75 000
14	32	16	128 000	64 000
15	52	32	104 000	64 000
16	80	64	80 000	64 000
17	59	32	118 000	64 000
18	22	5	308 000	70 000
19	18	5	234 000	65 000
20	50	16	200 000	64 000
Total	**928**	**418**	**4 969 000**	**1 326 000**

Table 2 An overview of the outputs of the linear programming model

3.3 Output of the goal programming model with additional constraints

An overview of the outputs of the goal programming model with additional constraints is shown in Table 3. The columns can be interpreted in the same way as in Table 2. The table also shows that units were placed beyond the minimum stored number for 4 types of handling units $i \in I$. As already explained, by changing the constant K, the maximum possible number of stored handling unit types $i \in I$ can be controlled. For example, if $K = 0{,}5$ was set, 11 types of handling units $i \in I$ would be placed and the total value of bound capital in the stocks would be roughly 4.6 million. On the contrary, if $K = 1{,}5$ was set, 3 types of handling units $i \in I$ would be placed and the total value of the bound capital in stock would be 4.11 million.

HU ID	Total stored quantity of HU	HU Stored beyond minimum	Bound capital	Bound capital beyond minimum
1	37	0	518000	0
2	49	0	245000	0
3	12	0	48000	0
4	33	0	165000	0
5	38	0	380000	0
6	19	0	19000	0
7	48	0	384000	0
8	149	119	149000	119000
9	13	0	156000	0
10	58	48	116000	96000
11	25	0	250000	0
12	12	0	96000	0
13	41	0	615000	0
14	16	0	64000	0
15	117	97	234000	194000
16	132	116	132000	116000
17	27	0	54000	0
18	17	0	238000	0
19	13	0	169000	0
20	34	0	136000	0
Total	**890**	**380**	**4168000**	**525000**

Table 3 An overview of the outputs of the goal programming model with additional constraints

3.4 Evaluation of models results

In this paper, a total of 3 optimization approaches suitable for the solved problem were compared. Depending on the nature of the individual approaches, the nature of the outputs can also be summarized on a general level. In a real application, a suitable method would then be selected according to the preferences of the client. A mutual comparison of the individual approaches is summarized in Table 4. The nature of the outputs is evaluated according to the handling units located beyond their minimum number.

Approach	The nature of the outputs beyond the requirement
Goal programming without additional constraints	1 type of handling unit $i \in I$ dominates
Linear programming	Uniform distribution of all handling units according to bound capital in stocks per stored unit
Goal programming with additional constraints	Placement of handling units with a minimum value of bound capital in stocks per stored unit with a limit on the maximum stored quantity that can be regulated by the constant K

Table 4 Comparison of the nature of the outputs of the researched optimization approaches

Goal programming without additional constraints is suitable if the client prefers to minimize the total bound capital in the inventory. This applies even if the available storage spaces were dominated with only one type of handling unit $i \in I$. It can be seen from the results of the computational experiment that the available storage spaces were filled with the maximum amount of handling unit, which binds the minimum value of capital in the storage of one handling unit per storage unit. It can possibly be supplemented with another handling unit with smaller proportions.

Linear programming presents the worst results in terms of total bound capital in inventory. However, the bound capital of handling units located beyond the minimum stored number is evenly distributed, which in practical applications can mean an advantage in terms of long-term supply. From a practical applications point of view, this represents another advantage in the case of an industry where design innovations occur during the life of the product. When a design change is approved after the transition period, the previous design cannot be used. The client, who can be a supplier in the automotive industry, for example, could then find himself in a situation where he would have a large amount of product in stock, which he was unable to sell, and could thus end up at a loss.

Goal programming with additional constraints represents the minimization of the bound capital in the inventory with the influence of the maximum stored quantity of the handling unit $i \in I$. By setting the constant K, the relationship between the total bound capital in inventory and the number of types of handling units located in the warehouse can be regulated.

4 Conclusion

In the paper, the authors presented 3 approaches for increasing the utilization of available storage space. When applying the solution to the given issue in practice, it would be up to the client to consider which approach he prefers, as each provides different outputs. In the evaluation of the results of the model, it was briefly described how the nature of the outputs of each approach differs, and how they reflect the preferences of the client.

The task was solved with only a limited number of input parameters. Specifically, for each type of handling unit $i \in I$, its width, the amount of bound capital in the stocks of one stored handling unit and the minimum stored number were determined. However, when using the models in practical applications, more parameters could be considered, such as, for example, the weight of the handling units, the load capacity of the racks, the stock turnover rate, the size of the delivery or the frequency of deliveries. Furthermore, the solution to the problem could be extended to include warehouses that do not have a homogeneous type of racks, the possibility of storing handling units in a row or the possibility of storage in the form of stacking. Also, future work could be extended by the possibility of storing collapsible packaging (the number of stored units would increase), as well as by different parameter values for safe handling. These suggestions will be considered by the authors in future research.

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Evaluation of hesitance in surveys related to education during and after COVID-19 pandemic

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Abstract. The COVID-19 pandemic has heavily impacted diverse activities for a longer time. The educational process has been one of the most affected one, because it involves vivid and dynamic relationships between students and teachers. Now, it is time for the evaluation of all stakeholder groups affected by the pandemic situation. In this article, we focus on the hesitance in providing categorical answers.
This topic has not yet been deeply explored in the literature in general, and in the education in particular. More precisely, we focus on the dependency of hesitance and answers provided by respondents in the survey (teachers and students from 3 countries), and whether the change of hesitance in time was significant. In this work, we adopted a statistical approach and we used a method based in computational intelligence field.

Keywords: Hesitance, fuzzy functional dependencies, survey, education.

JEL classification: C83, D83

1 Introduction

The COVID-19 pandemic has heavily impacted diverse human activities around the globe for a long time. The educational process faced the same impact, since the teaching process was forced to go online in many countries. However, education has been even more influenced, as it involves vivid and dynamic relationships between students and teachers.

According to Marinoni et al. (2020), more than two thirds of universities worldwide went online during the pandemic. After the pandemic started, many researchers focused their activities on the distance learning and related topics. One wave of topics focused on technical
improvements, new tools, ways of communications, etc., e.g., (Altbach and de Wit, 2020). The next wave focused on surveys among students, teachers, parents, on various education levels, e.g., (Akour et al., 2020; Almendingen et al., 2021). Studies differ in the geographical location, i.e., where the survey was done, the types and categories of surveys, etc. A lack of direct social contact, motivation to work hard, the necessity to adopt new skills in a short time are among the most frequently mentioned issues.

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For instance, the study presented by (Akour et al., 2020) confirmed the negative psychological impact of distance teaching during the COVID-19 pandemic. Hoofman and Secord. (2021) revealed that the necessary rapid adaptation of students and teachers was uneasy and brought several negative impacts. Jakubowski and Sitko-Dominik (2021) focused on mental health of teachers during the pandemic in Poland due to the high pressure during the first lockdown wave when the sudden switch to the virtual teaching environment occurred.

To our best knowledge, surveys related to education in general and education under the pandemic measures have not considered hesitance in providing categorical answers. In our survey, conducted in the frame of the Dante project titled *Digital area for networking teachers and educators* (realized under the Erasmus+ Strategic partnership), we handled hesitance in answers to categorical questions before, during and after the pandemic. Our goal was, among others, to explore how hesitant were respondents when they answered questions in countries included in the project, i.e., Czech Republic, Poland, and Slovakia. The details about the conducted survey are provided in Sec. 2.

The remainder of this contribution is organized as follows. The key information regarding the conducted survey are in Section 2. Section 3 introduces applied methods, followed by the experiments on data in Section 4. Section 5 focuses on the discussion, while article finishes with the concluding messages in Section 6.

2 The survey

Surveys are well-known and established tools for measuring respondents' opinions (Albert and Tullis, 2013). On the other hand, the careless answers (i.e., respondents provide the neighbouring values instead of the desired ones), and hesitance (i.e., respondents are not sure which category to choose, so they select one by chance) should be considered as well (Rakovská and Hudec, 2019).

The survey was conducted in 2022 at three central-European universities (VŠB - Technical university of Ostrava in the Czech Republic, University of Economics in Katowice in Poland, and Technical University of Košice in Slovakia). The goal of the survey was to assess the satisfaction of students and teachers with distance learning during the COVID-19 pandemic and compare their satisfaction with the former, i.e., non-pandemic environment. Both teachers and students had to evaluate subjectively their satisfaction with selected factors using 5-point Likert scale (from absolutely unsatisfied to absolutely satisfied). The respondents provided us with the evaluations for the period before pandemic, at the beginning of the pandemic, and at the end of the pandemic (to capture the development of opinions). What is crucial for this paper, they had to accompany their satisfaction evaluations with the level of hesitance, i.e., to what extent they were sure with their answers (before and at the end of the pandemic). The source of the hesitance was not distinguished - they just had to express if (a) they are absolutely sure with their answers, (b) if they slightly hesitated, (c) if they strongly hesitated and, therefore, based the answer rather on intuition or feeling.

As for the questions, both groups had to answer to questions in three categories:

- Technical issues (internet quality, hardware and software equipment);
- Teaching issues (lessons attractiveness, motivation to work hard, quantity of duties and study materials, evaluation of courses by students);
- Communication issues (communication between teachers and students, communication with non-teaching staff and the university management).

We gathered data from 55 teachers and 294 students in the Czech Republic, 27 teachers and 221 students in Slovakia, and 113 teachers and 333 students in Poland.

3 Preliminaries of method used

In order to make this contribution as self-contained as possible, the key concepts that are used throughout the article are presented below.

3.1 Preliminaries of statistical testing hypotheses

Within the statistical analysis of the input data, we test the proportions of responses of paired ordinal data and the means of more samples with ordinal data. To do this, the following well-established tests were applied:

- χ^2 **homogeneity test in contingency table** (to determine the proportions of responses from more populations with regards to the categorical variable);
- **Wilcoxon test** (to determine if the mean values of hesitance evaluation of two dependent groups differ significantly);
- **McNemar test** (to determine if the proportion of hesitance of categories at two time periods significantly differ from each other).

More information about these tests can be found in, e.g., Agresti and Franklin (2007).

3.2 Preliminaries of fuzzy functional dependencies

Evaluation depends on the opinion of the respondents' experience. In categorical answers, respondents might select the neighbouring value by mistake or they are not sure which one to select (Rakovská, 2021). On the other hand, we consider terms like *Rather no* and *Clearly no* more similar than *Rather yes* and *Rather no*. Thus, when there are two respondents with the same answer to one question and neighbouring answers to another question, we should recognize partial functional dependency. Thus, we applied recently improved methods of flexible functional dependencies.

Canonical Functional Dependency (FD) denoted by $X \rightarrow Y$ expresses that a function exists between attributes X and Y. If respondents t_1 and t_2 share a common value on the domain of attribute X, they also have the same value on the domain of attribute Y. The relaxed form of the functional dependency (Vučetić et al., 2013) allows for the recognition of similarity (explained in the previous paragraph as well) as its intensity. When respondents choose categorical answers (neighbouring of choices of the other respondents), we still have a significant dependency which is not recognized as a functional dependency.

In a general case, a fuzzy functional dependency (FFD) is denoted by $X \xrightarrow{\theta} Y$. It means that if respondents have similar value on attribute X, then they have also similar value on attribute Y with a similarity strength measure $\theta \in [0, 1]$.

We introduce a method for computing similarity between tuples based on fuzzy conformance as proposed in (Sözat and Yazici, 2013):

$$C(X_k[t_1, t_2]) = \min \left\{ \min_{x \in d_i} \left\{ \max_{y \in d_j} \{s(x, y)\} \right\}, \min_{x \in d_j} \left\{ \max_{y \in d_i} \{s(x, y)\} \right\} \right. \quad (1)$$

where d_i is the list of categorical values of the attribute X_k for tuple t_i, d_j is the list of values of the attribute X_k for tuple d_j, $d_i \in D$ (where D is a domain of acceptable categorical values), $s(x, y)$ is a proximity relation for the values x and y in domain D. Observe that this equation is also applicable to numeric data which should be fuzzified before applying this equation. Observe also that in Eq. (1), the second part is not necessary when the proximity relation is symmetric. Usually, it is the case, but the equation is a general one.

The next required concept is the proximity relation defined as a mapping $s : D \times D \to [0, 1]$ such that for each $x, y \in D$ Shenoi and Melton (1999):

1) $s(x, x) = 1$ (reflexivity)
2) $s(x, y) = s(y, x)$ (symmetry)

Next, we apply implication. The suitable one is so-called Mamdani implication (Vučetić et al., 2020), which, in fact, is the application of minimum t-norm in inference by residual implications (Bouchon-Meunier et al., 2003):

$$I_{MM} = \min\big(C(X[t_i, t_j], C(Y[t_i, t_j])\big) \tag{2}$$

The proportion of entities (P) expresses the proportion of all pairs of entities where FFD's condition is recognized (Vučetić et al., 2013):

$$P = \frac{C}{C_{uk}} \tag{3}$$

where C is the number of pairs of entities with the recognized FFD of strength θ, while C_{uk} is the number of pairs of all entities:

$$C_{uk} = \binom{n}{2} \tag{4}$$

In the final step, the computed proportion is converted into a linguistic interpretation (Vučetić et al., 2020). The Eq. (3) computes the proportion of entities where the condition of FFD with degree θ is recorded. When $P = 0$, no dependency exists. In the opposite case, when $P = 1$, the full canonical dependency exists (all entities have the same value for X and the same value for Y), or full fuzzy dependency is recognized (values of attributes X and Y for entities that are similar with a degree at least equal to the value θ). Hence, the computed value of P around 0.5 indicates a significant dependency between the attributes when they have diverse values. Thus, linguistic interpretation is realized by the family of fuzzy modifiers to express the meaning of P which includes the following terms: *very little*, *little*, *more or less*, *significantly* and *fully*.

4 Experiments and results

This section shows the results obtained within the still ongoing research on the topic of this paper.

4.1 Experiments using statistical methods

Hesitance of survey participants was evaluated using a series of statistical tests. First, we examined hesitance at the level of different groups. Inside each group, all hesitance-related questions were considered together as being part of the sample. The following questions were investigated:

1) Is there a difference in the hesitance between teachers from different countries?
2) Is there a difference in the hesitance between students from different countries?
3) Inside each country, is there a difference in the hesitance between teachers and students?

When it comes to question 1, there was no statistically significant difference in the hesitance between Czech and Slovak teachers. However, compared to other countries, Polish teachers were more hesitant. When examining students (question 2), it was discovered that Polish students are the least hesitant, while students from Slovakia were the most hesitant. Finally, the comparison of students and teachers inside their own countries (question 3) showed statistically significant difference only in case of Poland. Polish teachers were more hesitant than Polish students.

Second, using the McNemar test, we evaluated changes in the hesitance over time (before the pandemic vs. during the pandemic) for individual questions and respondent groups. Out of 13 different question-group combinations where a statistically significant change took place, an increase was observed in 10 cases, and a decrease was observed in 3 cases. These statistically significant changes are summarized in table 1. It is worth noting that in many cases, the change was relatively small. Considering, e.g., the last record in the table 1, out of total 333 responses, we saw a decrease in hesitance in 26 cases and 14 students actually became more hesitant.

Question	**Group**	**Significance of change**	**Increase in time**	**Decrease in time**
Do you think that the exams are fair?	CZ-Teachers	**	10	2
Do you feel motivated enough to work hard?	PL-Teachers	***	33	8
Do you find your lessons attractive enough?	PL-Teachers	***	16	3
Do you think that the exams are fair?	PL-Teachers	***	14	2
Do you consider the course evaluation at the end of the semester beneficial?	PL-Teachers	**	7	0
Are you satisfied with the quality of digital communication with students?	PL-Teachers	*	15	6
Do you feel motivated enough to work hard?	CZ-Students	**	50	31
Are you satisfied with the quality of digital communication with teachers?	CZ-Students	**	8	23
Do you feel motivated enough to work hard?	SK-Students	**	60	31
Do you find the lessons attractive enough?	SK-Students	*	30	16
Do you think that the support by digital materials for courses is sufficient?	SK-Students	*	4	12
Do you find the lessons attractive enough?	PL-Students	**	29	14
Do you think that the support by digital materials for courses is sufficient?	PL-Students	*	14	26

Table 1 List of questions - respondent group pairs with statistically significant change of the hesitance over time. (* for $p < 0.1$, ** for $p < 0.05$, *** for $p < 0.01$)

4.2 Experiments using FFD

Fuzzy functional dependencies can be evaluated between any two attributes and, therefore, it can be a demanding task when evaluating a larger number of surveys or data subsets. Hence, we focus on the flexible dependency between the hesitance of providing answers and motivation to work hard before and after the pandemic for students in Czech Republic, Poland, and Slovakia. Straightforwardly, all other dependencies can be calculated.

The first step consists of constructing proximity relations for the considered categorical attributes: *Do you feel motivated to work hard?* (the question asked before and after pandemic) and *Did you feel any hesitation in your answer?* (the question asked before and after pandemic). The answers to the former belong to the domain: *Absolutely yes*, *Rather yes*, *Neither yes nor no*, *Rather no*, and *Absolutely no*. The domain for the answers to the latter are three options: *No, (I am completely sure with my evaluation)*, *Yes, I slightly hesitate*, and *Yes, I feel strong hesitance (and my answers were driven by feeling)*. In order to create a more legible proximity relation, we expressed the hesitance answers as *No*, *A little*, and *Strong*. The proximity of weak and strong hesitation is higher that the proximity between no hesitation and the weak one. Proximity relations of these two attributes are presented in Tables 2 and 3, respectively.

s_m	**Absolutely no**	**Rather no**	**Neither yes nor no**	**Rather yes**	**Absolutely yes**
Absolutely no	1	0.75	0.25	0.1	0
Rather no		1	0.6	0.3	0.1
Neither yes nor no			1	0.6	0.25
Rather yes				1	0.75
Absolutely yes					1

Table 2 The proximity relation for attribute *Do you feel motivated to work hard?*

s_h	**No**	**A little**	**Strong**
No	1	0.4	0.1
A little		1	0.7
Strong			1

Table 3 The proximity relation for attribute *Did you feel any hesitation in your answer?*

The FFD *Hesitance* $\xrightarrow{\theta}$ *Motivation* exists, although not very significant. The results are in Table 4.

FFD	**P (Eq. 3)**	**Linguistic interpretation***
	Czech Republic	
Before: Hesitation $\xrightarrow{\theta}$ Motivation	31.38	more or less
After: Hesitation $\xrightarrow{\theta}$ Motivation	18.83	little
	Poland	
Before: Hesitation $\xrightarrow{\theta}$ Motivation	29.66	little
After: Hesitation $\xrightarrow{\theta}$ Motivation	20.13	little
	Slovakia	
Before: Hesitation $\xrightarrow{\theta}$ Motivation	36.55	more or less
After: Hesitation $\xrightarrow{\theta}$ Motivation	17.74	little

* Linguistic interpretation taken from the family of modifiers proposed in (Vučetić et al., 2020) (see Figure 1).

Table 4 The proportion of fuzzy functional dependencies or influences of hesitance to answered question on motivation to work hard, for $\theta = 0.7$.

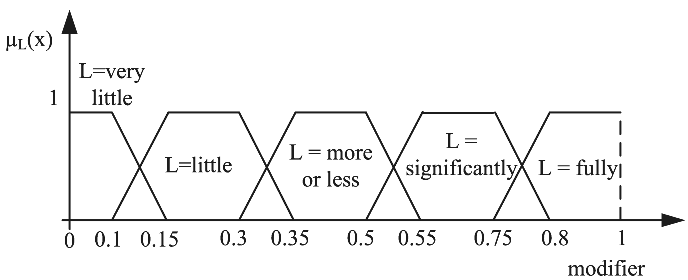

Figure 1 Linguistic interpretation by fuzzy modifiers (Vučetić et al., 2020).

The same pattern with small differences holds for all countries. At the beginning of the pandemic, the hesitance has more or less influenced the answers, while after the pandemic, the influence is low. The higher difference is for Slovakia (the highest value before and the smallest after the pandemic). The lowest difference is for Poland where the hesitance had little influence on answers to the questions in both cases.

In the same way, we can examine the other countries and stakeholder groups and summarize the findings.

When very strong dependency is recorded, then it holds on the whole domain. Medium dependency might indicate that it holds on the whole domain, or it is strong in one part, while in the other it is weak. To recognize these differences, the next step is, for instance, a quantified linguistic summarization. When a very weak dependency is recorded, there is no need for further evaluation.

5 Discussion

The FFD approach introduced in Section 3.2 and applied in experiments (Section 4.2) is also suitable when the respondent can select two neighbouring categories, e.g., wants to reply
seriously but is unsure which category is ideal so the respondent picks *Rather yes* and *I cannot decide* (if the survey allows it).

Looking at the results of statistical tests, there are several interesting findings to note. First, the situation in Poland seems to generally differ from the Czech Republic and Slovakia. It was the only country where a significant difference in hesitance between students and teachers was observed. We can also observe that Poland dominates the list of statistically significant changes in hesitance in case of individual questions from Table 1. Studying the cause of this difference is out of the scope of this paper and presented results can serve as an inspiration for further research.

Second, we generally saw a decrease of hesitance in questions that are related to technology. This could be potentially explained by users becoming more proficient in the use of digital tools over time. At the same time, the increase in the hesitance was observed for questions related to ”soft” psychological factors such as motivation or fairness. This increase could be potentially explained by the hectic character of the teaching process during the pandemic. However, these explanations should be understood only as hypotheses for further research as our work provides no concrete evidence in their favor.

Fuzzy functional dependencies revealed that the influence of the hesitance on answers was more significant at the beginning than after the pandemic. The focus was not to reveal whether the hesitance increases or decreases in time but how it influences answers - thus the differences in Tables 1 and 4. Next, FFDs recognized also that the highest influence of the hesitance was in Slovakia and the smallest in Poland. It correlates with the result of the statistical test which revealed that Polish students were the least hesitant and Slovak students were the most hesitant.

The further work should be focused also on the evaluation of FFD and statistical dependencies for the other questions and cooperation with education and social science experts. In a similar way, FFD were adopted for the explanation of the influence of financial literacy on emotional attributes (Vučetić et al., 2022).

6 Conclusions

In this paper, we demonstrated the possibilities of FFD between attributes, and statistical tests about hypotheses of the influence of hesitance on categorical answers and changes in hesitance. Thanks to the survey conducted in 3 countries, in which we collected a high number of answers related to the education before, during and after the pandemic as well as hesitance in respondents' answers, we were able to apply diverse methods to reveal valuable information. We have shown that statistical methods and FFD should be considered as complementing tools, since they provide interpretation of valuable information on the issue from different angles.

In future research, we should merge presented methods with the way the hesitance is integrated into the answers as proposed in (Zapletal et al., 2023), and compute conformance between the constructed triangular fuzzy numbers instead of conformance between Likert-scale categories. We would also like to focus our work on the evaluation of FFD and statistical dependencies for other questions and on cooperation with education and social science experts.

Acknowledgements

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System of strategic analyzes of the external and internal environment of the selected municipal company

Jakub Chlopecký[1], Roman Danel [2] , Omar Ameir [3], Václav Zyder [4], Dominika Bordácsová [5]

Abstract. Strategic analyzes serve as basic material for the formulation of a strategic goal, either company-wide or partial goals of individual activities, centers or areas of the company. The aim of the present contribution was to carry out a comprehensive analysis of a municipal company, which mainly deals with waste processing for the territory of the city of Havířov, with a proposal of strategies for the development of the company in a dynamic business environment. The result is PESTLE analysis, Porter's five forces model, VRIO analysis and subsequent SWOT analysis.

Keywords: Strategic analyzes, complex, environment, waste management, Havířov.

JEL Classification: L10, L100

1 Introduction

Today's time is characterized by a high degree of globalization and trade borders are both physically and commercially open, and a competitive organization must also take into account factors that were less important in the past. Any company that operates in a market environment is influenced by this environment and to some extent helps to co-create this environment. The current time in connection with the COVID-19 pandemic and the military conflict in Ukraine represents a difficult test for all business entities. The authors (Chlopecký et al, 2019 and Hys, 2017, 2020) stated in the paper that from today's business point of view, trade limits are practically missing.

Strategic analyzes serve as basic material for the formulation of a strategic goal, either company-wide or partial goals of individual activities, centers or areas of the company. The aim of the submitted contribution, even with regard to the scope of the contribution possibilities, is not only to summarize the results of the analyzes carried out, but also to bring to Technické služby Havířov, a.s. new results that he can incorporate into his business activity.

For the purposes of this contribution, the methods of PESTLE analysis, Porter's model of five competitive forces, VRIO analysis and SWOT analysis, which uses the results of previous analyzes will be used. In the practical part, the analysis of the external and internal environment of Technické služby Havířov, a.s. (hereinafter referred to as TSH, a.s.) will be carried out using explanation methods. using the aforementioned analytical methods with subsequent

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interpretation of the results. Due to the scope of the contribution, only one strategy for TSH, a.s. will be presented. More information can be obtained from the authors of the article.

1.1 Introduction to the issue

The principles of the circular economy are one of the priority topics of the entire European Union and bring material self-sufficiency, create new jobs and support investments in sustainable innovations. This is a new approach to managing not only limited resources, but also in the most efficient way possible (Secondary Raw Materials Policy, 2018).

In order to fulfill the main goal, it is necessary to carry out the best possible analyzes using the basic methods of strategic management, which, however, are elaborately conceived and are not purely a simple inventory of the subjective feeling of the author, but are also based on the suggestions of the expert group.

The partial objectives will be the analysis of the external and internal environment of the company. These analyzes will be conducted through basic and advanced strategic management methods. The synthesis of analyzed data based on the interpreted results of business analyzes is the realization of strategy proposals (due to the scope, only one is used in the text, as a preview of the results), which the analyzed company can use to strengthen its position in today's highly competitive market.

The basis of every strategy is the definition of long-term and short-term goals. The goals should reflect the future state of the company using the company's operational activities and should be implemented according to the basic methodology of strategic and project management, namely the SMART methodology (Chlopecký et al., 2019 and Chlopecký et al. 2018 and Anton, 2015). The principle of strategic management is a never-ending process, which by its very nature is based on the PDCA cycle (plan-do-check-act) in more detail in Figure No. 1.

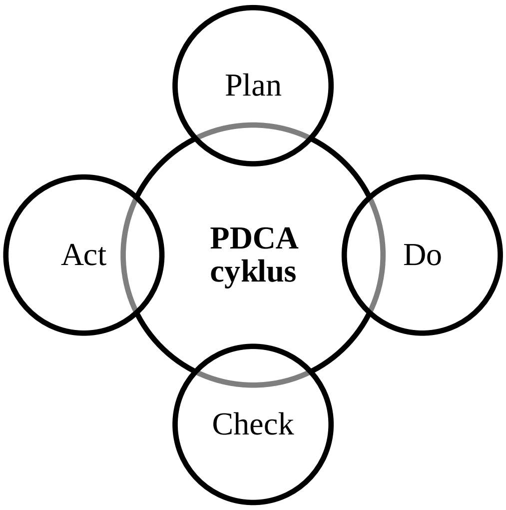

Figure 1 PDCA cycle

The sub-goals will therefore be:

- Analysis of the macro and micro surroundings of the municipal company;

- Demonstration of the strategy proposal based on the identified data and the analysis of these data bases.

In order to properly grasp the topic and the relevance of the results, and the ability to choose an adequate set of methods for the company's strategic analyzes, the following methods were used methodologically:

1. Induction – this is drawing general conclusions based on previous knowledge of the data set;
2. Deduction – more precise focus and derivation of new statements based on the established data;
3. Exploratory analysis – the best possible explanation for the observed phenomena;
4. Analysis – knowledge of phenomena and subsequent determination of the tactics of scientific research activity of strategic analyzes of the company;
5. Advanced methods of strategic analyzes - accurate expression of phenomena and relationships between the investigated phenomena;
6. Proposals of strategies - based on the results, analyzes of the direction of the company's business activity will be carried out (Chlopecký, 2019).

Research of the given issue

In April 2021, the Ministry of the Environment prepared a proposal for public consultation entitled: *"Strategic framework of the circular economy of the Czech Republic 2040 - a maximally circular Czech Republic in 2040."* This document, or its strategic framework is to formulate assumptions, goals and measures so that the Czech Republic is long-term resistant to future environmental threats, including climate change, and overall develops a sustainable social system through the circular economy (Secondary Raw Materials Policy, Kozel et al., 2015 and 2018, Acuña-Carvajal, 2019).

The legislative basis of the issue of waste is defined in the conditions of the Czech Republic by Act No. 541/2020 Coll. Waste Act. The issue of waste management, more precisely the introduction of new information technologies in the processes of handling all waste, is addressed in more detail by Kozel in the article Innovation in waste management. This publication aims to name the means of introducing information technologies into the waste management process and fulfilling the requirements of the waste management package of the European Union (Act No. 541/2020 Coll. Waste Act).

Besta and collective focuses on improving processes not only within the framework of waste management in the conditions of a manufacturing company focusing on the production of steel. and the life cycle of an enterprise can be greatly extended by appropriate strategic planning (Besta et al., 2020).

2 Characteristics of TSH, a.s. (Joint Stock Company)

The history of Technical Services in Havířov began on 1 July 1964. Technical Services in Havířov was founded on the basis of a resolution of the Municipal National Committee in Havířov under the name Technical Services in Havířov, a budget organization (hereinafter also

TSmH). Over the years, TSmH relocated and the construction of campuses at Karvinská Street 66 and 63 and Na Kopci in Dolní Suché was underway.

The diagram below presents individual business activities of TSH, a.s. in 2023.

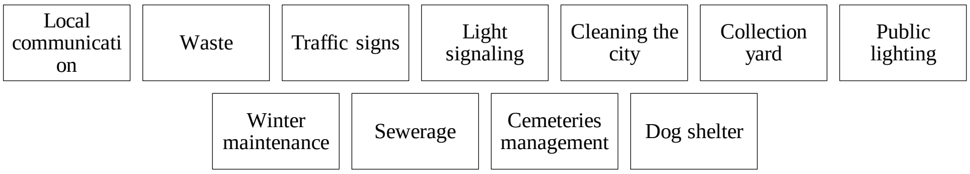

Figure 1 Individual activities of TSH, a.s.

The subjects of the business also include business in the field of hazardous waste management, assembly, repairs, revisions and tests of electrical equipment, locksmithing, tool making, masonry, operating a funeral service, road motorized freight transport, etc.

3 Methodology of Survey

The authors focused on some of the most used methods of external and internal strategic management environment, which are still effective and quickly applicable for practical use (Somosi, and Koczizsky, 2017). The results of the research are original and unique for a given type of business with a focus on the selected company and will help guide the creation of a strategy. Primary data for re-search and use in strategic analyzes is obtained using a basic survey of the issue. These were mainly available internal materials of TSH, a.s. (Kotler, 1998, Matusiková, 2014).

The main goal was to find the key parameters of the analysis of either the external or internal environment of the company. These data provided additional data for expanding the information base. The methods used in the analysis are:

- PESTLE analysis;
- Porter's Model of Five Forces;
- VRIO analysis;
- SWOT analysis.

These used strategic management methods are in comparison with the SMART methodology, which is mentioned above, and are also defined in the methodology of the contribution, which is also described above. The evaluation method chosen based on Kotler appears to be an ideal form for the results of the SWOT analysis. This method consists in implementing an evaluation using points, assigned according to how the strengths and weaknesses were evaluated according to importance, in an interval of whole numbers. The interval range of the Kotler method was set in the range <-2;+2> including zero. The latter indicates the neutral significance of the factor. Opportunities and threats are evaluated using this method, the attractiveness of the opportunities, or the impact of the threat and the probability of the occurrence of the identified facts (Kotler, 1998).

4 Results

Empirical results of individual strategic analyzes processed in the paper lead to the fulfilment of partial goals (Ministr, 2019). These sub-objectives, resp. their evaluation is another basis for the main goal of the presented paper, namely the elaboration of a strategic analysis. This is one of the most important parts of the research work of the author's team.

An expert group of contributors and company representatives

In order to correctly grasp the results of the individual strategic analyzes (PESTLE, Porter's five forces model, VRIO analysis and SWOT analysis), an expert team was created (the vice chairman of the company's board of directors - the main author of the contribution, the chairman of the company's supervisory board, the company's director and the company's deputy director, who is also the author) article). The expert team in this composition was chosen so that the results were relevant and not based only on the subjective feeling of the authors acting in a proportional representation in the academic environment. The expert team is also responsible for point assessments, e.g. for Porter's five forces model.

4.1 PESTLE analysis TSH, a.s.

For an overview, Table 1 shows the PESTLE analysis of TSH, a.s. and described the individual most significant influences that were captured for the individual factors of the analysis.

Political factors	Executive and legislative power of the European Union and the Czech Republic
	The political influence of a single shareholder
	Factors of local character
Economic factors	Basic development of the economy of the Czech Republic
	Prices of energy raw materials and Fuels
	Monetary indicators (policy of the Czech National Bank)
Social factors	The demographic curve
	The development of unemployment not only in the city
	Aging of the population of Havířov
	Generally unfavorable public opinion
Technological factors	A dynamic sector of technological change
	Automation and robotization of industry
	Involvement in the CEVYKO[3] project
Legislative factors	Amendment of the Waste Act
	The unpredictable environment of European Union regulations
	Unclear conditions of the end of the landfill
Ecological factors	Pressure for higher sorting
	Environmental policy of the Government of the Czech Republic
	Efforts to minimize waste production

Table 1 PESTLE analysis of TSH, a.s.

[3] Center for the use of municipal waste.

The political factors segment of this company, which is 100% owned by the statutory city of Havířov, can be divided into two parts, respectively on two levels.

The first level is the political factors that influence TSH, a.s. influence and can be monitored on a re-public level. These factors are represented by the executive and legislative power of the Czech Republic. These factors represent influences from international agreements, treaties and commitments. The second part of the factors are political factors and the influence of the local influence of the company. The second area of the given factors is the action of the local government as the founder and sole owner of the joint-stock company.

The largest share of business activity goes from households to TSH, a.s. It can be considered that the economic condition of the Czech Republic in connection with the growth/decrease of the gross domestic product (hereinafter referred to as GDP) has an indirect effect on the waste management sector. There are no more significant causalities in this main performance indicator of the Czech Republic's land economy.

Currently, according to the Czech Statistical Office, the rate of inflation is at very high levels (16.4%), comparable to the year 1992. (CZSO Public Database, 2023) Since TSH, a.s. in the field of business, it is not only waste management, but also public lighting management, construction activities, etc. Inflation and its level is a negative factor for input raw materials, e.g. for green maintenance, maintenance and renewal of public lighting, asphalting, paving, construction work and labor prices subcontractors working for TSH, a.s.

The interest rate of the Czech National Bank (hereinafter CNB) affects the business of TSH, a.s. as well as in other sectors of the economy and households. The company TSH, a.s. uses the maximum possible amount of its own funds for investment activities (property, renewal of the vehicle fleet, investment in machinery).

With falling unemployment, even assuming that a further decrease due to seasonal work can be expected, according to data from the Czech Statistical Office in the Czech Republic (2.5%) (CZSO Public Database, 2023), pressure is created on wages, which in case of incorrect management policy of human resources (no or minimal growth, insufficient benefits, etc.) can translate into higher turnover in the company. With higher turnover, the costs of the company are also higher, and related to this are higher costs for training new employees, etc.

Another social parameter is the increase in the average age of the population of the given city. In 2017, the average age of the inhabitants of the city of Havířov was 43.5 years, in 2022 it was already 44.21 years. (Internal data of the city of Havířov). From a long-term point of view, it can be said that the decrease (in 2017 there were 73,274 inhabitants in the city of Havířov, but in 2022 only 69,084 inhabitants) and the aging of the population can negatively affect the total production of waste and the amount of work for the city. (Internal data of the city of Havířov) The authors believe that with the decreasing number of inhabitants, the total production of waste will decrease, as the main business activity of TSH, a.s. Based on their experience, the authors believe that the aging population will not have a positive relationship with waste sorting, and thus the company TSH, a.s. additional costs of waste treatment as a whole.

The company TSH, a.s. it also affects citizens' relatively bad opinion of these services provided by residents, because these services are charged for and in some parts of the Moravian-Silesian Region there are municipalities that have, for example, a fee for municipal waste of CZK 1 per year. It is difficult to explain that otherwise the costs would be directly reflected in the management of the municipality and these funds would be missing for other investment actions, but also for actions of an operational nature, which entail mandatory obligations. .

The waste management sector is developing dynamically, as is, for example, energy. Technological progress with the maximization of the use of automation, robotization and Industry 4.0 in general creates pressure for more efficient, faster and better waste processing in the principles of the circular economy and the circular economy as a whole. (CZSO public database, 2023)

The waste management sector is relatively extensively regulated by state administration institutions.

Environmental protection and everything related to it has become a societal trend in recent years. The topic is mentioned a lot and one of the easiest activities that an individual can engage in is to try to minimize the production and sorting of waste.

4.2 Porter's Model of Five Forces TSH, a.s.

Effects of Porter's Model	**Average point estimates**	
	year 2024	**year 2025**
Existing industry competitors	2,93	7,57
Threat of entry of new competitors	2,22	3,05
The threat of substitutes	4,48	5,27
Bargaining influence of suppliers	1,87	3,67
Bargaining influence of customers	6,49	2,91

Table 2 Porter's Model of Five Forces TSH, a.s.[4]

Existing competition for TSH, a.s. the competition that has the same field of business, experience in the field, capital and technology for processing waste and other activities, e.g. construction or electrical activities, is considered. In this specific field of business, it should be noted that small and medium-sized enterprises are relatively excluded from competition. Waste processing technologies are a one-sided field of business, because the given technologies and technological procedures cannot be used in another field of business, which makes the entry of new competitors more complicated and more demanding of investment. Substitution items defined in Porter's model of five competitive forces are primarily oriented towards the possible use of waste without a major processing process. The market here is somewhat oligopolistic. A change of supplier in the waste sector is possible in a relatively medium-term period, so it is not a short-term process.

Through control and regulatory bodies, it is possible to exercise partial influence of customers on suppliers in this matter. Within the market environment, sorted waste components

[4] The results were evaluated primarily using the brainstorming method of the expert group.

are considered as commodities, and buyers of these commodities (secondary raw materials) have a certain negotiating influence on waste processors.

4.3 VRIO analysis TSH, a.s.

Category	Source	Creating value	Rare	Hard to imitate	Organizationally usable
Human resources	Labor professions	Yes	Yes	No	Yes
	Expertise of workers	Yes	Yes	No	Yes
	Motivation of employees	Yes	No	No	Yes
	Staff skills	Yes	Yes	Yes	Yes
	Company management	Yes	Yes	Yes	Yes
Financial resources	Liquid assets	Yes	Yes	Yes	No
	Subsidy	Yes	No	No	Yes
	The creditworthiness of the company	Yes	Yes	Yes	No
	Sales growth	Yes	No	No	No
Physical resources	Quality equipment	Yes	No	No	Yes
	Buildings	Yes	No	No	Yes
	Machinery equipment	Yes	Yes	No	Yes
	Vehicle fleet	Yes	No	No	Yes
	Locker rooms and facilities	Yes	No	No	Yes
	Parking	Yes	Yes	No	Yes
Intangible resources	Software	Yes	No	No	Yes
	Certification	Yes	No	No	Yes
	Tradition	Yes	Yes	Yes	Yes
	Attractive employer	Yes	Yes	Yes	Yes
	Corporate Culture	Yes	Yes	Yes	Yes

Table 3 VRIO analysis TSH, a.s.[5]

The territory of Havířov, as well as the entire Moravian-Silesian region, is an industrial area with a long history of this sector of the economy. As already mentioned above, blue-collar professions are highly prevalent in society. It is possible to consider the fact that these two characters have a positive influence in terms of future employees. It is important to keep those employees in the company who are qualified, experienced and reliable even in these positions.

Also from the point of view of TSH, a.s. job positions. the company contributes in education, courses and training (drivers, etc.). Employees also undergo so-called cross-certification so that one is able to replace the other in case of absence (head of centers, selected labor professions). The management's foresight in cross-certification and the application of these principles was manifested in a positive spirit in the last two years during the COVID 19 pandemic, when the

[5] The results of the authors are based on the experience of the representatives of the expert group.

company and all its centers fulfilled their functions and obligations to shareholders despite quarantine measures and illness.

Motivation is not always just about the financial side, that is why the company organizes various social events, parties and children's days with TSH, a.s. These non-financial actions lead to the improvement and strengthening of mutual relations and generally contribute to a good company culture and environment.

4.4 SWOT analysis TSH, a.s.

The SWOT analysis was processed according to the method of combining the data obtained above from the performed analyses. The results of the previous three analyses, i.e. PESTLE analysis, Porter's model of five competitive forces and VRIO analysis were assessed and incorporated into the identification of the quadrants of the SWOT analysis.

The intersection of the assessed factors constitutes part of the opportunities and part of the threats for TSH, a.s. For the completeness of the SWOT analysis, the strengths and weaknesses of TSH, a.s. These strengths and weaknesses of the company were consulted as part of the brainstorming method in the company's bodies with prior consultation with the management of TSH, a.s.

Reduced SWOT analysis of TSH, a.s.

Municipal Corporation Experience in waste management Financially stable company Maturity in waste management	Complex processes in society Slower asset recovery The sole shareholder is tied to the political environment
Amendment to the Waste Act Cooperation with the CEVYKO project Development of the company through the CEVYKO project	Commodity volatility Political changes after municipal elections Demographic development of the city

Table 4 Reduced SWOT analysis of TSH, a.s.

Graphic processing of the SWOT analysis gives the following results:

- The most significant strength of the company is the shareholder structure, or the fact that the company is owned by a single shareholder, namely the city of Havířov;
- Rich experience in waste management with a financially secure and healthy company using a reasonable amount of foreign capital is also a strength;
- Maturity factor in the field of waste collection, processing and management, these experiences are given by many years of handling different types of waste.

According to the authors, the weakest point of the reduced SWOT analysis is the following:

- Complex processes in the company, which are connected with the shareholder structure and the influence of the political environment;
- Slower property recovery (results in increased repair costs);
- The sole shareholder is tied to the political environment and any change after the municipal elections (or even during the election period) has a logical impact on municipal companies, TSH, a.s. without exception.

Selected factors of the reduced SWOT analysis, or quadrant of opportunities for TSH, a.s. are listed below:

- The amendment to the Waste Act brings significant legislative changes and opportunities for TSH, a.s. is to incorporate these changes without lengthy processes into the functioning of the company, thereby reducing the risk of non-fulfillment of legal obligations arising from the new Waste Act;
- Cooperation with the CEVYKO project, this project is unique mainly because the shareholders are purely municipal in nature;
- Development of the company through the CEVYKO project;
- Selected factors of the reduced SWOT analysis, or threat quadrant for TSH, a.s. are listed below:
- The volatility of commodities and their prices threatens society both in terms of waste management, but also from an operational point of view, such as the prices of energy, fuel, construction work, materials, etc.
- Political changes after the municipal elections – these changes are related to the above-mentioned opinions already described in the weaknesses of the SWOT analysis of TSH, a.s.
- The demographic development of the city threatens the production of waste for society

5 Suggestion of strategy

Due to the scope of the boat, one strategy is described from the package of strategies that were identified through research and implemented in the strategic document of TSH, a.s.

SO strategic goal of the company

Development of TSH, a.s. through the CEVYKO project

Description of goal realization

The CEVYKO project is at a high level of development, a similar purely municipal project currently does not exist in the territory of the Czech Republic. Through new legislative requirements, an experienced team of experts and good physical condition, TSH, a.s. with the important CEVYKO project, cooperation on waste processing will be a significant opportunity.

The aim is to support the CEVYKO project as much as possible, to offer their experience and knowledge. This goal is already connected with a participating interest in one of the shareholders of the company CEVYKO, which implements the already mentioned project. Waste is the last commodity that municipalities can deal with through companies like TSH, a.s. load and process them.

6 Conclusion

Waste management is a specific area of the national economy, which historically is not subject to standard market principles, which are typical for a whole range of other publicly or privately provided services. Humanity and waste, two quantities that have been intertwined since ancient times. All human activity produces a significant amount of waste, whether it is generated in agriculture, the industrial sector, services or in ordinary human life. The connection with consumer life leads to considerable production of municipal waste.

Waste management is an important and dynamically developing area of the national economy, which is fundamentally regulated by national and European legislation. The importance of these legislative documents and regulations is constantly and significantly increasing over time. Risks can be detected from the results of Porter's analysis, where the development over time was also predicted in this analysis. The most current threat for 2024 is the bargaining power of customers with a value of 6.49 points. The second highest ranked factor for 2024 is the threat of substitutes. These two factors are in a higher interval mainly because, as already mentioned above, the market within waste management is very specific and factors of experience in the field play a big role here. The biggest threat in 2025 is the influence of existing competition in the industry and the related threat of substitutes in the industry.

The lowest factors in the analysis are supplier bargaining power with values of 1.87 points in 2024 and 3.67 points in 2025.

By comparing and then comparing the results of the PESTLE analysis, which assessed the effects of the macro environment of the company TSH, as, and the results of the Porter's Five Force analysis tool and VRIO, which evaluated the company's micro environment in terms of competitiveness, a portfolio of the most significant threats and opportunities was selected for the SWOT analysis, which was for completeness supplemented by company strengths and weaknesses.

The strongest factors of TSH, a.s. factors are the community of the company, an experienced team of experts related to maturity in waste management and a financially stable company. Factors that are important for TSH, a.s. the weak point is the experienced complex processes, slower recovery of property and dependence on a single shareholder, the city of Havířov.

Opportunities for the company are tied to the success of the CEVYKO project, which is still unique in today's situation.

The CEVYKO project aims to ensure the treatment of waste, especially from the city of Havířov, in a modern and efficient way. This project is based on the regulation of the European

Union, which was transferred to Act No. 541/2021 Coll. Waste Act. This law mandates a higher rate of waste sorting, a smaller share of landfilling and a higher share of waste for energy use, or partial replacement of fossil fuels. The company TSH, a.s. would not be able to achieve the goals defined in Act No. 541/2021 Coll. to achieve, therefore the results are linked to the CEVYKO project, which, after successful implementation, will achieve these goals. Like any company, the biggest threat right now is commodity volatility and inflationary pressures related to the dire global situation. The specificity of the threats to the municipal society of this sector is the follow-up to the political changes that occur after the municipal elections in municipalities and cities and the demographic development in the given territory.

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Attendance of the Theatres in the Czech Republic - Regression Model and Prediction

Lucie Chytilova [1] , Blanka Bazsova [2]

Abstract. Theatres are an important part of every country's culture. Attendance is a key element that shows the success of a theatre. It is also a key issue that contributes to the profitability and development of a country's culture. Theatres should be efficient, just like businesses and other economic entities. This paper presents the factors that affect theatre attendance. This paper aims to measure the strength of influence of the selected factor from the Czech theatres using regression analysis. This paper aims to propose and select a regression model of theatre attendance in the Czech Republic. For modelling and evaluation, six variables that can influence the attendance rate were analyzed and evaluated. After evaluation using economic and statistical analysis, two regression models were tested and a prediction of attendance development in the next two years was determined. The results showed the most important influencing factors and together with the prediction can show how to positively influence the area and develop culture in the Czech Republic.

Keywords: attendance, influence, regression function, theatres.

JEL classification: C12, C32, E31

1 Introduction

Culture is an integral part of our life. Scholars are constantly measuring the benefits of culture because cultural performance is part of any country's performance measurement. The reason for this constant interest in measuring cultural performance is the danger of slowing down its dynamic development due to the influence of low-income and socially weak groups of the population, and especially the outflow of interest in culture among young people because they are the ones who do not have the means to go to the theatre, to a concert, or another cultural event. The authors of Montalto et al. (2023) used cultural indicators to measure cultural performance and explored the level of culture in selected European cities. They used 29 culturally relevant indicators for the evaluation. They found that there is no strong correlation between empirical indicators of a city's cultural vibrancy and its creative economy performance. Ozhegov and Ozhegova's (2023) analysis of the demand for performing arts. They recognised the presence of consumer segments with different purposes of going to the theatre and willingness to pay for performance and ticket characteristics, which compels them to account for heterogeneity in theatre demand. The authors predicted the demand for the theatre. Estimation was based on the idea of classification and regression trees and aggregation of bagging prediction. In Turkey, an empirical study focused on state subsidies and private theatres was provided. (Akdede and Ozpinar, 2021). Tontini et al. (2022) used the regression analysis and the penalty-reward contrast analysis to discover the influence and behavioural intention of movie theatre customers. Another research subject was cultural marketing in the theatre sphere. Jukic (2018) brought up states that society is based on the production and exchange of images, which are based on the symbolism of the brand. From the aspect of cultural management, the work of art is a prototype, and the purpose of the prototype is to reproduce to exist in multiple copies. The theatre is very specific because it represents the place of production, the place of distribution, and the brand.

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The specificity of the cultural product itself is in a paradox. An artist should offer his work, which is a moment of inspiration, while at the same time, the consumer needs to adapt to his product. Jukic (2018) analysed the gap between artistic dreams and marketing reality in the theatrical act model.

Due to the broad concept of culture, the state's cultural policy represents a strategic framework of culture and creativity. It is based (cultural policy) on the traditional pillar of the system of goals and is within the purview of the Ministry of Culture. Its activities are also specified in this strategic framework. Another of the goals of this framework is the care of cultural heritage and especially the development of cultural and creative industries. One of these industries is theatre, among others. Given the low profitability of this industry and the entire sector in general, the financial assistance policy is an integral item and part of the negotiations on the state budget. The state cultural policy serves as a basis for public debate on the necessity of allocating 1% of the state budget without transfers to churches and religious women's societies for state programmes for the development of the cultural and creative sector. Part of the monitoring of certain indicators in the culture of the Czech Republic is regularly carried out with descriptive statistics. However, these data describe longer-term processes before 2020. The consequences of the crisis and Covid are extreme, and their impact on culture is not only short-term but also long-term.

The theatre system in the Czech Republic is structured and statistically monitored as a network of public theatres, the non-profit sector, and the business segment. The subject of statistical investigation is the performance and management of theatres that regularly produce theatrical or dance performances. The authors of this article discovered that the data and information collected in the field of culture in the Czech Republic, specifically in the theatre sector, are summarised and not examined in a broader context. From the annual reports of the Ministry of Culture of the Czech Republic, we can find data on the number of theatres established by the Ministry of Culture, the Ministry of Education, Culture, Science and Technology, the region, municipalities and cities, their capacity, the number of theatre companies, the number of permanent employees and the number of theatre visitors. From the financial data, we can obtain information about the average ticket price, about revenues and contributions from the Ministry of Culture, individual regions, etc. From the analysis of the available literature, it was found that the dependence between theatre attendance and macroeconomic indicators, such as population, employment, GDP, etc., has not yet been monitored in the Czech Republic. Furthermore, it is not foreseen how the development of attendance in theatres will proceed in the next nearest period.

The contribution aims to create a model of the dependence of attendance development on selected economic indicators in the Czech Republic and to estimate, confirm, or refute the influence of the selected variables on theatre attendance. For modelling and evaluation purposes, a regression model was chosen, in which the dependence of attendance on the number of theatres, the size of the population, the level of GDP, the employment rate, the average monthly rate of old age pensions paid, and the number of performances of ensembles performed in the Czech Republic would be monitored.

2 Analysis of data in the theatre sphere

Theatre attendance is one of the most important indicators of cultural interest and, therefore, it is important to monitor it (attendance). Most of the income from individual theatres is dependent on attendance. Data on the development of theatre attendance in the Czech Republic show a growing interest in this segment of culture. The authors of this article focused on monitoring the development of traffic, which would confirm the dependence using a regression model, which will be considered here as the dependent variable (y_t). Attendance data were expressed in thousands of people and were monitored from 1996 to 2022. From the annual reports of the Czech Republic Ministry of Culture, an increasing trend of attendance can be seen from 1996 to 2020, which was practically continuous from 2003 until 2019, when attendance reached 6,831,000 people. The Covid period in 2020 and 2021 strongly affected the development of culture, which was manifested by a deep drop in attendance (in 2020 it was only 2,435,804 viewers). The number of theatres has also been increasing since 1996, with a slight drop in 2002 and 2003. Since 2004, the number of theatres has risen dramatically and reached 210 in 2022. This variable will be considered an independent variable and will be denoted x_{1t} in the model. The population in the Czech Republic has increased slightly since 2004 and reached 10,500,000. It was once again broken by the ”Covid period”. We call this variable in the model the independent variable x_{2t}. The gross domestic product showed a slightly increasing character throughout the monitored period. In 2022, it reached the amount of CZK 6,108,428 million. (independent variable x_{3t}, units CZK million). The annual percentage of employment decreased for the first time but started to increase in 2010 (variable x_{4t}). Monthly paid pensions increased linearly throughout the monitored period and reached CZK 15,812 in 2021. (independent variable x_{5t}). The number of theatrical performances realised in the Czech Republic was increasing, but it encountered the ”Covid period” again, which meant a sharp decline and growth again, reaching 15,098 in 2021 (independent variable x_{6t}). Considering that visitation and all other dependent variables were monitored in annual time series from 1996 to 2021, none of them shows the character of seasonality. This analysis also shows an increasing trend for all variables in Figure 1. For some variables (y_t, x_{2t}, and x_{6t}), this trend was interrupted by the ”Covid period” (2019, 2020). Outliers were observed for attendance in 2020 and 2021. Since this is a small number of the total number of monitored values (up to 5%), we can call this phenomenon insignificant.

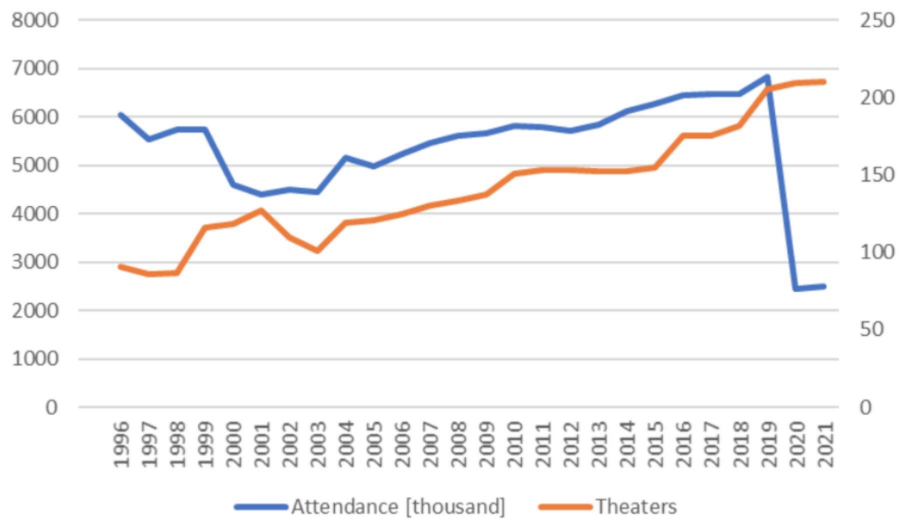

Figure 1 Development of attendance in the theatres and number of theatres (Data: NIPS; own processing).

From the descriptive statistics of the monitored variables (time series), shown in Table 1, it can be read that the smallest attendance was 2435.8 thousand people and the highest 6 831 thousand people. The average attendance was 5373.86 thousand people. The lowest number of theatres was 86 and the highest was 210. The population reached its maximum of 10.700 thousand. people in 2020. The gross domestic product was the lowest in 1996 (1 829 255 million CZK) and the highest in 2021 (1829255 million CZK). The employment rate was the lowest at 54.1877% and the highest at 59.059%. The smallest monthly amount of pensions paid for old age was in 1996 (CZK 4,744) and the highest was in 2021 (CZK 15.812). The average number of performances was 24,560.

	Mean	**Median**	**Std. Deviation**	**Variance**	**Minimum**	**Maximum**
y_t	5,374	5,678	1,076	1,158,576	2,436	6,831
x_{1t}	141	135	36	1,280	86	210
x_{2t}	1×10^7	1×10^7	158,704	2.5×10^{10}	1×10^7	10,700,155
x_{3t}	3,793,370	3,973,595	1,240,476	1.5×10^{12}	1,829,255	6,108,428
x_{4t}	56	56	2	3	54	59
x_{5t}	9,223	9,223	2,998	8,988,757	4,745	15,812
x_{6t}	24,560	25,296	4,820	2.3×10^7	12,709	31,283

Table 1 Descriptive statistics of all considered variables. Own calculation using SPSS software.

Description of the solution procedure: Original variables y_t and $x_{1t} - x_{6t}$, which represent the time series of the variables considered, did not show missing values. Dependency testing using both a regression model and a correlation matrix was used. Furthermore, it can be confirmed that all variables (time series) are monitored annually, therefore, they do not show a seasonality factor. The data did not need to be further cleansed of the cyclical component. All variables (time series) of the originally intended model (with one output variable and six input variables) were tested for stationarity. Statistical verification was done. The results for the original time series showed that data were not stationary. A modified time series with logarithms and differences were also tested for stationarity. The reasoning behind the use of differences in this time series came out as the best in terms of achieving stationarity - all used variables are now in units of year change and the notation will be as dy_t and dx_{1t} – dx_{6t}.

3 Regression model

When managers want to forecast future performance, a time series of past performance is used to identify drivers and fit a model. A time series model can be used to identify the driver whose variation over time is associated with subsequent variation in performance over time (Fraser, 2013). A regression model from time series data allows us to identify performance drivers and forecast performance gave specific driver values, just as regression models from cross-sectional data do. We consider in this paper the multiple linear regression based on the relation (Budíková, et al., 2011):

$$y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + ... + \beta_k x_{kt} + \epsilon_t \quad t = 1, ..., T, \tag{1}$$

where y_t is the variable to be forecasted and the $x_1, ..., x_k$ are the k predictor variables. The coefficients β_0 is the constant, $\beta_1, \beta_2, ..., \beta_k$ are unknown model parameters and measure the effect of each predictor. The variable ϵ_t is the residual component. It is worth noting that the overall model must satisfy classical statistical and econometric assumptions (such as the absence of autocorrelation, multicollinearity, etc.).

As a starting point for building a regression model and the hypotheses for the relationship between dependent and independent variables for this paper, we can use the formulation with the knowledge of stationary time series (differential time series):

$$dy_t = (dx^+_{1t}, dx^+_{2t}, dx^+_{3t}, dx^+_{4t}, dx^+_{5t}, dx^+_{6t}), \tag{2}$$

where $dx_{1t}, ..., dx_{6t}$ are independent variables in years differences. These variables are supposed to have a positive (growing) relationship with the dependent variable dy_t in year differences for this proposed model. The positive relationship is logical from the theory point of view - all independent variables positively influence a dependent variable, ceteris paribus.

In the beginning, before the economic, statistical and regression analysis the regression model with stationary variables in year differences had been defined as:

$$dy_t = \beta_0 + \beta_1 dx_{1t} + \beta_2 dx_{2t} + \beta_3 dx_{3t} + \beta_4 dx_{4t} + \beta_5 dx_{5t} + \beta_6 dx_{6t} + d\epsilon_t \quad t = 1996, ..., 2021, \quad (3)$$

where dy_t is the dependent variable in year differences, more precisely yearly change of number theatres. The $dx_{1t}, ..., dx_{6t}$ are independent variables in years differences as it is define in Chapter 2.

4 Results

Based on the first regression model (3), two functional models were created - they will be referred to as Model A and Model B. These models are similar and are presented in the following two subsections.

To define these two models, statistical and econometric analysis had to be performed. All analysis had been done on a 5% significant level. More precisely, a correlation analysis and a cross-correlation analysis were first performed. Here, several findings were made, specifically the largest removal of explanatory variables. This was primarily due to the poor statistical relationship between the explained variable and the explanatory variable (even after time adjustment). At this point, variables were not eliminated if they did not fit with economic theory but were statistically significant. This step was done after the first regression estimation unless the regression coefficient was in analogy with a given Pearson coefficient. Next, a t-test and F-test were performed to generate the two models mentioned above.

The basic regression statistics for the two models are shown in Table 2. The models are then presented in more detail in the following subsections.

Model	R^2	R^2_{adj}	**DW coefficient**
Model A	0.891	0.874	2.008
Model B	0.887	0.876	2.112

Table 2 Results of the basic regression analysis for both models with significant independent variables.

Based on the results in Table 2, it can be seen that both models are very good - both models have stationary time series, statistically significant variables (at 5% significance level), coefficients of determination R^2 (and adjusted R^2_{adj}) are high (around 0.8, so all models are 80% good) and the Durbin-Watson coefficient (which gives an insight into autocorrelation) is around 2, so the following subsections will describe the models more specifically.

4.1 Model A

Model A is generally defined as:

$$dy_t = \beta_0 + \beta_1 dx_{1t-1} + \beta_3 dx_{3t} + \beta_6 dx_{6t} + d\epsilon_t, \quad (4)$$

and specifically looks like:

$$dy_t = -95.015 - 17.579 dx_{1t-1} + 0.003 dx_{3t} + 0.190 dx_{6t} + d\epsilon_t. \quad (5)$$

At first glance, it can be seen that Model A has only three variables (the other variables were excluded as statistically insignificant) and a negative constant (-95.015). It can also be seen that the variable dx_{1t} is also time-shifted, or more precisely lagged by one period. Thus, it is clear that the annual change in the number of theatres depends on the annual change in the number of visitors of the previous season. This is logical, but what is against the hypothesis given at the beginning of the paper is that this relationship is negative, not positive. The other relationships between the annual change in theatres and the annual change in GDP and the number of performances are positive and depend on the same annual change.

Table 3 shows the summary of the basic econometric verification. Model A can also be regarded as very good and possibly suitable for prediction from this perspective - no autocorrelation, no multicollinearity, normally distributed residuals and the heteroscedasticity had been ok at 10%.

4.2 Model B

Model B is generally defined as:

$$dy_t = \beta_0 + \beta_1 dx_{1t-1} + \beta_6 dx_{6t} + d\epsilon_t, \tag{6}$$

and specifically looks like:

$$dy_t = -7.451 - 17.083 dx_{1t-1} 0.198 dx_{6t} + d\epsilon_t. \tag{7}$$

Model B even includes only two variables (the other variables were excluded as statistically insignificant and dx_{3t} was excluded based on the small and perhaps insignificant value $\beta_3 = 0.003$) and a negative constant (-7.451, which is probably more logical). The variable dx_{1t} is again time-shifted, more precisely lagged by one period (the annual change in the number of theatres again logically depends on the annual change in the number of visitors of the previous season). The second relationship between the annual change in the number of theatres and the annual change in GDP is also positive.

Table 3 shows the summary of the basic econometric verification. Model B can also be regarded as very good and possibly suitable for prediction from this perspective - no autocorrelation, no multicollinearity, normally distributed residuals and the heteroscedasticity had been ok at 10 %.

4.3 Comparison of models

Both models are quite similar (see table 3). So it was hard to decide which model is better. Both the positives and the negatives were the same. The only big difference was the number of independent variables. Specifically, the variable dx_{3t}. Since the value of $beta_3$ was only an annual change of 0.003, so it was a very small value and had little effect on the variable being explained, it was decided that Model B was more appropriate. This decision was reinforced by the value of R^2_{adj}. The R^2_{adj} was larger for Model B and hence the significance of the model is greater even without the variable. And among other things, the rank of the constant, which is only in the order of ten, is more logical for this model. Therefore, for future work, this model will be worked with and will be used for future predictions.

Assumption	Model A	Model B
R^2_{adj}	0.874	0.876
Autocorrelation	ok (2.008)	ok (2.112)
Heteroskedasticity	ok*	ok*
Multicollinearity	ok	ok
Normality	ok	ok

Note: * means tested at 10% significant level.

Table 3 Summary of econometric verification of both regression models (own processing using SPSS software).

5 Conclusion

This article serves as the beginning of a study to understand the culture in the European Union before and after Covid, with the first analysis being conducted in the Czech Republic. A deterministic regression model was used to examine the relationship between variables, where theatre attendance, number of theatres, population, GDP, employment rate, the average monthly amount of retirement pensions paid and number of performances in the Czech Republic were projected. Based on stationarity testing, the conventional time series was changed to annual changes. In addition, correlation and cross-correlation analyses were performed to exclude some variables. Furthermore, regression analysis was performed. Which yielded two models that were similar in meeting the assumptions of the least squares method (all tested at the 5% significance level, except for heteroskedasticity). Based on expert estimation, Model B was selected, which, although having only two explanatory variables, was otherwise very good (in terms of the assumptions mentioned and the regression coefficient, which was around 88 %).

The validated regression Model B is suitable for prediction and although it predicts an increasing trend for the ”theatre industry”, it can be seen that this trend will slow down in the Czech Republic. This sounds logical both in terms of market saturation and in light of modern trends - online cinema streaming, Netflix, etc. However, this area also deserves more research. Therefore, in the future, the authors plan to expand their research to other countries (as already mentioned), as well as to focus on the types of theatres or demographic attendance curves.

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Adaptive Parameter Setting for Public Service System Design

Jaroslav Janáček[1], Marek Kvet

Abstract. This paper deals with such discrete location problems, which find their application area in public service system designing. Whenever the associated mathematical model needs to consider more than one objective function, a conflict between different objectives may bring several computational difficulties and, thus, a Pareto front of solutions is usually searched for. Since completion of the whole Pareto front is computationally hard, the attention of experts aims at development of such heuristics that are able to produce a good approximation of the original Pareto set in acceptably short time. On the other hand, efficiency of many approximate approaches is sensitive to various parameters, which directly affect the results accuracy. Therefore, we focus on adaptive parameter setting with experimental verification making use of real-world dataset.

Keywords: Public service system design, location problems, conflicting criteria, Pareto front, heuristics, adaptive parameter settings.

JEL Classification: C61, C63

1 Introduction

When a long series of complex problems is to be solved, heuristic approaches may play an important role due to their flexibility to exchange computational time demand for result accuracy. Various thresholds and other parameters, which influence further progress of the associated algorithms, control performance of heuristic methods. Efficiency of most of the heuristic approaches depends on setting of the parameters. It is commonly known that tuning of heuristic parameters demands for the same time as the heuristic design (Arroyo et al. 2010); (Doerner et al. 2005); (Gendreau et al. 2010); (Gopal 2013). Content of this contribution is focused on an online adaptive method, which exploits experience obtained during performed runs of the heuristic and adjusts the values of the heuristic parameters based on that knowledge. An application of the adaptive method is studied with connection of the process, which is determined for finding a good approximation of Pareto front of bi-objective public service system designs (Janáček and Fabricius 2021); (Kvet and Janáček 2021); (Kvet and Janáček 2022). The public service system provides public of a geographical region with service from given number of service centers. A deployment of the centers in a finite set of possible service center locations determines the public service system design (Ahmadi-Javid et al. 2017); (Avella et al. 2007); Brotcorne et al. 2003); (Current et al. 2002). As serviced public is concentrated at dwelling places which number is greater than the number of service centers, some geographically worse situated users may perceived unfair disutility in comparison with users from other dwelling places. This fact gives raise of two conflicting criteria of the system utility evaluation. The first of them is generally called system criterion and reflects system disutility perceived by an average user (Ingolfsson et al. 2008); (Jánošíková 2017); (Kvet 2014);

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(Marianov and Serra 2002). The second one called fairness criterion reflects disutility perceived by the worst situated minority of system users (Bertsimas et al. 2011); (Buzna et al. 2013). Pareto front of the public service system designs consists of such designs, which cannot be dominated by any other design in the both criteria. As Pareto front constituting is extraordinary demanded task, various heuristic approaches are used to obtain a good approximation of the Pareto front. One of the heuristic approaches called gradual refinement is based on step-by-step improvement of a current approximation of the Pareto front by searching neighborhood of a current design and including admissible neighborhood designs in the current approximation. Performance of the used neighborhood search heuristic is influenced by a threshold and determination of the threshold value by the adaptive method is matter of presented study.

2 Parametrized neighborhood search for Pareto front approximation

Let us formulate the bi-objective public service system design problem on a set J of system users' locations and a finite set I of possible service center locations. A system design is determined by sub-set $\boldsymbol{a} \subset I$, which consists of p selected locations. Within this contribution, we will evaluate system criterion f_1 by the function (1), where t_{ij} denotes traversing time from center location I to users' location j, b_j denotes frequency of randomly emerging demands of users' location j and $q_1, \ldots, q_r$ are probability values of cases $k = 1, \ldots, r$ that the k-th nearest service center is the closest one, which is not occupied by servicing a previous demand.

$$f_1(\boldsymbol{a}) = \sum_{j \in J} b_j \sum_{k=1}^{r} q_k \min{}_k \{t_{ij} : i \in \boldsymbol{a}\} \tag{1}$$

The fairness criterion gives the number of demands located outside a radius T from the nearest service center and it can be described by (2).

$$f_2(\boldsymbol{a}) = \sum_{j \in J} b_j \max\{0, sign(\min\{t_{ij} : i \in \boldsymbol{a}\} - T)\} \tag{2}$$

We say that a design $\boldsymbol{a}$ dominates design $\boldsymbol{e}$ if the following inequalities hold $f_1(\boldsymbol{a}) \le f_1(\boldsymbol{e})$ and $f_2(\boldsymbol{a}) \le f_2(\boldsymbol{e})$. Minimal set of designs such that for any design $\boldsymbol{e}$ it contains at least one design which dominates the design $\boldsymbol{e}$ is called Pareto front of bi-objective designs.

An approximation of Pareto front is a set of mutually non-dominated designs, which contains the two Pareto front members with minimal value of f_1 and f_2. A Pareto front approximation will be denoted as *PFApprox* and it will be represented by sequence of *noApprox* designs $\boldsymbol{a}_1$, …., $\boldsymbol{a}_{noApprox}$ increasingly ordered according to the values of f_2. This representation enables easy update of the *PFApprox* by a new design $\boldsymbol{e}$. It can be quickly decided, whethere $\boldsymbol{e}$ is dominated by some of the members of current *PFApprox* or it can be inserted into *PFApprox* as its new member. The associated procedure will be denoted as *Update*(*PFApprox*, $\boldsymbol{e}$). To measure quality of the Pareto front approximation, a notion *PFApprox_Area* has been introduced (Janáček and Kvet 2020); (Janáček and Kvet 2021a); (Janáček and Kvet 2021b); (Janáček and Kvet 2022a); (Janáček and Kvet 2022b), (Janáček and Kvet 2022c); (Kvet and Janáček 2021); (kvet and Janáček 2022). The associated value can be computed by formula (3).

$$PFApprox\_Area = \sum_{k=1}^{noApprox-1} (f_1(\boldsymbol{a}_k) - f_1(\boldsymbol{a}_{noApprox})).(f_2(\boldsymbol{a}_{k+1}) - f_2(\boldsymbol{a}_k)) \qquad (3)$$

An arbitrary *PFApprox_Area* is greater than or equal to the area computed for Pareto front. The behavior of the adaptive method will be studied in connection with the following parametrical neighborhood search heuristic (*NHS*) equipped with some elements of simulated metaheuristic. The heuristic starts with a given initial design ***a*** parameters *Threshold* and *Temp* and continuously updated *PFApprox*.

NHS(***a***, *PFApprox*, *Threshold*, *Temp*)

0. Set *cont* = "false" and continue with 1.

1. If *cont*, then terminate. Otherwise, set *cont* = "true", copy ***a*** to ***x*** and continue with 2.

2. If *cont* and $\boldsymbol{x} \neq \emptyset$, withdraw center location *i* from ***x*** and copy *I* – ***a*** to ***y*** and continue with 3. Otherwise continue with 1.

3. If *cont* and $\boldsymbol{y} \neq \emptyset$, witdraw a possible center location *j* from ***y*** and continue with Otherwise continue with 2.

4. Define the neighborhood solution $\boldsymbol{e} = (\boldsymbol{e} - \{i\}) \cup (j)$. Perform *Update*(*PFApprox*, ***e***).
   If the update is successful, compute decrease *Dec* of *PFApprox_Area* and generate randomly a real number *R*, $0 \le R \le 1$.
   If $R \le exp((Dec - Threshold)/Temp)$, then set ***a* = *e*** and *cont* = "false".
   Continue with 3.

3 Analysis and implementation of adaptive learning method

The studied adaptive method has been implemented to adjust parameter *Threshold* in the heuristic algorithm *NSH*. The adaptive method takes the total decrement of *PFApprox_Area* during one run of the algorithm as result of *Threshold* setting. This way, we use some ambiguous mapping *Decrement* = *F*(*Threshold*). The adaptive method adjusts the parameter *Threshold* based on preliminary experience and recent experiment. The preliminary experience up to recent experiment is quantified by so called state *s*, real value of which indicates whether the next experiment with adjusted *Threshold* should be concentrated on increasing (positive value of the state) or decreasing the parameter. The very change of parameter *Threshold* depends on result of random trial with probability *P* in favor of increasing *Threshold* by increment *Inc*. In the opposite case, the *Threshold* is decreased by *Inc*. Depending on the state value, the probability *P* is set at the value according to the following rules: if $s < -1$, then $P = 0$; if $s > 1$, then $P = 1$; if $s \in [0, 1]$, then $P = (1+s)/2$.

If the last run of *NSH* has been performed for value *Threshold* and the last but one run was performed for *Theresholdθ* , then the state *s* is updated according to (4). The associated values of *PFApprox_Area* are denoted *F0* = *F*(*Threshold0*) and *F1* = *F*(*Threshold*).

$$s = \alpha.s + \beta.sign((F0 - F1 - Threshold).(Threshold - Threshold0)) \qquad (4)$$

It can be seen that if the decrement of *PFApprox_Area* is greater than the current *Threshold* and the *Threshold* has been increased, then a value β is added to the new state value. The adaptive method *AM* can be described by the following steps.

AM(*Threshold*, α, β, *PFApprox_Area*, *Inc*)

0. Set $s = 0$, $P = 0.5$, *Threshold0* = *Threshold*, *F0* = *PFApprox_Area*.
1. Generate random number R, $0 \le R \le 1$. If $R < P$ then *Threshold* = *Threshold0* + *Inc*, else *Threshold* = *Threshold0* – *Inc*.
2. Compute *F1* = *F*(*Threshold*).
3. Update s according to (4) and update the value of P and set *F0* = *F1*.
4. If termination rule is met, then terminate. Otherwise continue with 1.

The adaptive method performance depends on the parameters α and β. Let us perform an analysis of the state progress. Two extreme cases will be studied. In the extreme case, the second right-hand-side member of (4) is constantly equal to β or -β. After t-th step, the state s_t takes the value of $s_t = \alpha s_{t-1} + \beta$ and the formula (5) can be derived.

$$s_t = (\alpha)^t . s_0 + \beta . \sum_{k=0}^{t-1} (\alpha)^k = (\alpha)^t . s_0 + \beta . \frac{1-(\alpha)^t}{1-\alpha} \tag{5}$$

It follows that s_t converges to $\beta/(1-\alpha)$ for enough large number of steps. In the second extreme case, the limit will be $-\beta/(1-\alpha)$ regardless the value s_0. These two values border the range of limit of s_t in general.

If the value of $\beta/(1-\alpha)$ is close to zero, the state converges also to zero and the prevailing probability P will be near to 0.5, what corresponds to Monte Carlo way of search. If a stronger effect of experience on search direction is to be achieved, the value of $\beta/(1-\alpha)$ should be greater than one. Nevertheless, the concrete results of the adaptive method depends also on other circumstances and so, numerical experiments are an inevitable tool for determining the characteristics of the adaptive process.

4 Numerical experiments

The numerical experiments reported in this section were aimed at practical verification of suggested approach. The scientific goal of the following case study consists in analyzing the suggested algorithm from the viewpoint of Pareto front approximation quality and computational time requirements as well.

Before reporting the obtained results, it is necessary to point out the hardware and software support of performed research. For this study, the programming language Java embedded in NetBeans IDE 8.2 development kit was used to implement all necessary functionalities. The experiments were run on a common PC with the Intel(R) Core(TM) i5-9300HF 2.40GHz processor and 16 GB RAM. The set of problem instances was taken from our previous research activities, the results of which are available in (Janáček and Fabricius 2021); (Kvet and Janáček

2021), (Kvet and Janáček 2022). Since the exact Pareto fronts of all problem instances are available, the quality of suggested heuristic approach could be easily evaluated.

As far as the results accuracy measurement is concerned, it must be noted that the original Pareto front and its approximation may differ in the number of elements. Therefore, two sets of solutions were compared in the following way. For each set (either exact or approximate), the area was computed according to (3). Under the assumption that *PF_Area* denotes the area of the exact Pareto front and *PFApprox_Area* denotes the area of the Pareto front approximation, the results accuracy can be evaluated by so-called *gap*, which can be expressed in percentage according to the expression (6).

$$gap = 100\frac{PFApprox\_Area - PF\_Area}{PF\_Area} \tag{6}$$

The reported case study was performed with the dataset derived from the road network of Slovak self-governing regions. Individual instances are denoted by the following abbreviations: Bratislava (BA), Banská Bystrica (BB), Košice (KE), Nitra (NR), Prešov (PO), Trenčín (TN), Trnava (TT) and Žilina (ZA). The sizes of the individual benchmarks are determined by integer values m and p. While the number m gives the cardinality of the set I, the symbol p is used to denote the number of centers (facilities) to be chosen. In the benchmarks, all inhabited network nodes represent both the set of candidates for service center location and the set of system users' locations. The first studied criterion $f_1(\boldsymbol{a})$ expressed by (1) was computed for $r = 3$. The coefficients q_k for $k=1 \dots r$ were set according to (Jankovič 2016) so that $q_1 = 77.063$, $q_2 = 16.476$ and $q_3 = 100 - q_1 - q_2$. The parameter T in the fair criterion (2) was set to 10. Such settings correspond to the results of previous research reported in (Grygar and Fabricius 2019); (Janáček and Fabricius 2019); (Janáček and Kvet, 2020); (Janáček and Kvet, 2021a); (Janáček and Kvet, 2021b), (Janáček and Kvet, 2022a); (Janáček and Kvet, 2022b), (Janáček and Kvet, 2022c) and in many others. The random acceptation rule of *NHS* at the step 4 was inactivated by setting of *Temp* at low value (0.001).

The following Table 1 summarizes the exact Pareto front characteristics, which were used as referential values, to which the obtained results were compared. Each row corresponds to one studied benchmark characteristic. The columns of the table correspond to the individual problem instances. The row denoted by *NoS* gives the number of Pareto front solutions. In the row denoted by *PF_Area* we provide the readers with the size of the polygon formed by all members of the set of non-dominated solutions.

	BA	**BB**	**KE**	**NR**	**PO**	**TN**	**TT**	**ZA**
m	87	515	460	350	664	276	249	315
p	14	36	32	27	32	21	18	29
NoS	34	229	262	106	271	98	64	97
PF_Area	569039	1002681	1295594	736846	956103	829155	814351	407293

Table 1 Benchmarks characteristics and the exact Pareto fronts descriptions

An individual experiment was organized so that the suggested algorithm was run 10 times for each benchmark due to randomness in the method. The parameter α was set to 0.3 and the parameter β took the value 0.7. Obviously, we have tested several other settings, but no significantly better results were obtained. Therefore, we do not report complete description of them. Nevertheless, we report the gaps for α = 0.1, 0.3, 0.5 and 0.7 (see Table 3). Computational time of suggested method is not included in the summary of results, but let us note that it was limited to five minutes. The average values of studied characteristics are summarized in Table 2, the structure of which takes the following form: Each row of the table corresponds to one studied property. The columns correspond to individual problem instances, for which the average results are reported. The row denoted by *StartThreshold* contains the information about the starting value of *Threshold*. It corresponds to one thousandth of the area created by two-element Pareto front containing only the bordering solutions. Corresponding value of *Threshold* at the end of the computational process is reported in the second line. The symbol s_{res} denotes the resulting value of s, which was updated by (5). The initial value of s was set to zero. The row denoted by *noNSHA* reports the number of neighborhood search runs. The cardinality of the resulting Pareto front approximation is given by *noApprox*. The absolute value of area formed by found elements of the non-dominated solution set is not reported here, but the result accuracy is given by *gap* computed according to (6). Finally, we report also the number of time runs in the row denoted by *noTimeRuns*.

	BA	**BB**	**KE**	**NR**	**PO**	**TN**	**TT**	**ZA**
StartThresholdc	4553.64	4190.51	8453.16	4651.34	5276.61	3642.96	3591.85	2803.71
Threshold	118895.54	8716.26	23668.85	12000.47	14088.55	16211.17	19108.62	12869.03
s_{res}	-0.13	0.04	-0.07	0.10	0.09	-0.03	-0.08	0.04
noNSHA	167199.50	2060.60	2986.30	5190.80	1471.30	10737.10	14719.30	6334.70
noApprox	31.00	213.70	245.90	94.50	264.50	92.50	62.30	92.40
gap	1.94	1.46	2.01	1.82	1.29	1.44	0.31	0.29
noTimeRuns	4220.50	5.00	6.70	28.00	3.20	77.70	183.30	46.00

Table 2 Results of numerical experiments for α = 0.3

α	**BA**	**BB**	**KE**	**NR**	**PO**	**TN**	**TT**	**ZA**
0.1	1.94	1.40	1.24	2.91	1.13	0.72	0.31	0.19
0.3	1.94	1.46	2.01	1.82	1.29	1.44	0.31	0.29
0.5	1.94	1.30	2.09	3.16	1.24	0.72	0.31	0.74
0.7	1.94	1.79	2.30	1.02	1.87	1.44	0.20	0.15

Table 3 Resulting gaps for the instances with various settings of α

5 Conclusions

This paper focused on advanced public service system design problem, in which two contradictory objectives needed to be managed. Since the character of conflicting criteria does not allow their parallel optimization, a Pareto front of solutions had to be searched for. Due to big computational demands of the full Pareto front completion process, we concentrated our effort to heuristics, which produce a good approximation of the Pareto front. As the approximate approaches may be sensitive to various parameter settings, we focused on the proper way of mastering mentioned property.

The results of performed numerical experiments have shown that the suggested heuristic is able to approximate the original Pareto front in a very promising way. The average value of gap di not exceed two percent that makes the algorithm suitable for practical usage. To conclude the paper, we have constructed a very useful tool for public service system designing with two contradictory objectives.

Future research in this field could be aimed at such approaches to the public service system design, which could bring better results in a short time. Another research topic could concentrate on advanced way of parameter settings and on searching for a toll for their automate determination.

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Time deviations of arriving and departing airplanes

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Abstract. This article deals with the real time deviations of arriving and departing airplanes from the planned times. The punctuality of the air transport process is, along with price and convenience, one of the most important criteria required by passengers. Weekly traffic at three international airports of different busyness was investigated. These were airports in Prague, Atlanta and Lome. Data was collected daily and was obtained from the publicly available flight database Flightradar24.com. In addition to the intensity of traffic, the research was also focused on the intensity of aircraft movements of three weight categories (light, medium and heavy). The research is related to the topic of the dissertation Evaluation of the Quality of Services Provided by Air Carriers.

Keywords: commercial air transport-time deviations-airport delay-statistical hypothesis testing.

JEL Classification: C44

1. Introduction

The development of air transport has been continual since the beginning of aviation, when during short-distance transport passengers were first moved in the order of units, with the growing demand for air transport, then in the order of tens or hundreds of passengers. The process of planning a specific flight and determining the exact time when the plane will be ready for departure on its apron stand, or when it will land on the runway of the destination airport, is very complex and hard to predict. This is mainly due to the fact that there are many factors influencing the estimation of these times.

The aircraft check-in process therefore includes many tasks, such as: wheel chocks installing, securing the aircraft with cones and tapes, cargo handling, passengers boarding and disembarking, cleaning the aircraft cabin, replenishing catering and drinking water, waste water pumping out, pre-flight inspection, de-icing the aircraft and washing it.

In addition to the tasks already mentioned here, the flight time, and therefore also the aircraft delay can affect the following factors such as: weather conditions at the departure and arrival airports, aircraft type, airspace capacity, selected flight trajectory and the accuracy of the calculation of the aircraft's performance characteristics, the capacity of the arrival and departure airport and the distance between the departure and arrival airport.

The process of ground handling of the aircraft has already been dealt with by some students in their final theses (Kolář, 2018) and journal contributors (Slutsken, 2022). Textbook for university subject of Statistical methods in engineering practice and procedures for statistical analysis in practice were created by university teachers (Briš and Litschmannová, 2004).

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Methods for statistical hypotheses testing were developed by American scientists (J. W. Tukey, 1970) and multiple comparison methods were used in research by the Institute of Biostatistics and Analyses of the Faculty of Medicine of Masaryk University.

2. Methodology and results

The purpose of the research on the time deviations of arriving and departing aircraft was to find out whether there is any dependence between the intensity of traffic (number of aircraft movements) and the magnitude of the time deviations of arriving and departing aircrafts.

Due to the large amount of data on the possible time delays mentioned above, and especially due to its unavailability, it would be very difficult to determine the origins and causes of flight delays. So the research was focused just on easy-to-find data that was obtained from flight tracking server Flightradar24.

It was a weekly data collection of the arrival and departure times of airplanes at three international airports of different sizes. The data are from the period from 04/10/2022 until 10/10/2022. Monitored airports have different traffic treatments. Prague airport has around 200 flights/day, Atlanta airport 2000 flights/day and Lome airport 30 flights/day. The total number of flights obtained from Flightradar24 was around 16,000. The Excel computer program and the available Kutools add-in were used for data processing. Thanks to this tool, it was possible to convert times from the classic 24-hour format to times in minutes after midnight.

2.1. Testing of normality

In order to be able to test possible dependencies of the magnitude of time deviations on the weight category of the aircraft and the intensity of traffic at the airports, it was first necessary to determine whether the data are normally distributed. Statistical test methods were then selected accordingly to the data distribution type. Data normality was tested with the Shapiro-Wilk test in the Statgraphics 19 program. Normality of deviation values of all three airports was tested separately for each day, mainly to ensure that the value of 5,000 samples was not exceeded. After running tests for all airports and every day of the week, it was found that the P-Value of 0.05 was not exceeded, thus rejecting the hypothesis that the data came from a normal probability distribution.

The table below shows the result of data normality testing using the Shapiro Wilk test, which was performed in the Statgraphics 19 program.

Test	**Statistic**	***p*-value**
Shapiro-Wilk W	0,764222	4,02745E-12

Table 1 Results of normality testing using the Shapiro-Wilk test for departures from Lomé airport [Statgraphics 19]

2.2.Data similarity testing – Kruskal-Wallis test

As the selected airports are located in different and independent locations it was also tested whether the value of the deviation of the actual times from the scheduled times of arrivals and departures depends on the airport's busyness.

This hypothesis was tested with the Kruskal Wallis test in Excel program. The test was carried out separately for both departures and arrivals of aircraft. For greater accuracy of the test, it was decided to use medians instead of average values of time deviations. Medians were calculated for each airport, day and departures and arrivals separately. At the beginning of the test, a null and an alternative hypothesis was set up.

Null hypothesis: Alternative hypothesis:

$H_0: x_{0,5}^1 = x_{0,5}^2 = x_{0,5}^3$ (data are similar) $H_A: H_0$ does not apply (data are different) (1)

Where:

- $x_{0,5}^1$ – median deviations of arriving/departing planes at Prague airport
- $x_{0,5}^2$ – median deviation of arriving/departing aircraft at Atlanta Airport
- $x_{0,5}^3$ – median deviation of arriving/departing aircraft at Lome airport

The tables shown below summarize the median time deviations of departures and arrivals in the monitored period for individual days and airports.

Arrivals – median deviation			
	Prague	Atlanta	Lome
4/10	-1.0	-19.0	-5.0
5/10	-3.0	-19.0	-26.0
6/10	-5.0	-19.0	-5.0
7/10	-1.0	-18.0	-17.0
8/10	-4.0	-17.0	-20.0
9/10	-4.0	-18.0	-5.0
10/10	-3.0	-18.0	-18.5

Departures – median deviation			
	Prague	Atlanta	Lome
4/10	13	15	24
5/10	16.5	15	12
6/10	16	14	9
7/10	17.5	14	13
8/10	13	15	15
9/10	14	13	11.5
10/10	17	10	5.5

Table 2 and 3 Median deviations of arrivals and departures [author]

In the next step, the medians of arrivals and departures were assigned ascending order.

The following tables refer to the ranking of the medians as performed by Excel's "RANK.AVG" function.

Order of medians for arrivals				
	Prague	Atlanta	Lome	
4/10	20.5	4.0	13.5	
5/10	18.5	4.0	1.0	
6/10	13.5	4.0	135	
7/10	20.5	8.0	10.5	
8/10	16.5	10.5	2.0	
9/10	16.5	8.0	13.5	
10/10	18.5	8.0	6.0	
				Sum
Sum	125	47	60	232
Count	7	7	7	21
$\frac{R_i^2}{n_i}$	2,214	309	514	3,038

Order of medians for departures				
	Prague	Atlanta	Lome	
4/10	7.5	14.5	21	
5/10	18	14.5	5	
6/10	17	11	2	
7/10	20	11	7.5	
8/10	7.5	14.5	14.5	
9/10	11	7.5	4	
10/10	19	3	1	
				Sum
Sum	100	76	55	231
Count	7	7	7	21
$\frac{R_i^2}{n_i}$	1,429	825	432	2,686

Table 4 and 5 Order of medians for arrivals and departures [author]

Formula for the test statistic calculation:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{C} \frac{R_i^2}{n_i} - 3(N+1) \tag{2}$$

Where:

- C – number of classes
- n_i – number of observations in the i class
- N – number of observations
- R_i – the sum of ranks in the i class

Sample calculation of the H value for arrivals:

$$H = \frac{12}{21 \cdot (21+1)} \cdot 3{,}038 - 3 \cdot (21+1) = 12.9 \tag{3}$$

Resulting values shown separately for arrivals and separately for departures after performing the Kruskal-Wallis test in the Excel program.

$\boldsymbol{H}$	12.9
$\boldsymbol{p}$**-value**	0.002

$\boldsymbol{H}$	3.8
$\boldsymbol{p}$**-value**	0.15

Table 6 and 7 Resulting values of the Kruskal-Wallis test [author]

The functions "CHIINV" and "CHIDIST" were used to find the critical value and p value. The significance level was chosen to be 0.05 and the critical value for arrivals was not exceeded.

Test Conclusion: The Kruskal-Wallis test found that with 95% probability there are statistically significant differences in the deviations of the arriving aircraft.

2.3. Post Hoc Analysis – Tukey 's Test

Since there are statistically significant differences between the medians, the research was continued by a Post-Hoc analysis using Tukey's method. This method was used to compare the differences between the mean values of the median deviations with the HSD (Honestly significant difference) value of the test criterion. The test was performed at a significance level of 0.05. To get the parameters into the formula more easily, the "Data Analysis" tool of the Excel program ("ANOVA: One Factor") was used.

The results of the "Data Analysis" tool for all airports and subsequently performed ANOVA Excel test results are shown in the tables below.

Airport	Count	Sum	Average	Variance
Praha	7	-21	-3	2.33
Atlanta	7	-128	-18.29	0.57
Lomé	7	-96.5	-13.79	75.32

Table 8 Data analysis for arrivals [author]

Source of variability	Sum of squares	Degrees of freedom	Mean square	F Value	P value	F critical value
Between Groups	863.88	2	431.94	16.57	8.30E-05	3.55
Within Groups	469.36	18	26.08			
Total	1,333.24	20				

Table 9 ANOVA table for arrivals [author]

The q_α value from the tables for 12 degrees of freedom, 3 airports and a significance level of 0.05 was found 2.971.

Sample calculation of the test criterion for arrivals:

$$T = q_\alpha \sqrt{\frac{MSE}{n_i}} = 2.971 \cdot \sqrt{\frac{26.08}{7}} = 5.73 \tag{4}$$

Where:

- T – the value of the test criterion
- q_α – Studentized Range q table critical value
- MSE – Root mean square error
- n_i – the number of values of the i criterion

Subsequently, the differences between the means were calculated as shown below.

Value difference		T – Value exceeded
$\lvert\bar{x}_1 - \bar{x}_2\rvert$	15.3	Yes
$\lvert\bar{x}_1 - \bar{x}_3\rvert$	10.8	No
$\lvert\bar{x}_2 - \bar{x}_3\rvert$	4.5	No

Table 10 Arithmetic mean differences between airports (arrivals) [author]

Two of the differences exceeded the HSD value. So it looks like statistically significant differences deviations occur at Atlanta and Lomé airports compared to the airport in Prague. Although considerable time inaccuracies in the planning of arrivals were detected in Atlanta, the airports in Prague and Lomé do not confirm the hypothesis that time deviations increase with the increasing number of arrivals.

3. Discussion and conclusion

The aim of the research was to identify the occurrence of time deviations during the arrivals and departures of aircraft for different sized airports and different weight categories of aircraft. Knowledge of the type of functional dependence of aircraft delay on airport occupancy (if a dependence has been detected) can help to create a more accurate flight schedule and reduce aircraft delays for subsequent flights as well. These delays could be reduced, for example, by moving the arrival to a later time position. For greater accuracy in arrival times planning, it is advisable to assess each airport and aircraft weight category separately. If there are more aircrafts of different mass category heading to the same destination, you can choose the one which you give a priority in ground handling tasks.

It would also be possible to monitor the delays of departures and arrivals on specific flight routes in the past and to adjust flight schedules accordingly in order to minimize the resulting delays. Also, flights that repeatedly arrive at the airport of destination with a long lead time compared to the flight schedule can be found using this method. However, factors that can change the regularity of the transport process and whose predictability will be almost impossible will continue to operate in air traffic.

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Optimizing the selection of a portfolio of transport infrastructure investment projects using the STEM method

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Abstract. The quality of the transport infrastructure has a significant influence on the development of the society, especially in the area of the economy growth. In our conditions, it is necessary to further develop and modernize the infrastructure. For this purpose investment projects are prepared by state management authorities. However, the financial value of all planned transport infrastructure investment projects is usually higher than the available budget, and it is therefore necessary to approach the selection of a portfolio of projects for implementation. The selected projects must meet not only the amount of the budget, but also the requirements arising from the transport policy and the rules of the investment funds represented by the required indicators. In the tasks of optimizing the portfolio of projects, in practice, it is often approached to repeat the selection of the portfolio with modification of the input conditions so that the distribution of the performance of the indicators more closely meets the expert requirements. This can be better solved using evaluation methods, the application of which is, however, lacking in the selection of the project portfolio.

The aim of the article is to present a solution to the task of optimizing the selection of a portfolio of transport infrastructure investment projects using the STEM method. This interactive method based on the alternation of computing and decision-making phases enables the application of expert requirements during the calculation in order to find the optimal solution in cases where not all combinations of fulfilment of the monitored indicators are known in advance.

Keywords: linear programming, multicriteria approach, STEM.

JEL Classification: C610

1 Introduction

The economic and social development of society depends in many ways on the extent and quality of the transport infrastructure. In the past, it has been repeatedly proven that infrastructure quality has a positive effect on GDP growth in the long term (Kalantzis et al., 2015). Rutkowski (2013) describes the positive effect of the increasing quality of infrastructure also on the recovery of the market from recession and economic crisis. At the same time,

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Sanchez-Roblez (1998) also points out that, especially in the field of public infrastructure, the problem is ensuring the necessary investment efficiency from the point of view of ensuring the optimal selection of projects. In the opposite case, i.e., in the case of inefficient selection of the portfolio of investment projects, the invested funds will not bring this intensification factor.

The state's available investment funds are usually lower than the value of all those considered transport infrastructure investment projects. Therefore, at the level of the decision-making bodies of the state administration, the selection of a portfolio of investment projects, which will be included in the preparation and subsequent implementation, takes place. This portfolio is selected from a set of considered projects based on a number of criteria, which represent, in addition to the condition of a limited budget, also the fulfilment of the conditions of investment programs and transport policy. In investment programs financed by the EU (in the Czech Republic, for example, the Transport Operational Program), indicators are monitored in accordance with Regulation (EU) No 1303/2013, which takes into account the degree of contribution of the projects to the fulfilment of the program's goals based on transport policy.

The selection of investment projects for the construction and modernization of transport infrastructure is therefore a very complex and responsible process. To ensure an effective selection of the portfolio of investment projects, the decision-making process can be supported using system optimization approach methods based on mathematical programming.

A common optimization task in the selection of a portfolio of investment projects is the maximization of the performance of monitored indicators. This task can be solved by different approaches leading to the maximization of the cumulative value of fulfilling the indicators, as shown in variants using linear and target mathematical programming in Ječmen et al (2022). A comparison of the two methods shows that optimization approaches need to be chosen appropriately depending on the boundary conditions of the portfolio selection task. The necessity of an expert approach is also proven in the article of Pilát et al (2022), in which the task of minimizing the maximum negative deviations from the minimum values of the indicators is solved, extended by a cascade approach. In this case, it was evaluated that the approach is suitable for the selection of a portfolio from a set of such projects that are interdependent, contribute to multiple indicators and their contributions are thus partially substitutable. Here, too, the situation needs to be expertly assessed when choosing a suitable optimization approach.

In practice, we also observe cases where, when selecting a project portfolio, the expert asks to examine a certain a posteriori change in indicator performance to better suit the current priorities, but where not all possible combinations of indicator performance values are known a priori. This situation can be solved by applying the STEM method. It is, as described by Benayoun et al. (1971), a stepwise method by which the search for an optimal solution can be replaced by a search for the best compromise solution. According to Jablonsky, Fiala, and Maňas (1986), STEM is an interactive method for solving multi-criteria linear programming problems and consists of alternating computing and decision-making phases in order to minimize the distance from the ideal variant. The STEM method can consist of one or several phases, with each phase consisting of a computing and a decision-making part. The process involves alternating them so that in the decision-making part, an expert assessment of the result from the previous solution part is made and a change is proposed to improve the relative distribution of indicator performance. The principle of these proposals is to define a set of criteria for which performance can be worsened at the expense of improving performance of another set of criteria.

Rodríguez, Luque and González (2011) describe the application of a STEM-based approach to the case of portfolio selection in the Spanish stock market in order to enable the decision maker to reach an efficient solution in a portfolio selection model in which the conflicting objectives of risk and return are pursued. The application of the approach appears to be appropriate in situations where the range of efficient portfolios is quite wide, so that the selection of a single portfolio is very difficult task. The interactive method will then enable the facilitation of this process aimed at guiding the decision-maker to the optimal solution based on his preferences. However, there is a lack of application to tasks of optimizing the scope of transport infrastructure.

The aim of the paper is to apply the STEM method to the problem of selection of a portfolio of transport infrastructure investment projects and to verify the suitability of its use on a sample of data representing real input values.

2 Problem formulation in the principle of the STEM method

Consider a set of indicators I and a set of projects J to be implemented on transport infrastructure. The indicators represent the contribution of each project to the monitored quantified values of society-wide benefits. The matrix c_{ij} determines the contribution of project $j \in J$ to the fulfillment of indicator $i \in I$ through its implementation. Furthermore, the parameter n_j is given, which determines the cost of implementing project $j \in J$. The amount of funds available to implement the projects is determined by the value of N. Consider each indicator $i \in I$ as an optimization criterion and the problem as a multi-criteria optimization. The problem is to determine which projects $j \in J$ to implement in order to meet the values of the indicators desired by the contracting authority and to respect the available budget.

The first step of the solving part is to find the ideal values of each criterion function. The ideal value of each criterion function can be obtained by performing an optimization computation using a single-criteria mathematical model, in which only the value of the criterion for which we are determining the ideal value is optimized on the whole set of input data. Thus, there will be as many partial calculations in this step as there are criteria in a given multi-criteria problem. The result is a matrix z_{ij}, where $i \in I$ and $j \in I$, which can be interpreted as the value of criterion $i \in I$, when criterion $j \in I$ is maximized. Thus, the search for the ideal values of the criterion functions is located on the diagonal of the matrix Z.

The matrix Z is further used to determine the weights of the individual criteria according to formula (1), subject to the equation (2).

$$w_i = \frac{\overline{z_{ii}} - \min_{j \in I}\{z_{ij}\}}{z_{ii}} \cdot \frac{\alpha}{\sqrt{\sum_{j \in I} c_{ij}^2}} \qquad \text{for } i \in I \qquad (1)$$

$$\sum_{i \in I} w_i = 1 \qquad (2)$$

The second step of the first phase consists in transforming the criterion functions to a single min-max criterion. Thus, it will be the minimization of the maximum weighted deviation from the ideal variant. The ideal variant is the one in which all criteria would take ideal values. The results of this step are then presented to the decision maker. The decision maker determines whether he is satisfied or dissatisfied with the level of performance of each criterion function. If he is satisfied with the values of one or more of the criterion functions, he determines whether and by how much he is willing to reduce them. Based on the creation of a space to reduce the values of one or more of the criterion functions, it is then possible to improve the values of another criterion function. If the decision maker is satisfied with the values of all the criterion functions or if no criterion function can be improved, the calculation ends. Otherwise, the decision maker sets a value Δf_i by which he is willing to reduce the value of criterion function $i \in I$ and the computation proceeds to the second phase. In the following computing phase, the mathematical model needs to be adjusted. Moreover, the model ensures that the values of the criterion functions do not fall below the value of q_i that can be obtained from (3). Next, the values of the criterion weights need to be recalculated. First, the weights are adjusted for all criteria where $\Delta f_i > 0$ according to (4), and then the weights for the other criteria are recalculated according to (1) and (2).

$$q_i = f_i - \Delta f_i \qquad \text{for } i \in I \qquad (3)$$

$$w_i = 0 \qquad \text{for } i \text{ where } \Delta f_i > 0 \qquad (4)$$

3 Computational experiment

This chapter presents the application of the above principles to a dataset representing the type of input data for the selection of a portfolio of transport infrastructure investment projects and a simulation of expert decision-making for the adjustment of output indicator values.

3.1 Computing part of the first phase

Following the procedure outlined in Chapter 2, the aim of phase 1 is to obtain weight estimates for the individual criterion functions, which can then be used to minimize the maximum deviation from the ideal variance. This article's computational experiment entails the consideration of cardinality $|I| = 3$ and $|J| = 10$.

Input parameters:

$$C = \begin{bmatrix} 16 & 5 & 5 & 8 & 1 & 6 & 4 & 7 & 4 & 8 \\ 7 & 2 & 2 & 3 & 3 & 1 & 1 & 3 & 2 & 1 \\ 11 & 2 & 3 & 4 & 3 & 4 & 2 & 3 & 3 & 1 \end{bmatrix}$$

$$n = [15, 4, 5, 6, 1, 7, 3, 5, 5, 5]$$

Since each indicator is also a criterion, each criterion function can be expressed according to the group (5).

$$f_i = \sum_{j \in J} c_{ij} x_j \qquad i \in I \qquad (5)$$

Mathematical model for calculation of ideal values of individual criterion functions:

$$f_i(x) \rightarrow max \qquad i \in I \qquad (6)$$

subject to:

$$\sum_{j \in J} n_j x_j \leq N \qquad (7)$$

$$x_j \in \{0,1\} \qquad \text{for } j \in J \qquad (8)$$

The mathematical model for the calculation of the criteria weights shall, in the first stage, be carried out separately for each $i \in I$, thus gradually maximising each criterion (6). The group of constraints (7) ensures that the available budget is not exceeded. The group of constraints (8) sets the definitional domains of the variables in the model.

Calculation of weight

The matrix of the criterion functions z_{ij}, which was obtained on the basis of the mathematical model, looks as follows:

$$Z = \begin{bmatrix} z_{11} & z_{12} & z_{13} \\ z_{21} & z_{22} & z_{23} \\ z_{31} & z_{32} & z_{33} \end{bmatrix} = \begin{bmatrix} 28 & 25 & 21 \\ 11 & 12 & 11 \\ 13 & 14 & 16 \end{bmatrix}$$

Based on the matrix z_{ij}, the weights for further calculations can be calculated according to formula (1):

$$w_1 = \frac{28 - 21}{28} \cdot \frac{\alpha}{\sqrt{552}} = \frac{\alpha\sqrt{138}}{1004}$$
$$w_2 = \frac{12 - 11}{12} \cdot \frac{\alpha}{\sqrt{91}} = \frac{\alpha\sqrt{91}}{1092}$$
$$w_3 = \frac{16 - 13}{16} \cdot \frac{\alpha}{\sqrt{198}} = \frac{\alpha\sqrt{22}}{352}$$

The value of α can then be calculated using (2):

$$\frac{\alpha\sqrt{138}}{1004} + \frac{\alpha\sqrt{91}}{1092} + \frac{\alpha\sqrt{22}}{352} = 1 \rightarrow \alpha \cong 29{,}5$$

Thus:

$$w_1 \cong 0{,}35$$
$$w_2 \cong 0{,}26$$

$$w_3 \cong 0{,}39$$

The mathematical model for minimizing the maximum weighted deviation from the ideal value of the indicators is designed as follows:

$$d \rightarrow min \tag{9}$$

subject to:

$$d \geq w_i(\overline{z_i} - \sum_{j \in J} c_{ij} x_j) \qquad \text{for } i \in I \tag{10}$$

$$\sum_{j \in J} n_j x_j \leq N \tag{7}$$

$$x_j \in \{0{,}1\} \qquad \text{for } j \in J \tag{8}$$

In the mathematical model of the second stage of the calculation, the objective function (9) ensures the minimization of the maximum weighted deviation, which is expressed in the model by a group of constraints (10).

The result of the first calculation phase

By performing the optimization calculation, the value of the weighted deviation $d = 1{,}05$ was determined.

The values of the criterion functions took the values $f_1 = 25,\ f_2 = 12,\ f_3 = 15.$

Decision making part of the first phase

The owner is satisfied with the values of the criterion functions f_1 and f_2 and is willing to reduce them by $\Delta f_2 = 4$ and $\Delta f_3 = 5$, i.e. to $q_2 = f_2 - \Delta f_2 = 8$ and $q_3 = f_3 - \Delta f_3 = 10$.

3.2 Computing part of the second phase

As added information on criteria preferences has been obtained, the weightings for each criterion function will change. The weights of the criterion functions will now take on the value 0 for those criterion functions with which the client is satisfied (w_2, w_3). In our case, it remains to determine the weight of only one criterion (w_1), whose value will be 1. Furthermore, it must be ensured by means of constraints that the value of the criteria does not fall below the minimum permissible value of q_2 and q_3.

$$w_1 = 1, w_2 = 0, w_3 = 0$$

The mathematical model form is then:

$$d \rightarrow min \tag{9}$$

subject to:

$$d \geq w_i(\overline{z_i} - \sum_{j \in J} c_{ij}x_j) \qquad \text{for } i \in I \qquad (10)$$

$$\sum_{j \in J} c_{ij}x_j \geq q_i \qquad \text{for } i \text{ where } \Delta f_i > 0 \qquad (11)$$

Compared to previous models, the mathematical model additionally includes a set of constraints (11), which ensures that the values of the criterion functions do not fall below the maximum possible value specified by the client. Since there is only one criterion left in this computational phase, it would also be possible to maximize the fulfilment of indicator 1 and delete set of constraints (10).

Result of the second computing phase

The next optimization calculation obtained the values of the criterion functions $f_1 = 28,\ f_2 = 11,\ f_3 = 13$.

Decision making part of the second phase

The decision maker is now satisfied with all the values of the criterion functions and the solution is therefore considered optimal. It should be pointed out that the value of the second criterion function has increased although it has been allowed to decrease. This is due to the nature of the input data. It can be assumed that for a larger sample of data, this phenomenon would not have occurred because a combination of projects would have been found that would have allowed a further increase in the third criterion function at the expense of a larger decrease in the second function, as requested by the client. A summary of the ideal values and weights of the criterion functions and the results of each phase of the calculation are summarized in Table 1.

Criterion function	Ideal value	First phase			Second phase		
		Weight	Result	Weighted deviation	Weight	Result	Weighted deviation
1	28	0,35	25	1,05	1	28	0
2	12	0,26	12	0	0	11	0
3	16	0,39	15	0,39	0	13	0

Table 1 Outputs of the computational experiment

3.3 Discussion of the solution

In order to evaluate the achieved results of the optimization of the selection of the portfolio of transport infrastructure investment projects using the STEM method, it is important to note that the final solution to the problem is the same as ideal solution for the first criterion. These situations may occur depending on the preferences of the owner.

In general, however, the value of the criterion could be reduced in the course of the calculation phases on the basis of adjustments made according to the requirements of the decision maker. In terms of maximizing the cumulative performance of indicators representing society-wide benefits, it would appear that the expert input could lead to a worsening of the results. However, in the case of transport infrastructure development, other contexts need to be considered beyond the fulfilment of the indicators in terms of the necessary construction sequences, modal preferences, regional distribution of network development and so on. This information is secured by the expert requirements and should be seen as relevant inputs to the needs of the decision maker, including changes based on a sequential identification of the distribution of indicator values over the calculation phases. Thus, although the value of the criterion function may decrease during the process, it is still optimal according to the preferences of the decision maker.

Conclusion

The goal of the STEM method applied to the optimization method of linear programming is to find a compromise solution by coordinating the problem solver and the decision maker. The method introduces an interactive solution discussion approach to the optimization computation allowing immediate change of priorities according to the expert requirement based on the knowledge of the output of the previous step. In this way, a solution satisfying the requirements of the decision maker can be found in several steps. The basic advantage of using the method in the selection of a portfolio of transport infrastructure projects for implementation is the possibility of finding a solution in a situation where not all possible combinations of indicator fulfillment values are known a priori and a decision-maker requires to check the portfolio selection options so that it better meets the current priorities. The mentioned approach will allow the expert to recognize the possibilities of distribution of benefits resulting from the realization of various portfolio selections according to the modified criteria based on the evaluation of individual steps of the solution. The disadvantage of using the method can be the dependence on the subjective point of view of the evaluator and the lengthiness of the solution during expert assessment of multiple variants.

According to the conducted experiment, the method seems to be suitable for optimization of selection with the need to find out the possibilities of distribution of the performance of indicators, or values of criterion functions, when simple steps replace complex changes of input parameters of the computational model in order to find such values of criteria weights that allow to meet the requirements of the decision maker to change the output. In a follow-up research, the STEM method will be tested on a sample of a large number of projects from which a portfolio of transport infrastructure investment projects is selected for implementation.

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Czech presidential inaugural addresses in 2013-18: a natural language processing analysis

Nikola Kaspříková [1]

Abstract. This paper addresses the formal analysis using natural language processing techniques of the two presidential inaugural speeches given by the recent president, the first Czech president elected directly by the public. The tokenization, lemmatization, identification of the parts of speech and frequency analysis of words and co-occurrences by parts of speech types is among the techniques used for the analysis.
The results show that the co-occurences found by NLP could be used for automated keywords identification in this case.

Keywords: Czech president, inaugural speech, natural language processing, co-occurrences, part-of-speech tagging.

JEL classification: D72, C80

1 Introduction

The recent presidential elections in the Czech Republic in the 2023 received great interest of the media and the public. Clearly the public in the Czech Republic considers the role of the president of the republic as important. The executive powers of the president in the Czech Republic are not as large compared to the powers of the prime minister. But there are still some important powers of the president influencing the Czech economy, for example through appointing the members of the Czech National Bank Board, the body in charge of setting the monetary policy in the Czech Republic.

The president elected in the Czech Republic in 2023 will come after two consecutive periods starting in 2013 and 2018 in which president Miloš Zeman won the elections. The recent president Miloš Zeman was the first one elected in the direct election by the public, not just by the Parliament members. Presidential inauguration speeches in the Czech Republic have long been among the traditionally highly watched by the public. The presidential inauguration speeches are supposed to be well-prepared and watched or read by many people in the country. It may be difficult to perceive the speeches given by the politicians objectively. One of the ways to read the presidential speeches dispassionately and perhaps even discover something what may be missed after traditional reading by human reader, is to use a formal analysis using the automated analysis with natural language processing (NLP) techniques. This paper addresses the formal analysis using NLP techniques of the two presidential inaugural speeches given by the recent president, the first Czech president elected directly by the public.

The NLP analysis of the presidential inaugural speeches is a popular topic of the research papers published recently around the world. The paper (Fowobaje et al., 2022) analyses inaugural addresses of Nigerian Heads of State and Presidents using term frequency analysis and sentiment analysis and compares the speeches of civilian and military heads of state. The civilian heads of state produced speeches with mostly higher sentiment scores. Regarding the length

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of speech, the paper (Fowobaje et al., 2022) reports, that the civilian heads of state produced longer speeches compared with military heads of state. The most frequently occurring word in the speeches analysed in (Fowobaje et al., 2022) is government. Machine learning provides excellent tools for understanding the huge amount of textual data by providing a succinct summaries, claims (Han and Lim, 2021) and analyses the US presidential inaugural speeches to distinguish between Democrats and Republicans. The model reported in (Han and Lim, 2021) has been able to perfectly distinguish between presidential inaugural speeches of Democrats and Republicans, since the two party system generated clear differences in speeches when considering the usage of patriotic terms.

The goal of this paper is to formally analyse the two inaugural speeches and evaluate the benefits of using basic NLP techniques for the analysis in this case.

2 Data and methods

The texts of the inaugural speeches of the Czech presidents can be obtained from the WikiSource.org website (Wikisource.org, 2023).

The NLP techniques allowing automated text analysis have recently become near perfect thanks to advances in deep neural network models, among others. Clearly the NLP tools developed for English may be still among the most advanced ones, but there are already powerful tools available even for the minor languages in the world, such as Czech.

The data preparation, or preprocessing of text for the analysis, which included text normalization (converting to some standard, convenient form), tokenization (separating out words from running text) and lemmmatization (determining that two words have the same root) has been done in this paper with the udpipe (Wijffels, 2023) R (R Core Team, 2023) extension package tools. The NLP methods are in detail described in textbook (Jurafsky and Martin, 2023).

Basic analysis of the inaugural speeches given in 2013 and 2018 have been performed. This analysis included first the identification of the parts of speech in each of the texts. Then the most frequent nouns, adjectives and verbs have been searched in the texts. Finally the most frequent co-occurrences of nouns and adjectives following one another have been found in each of the texts. The formal profiles of the two texts can then be compared. The statistics presented in the following section of this paper are based on lemmas.

3 Results

The length of the inaugural presidential speech given by president Miloš Zeman was 955 words in the year 2013 and 2430 words in the year 2018. The length of the second inaugural address of president Miloš Zeman was considerably longer than the first one. It may be interesting to consider the length of the inaugural addresses of the previous president Václav Klaus, which were 692 words in 2008 and 645 words in 2003.

The Figure 1 shows the frequencies of the parts of speech types which have been identified in each of the texts. The part of speech is the category to which a word is assigned in accordance with its syntactic functions. Clearly the highest frequency of occurrence is in case of the nouns. Nouns are then followed by punctuation, adjectives, and verbs in both speeches. Determiners are ranked as the 5th in the 2013 speech, followed by adpositions. The determiners are slightly

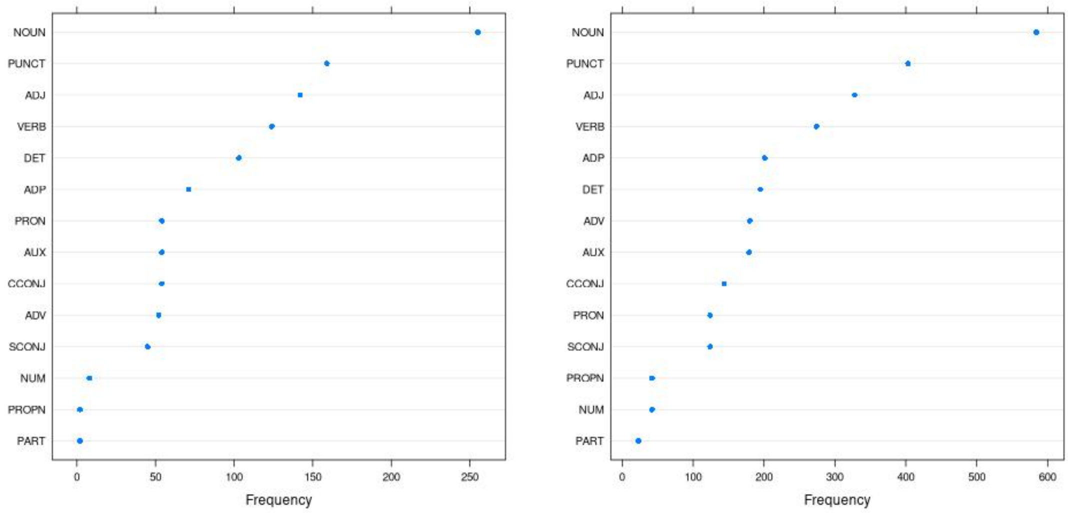

Figure 1 Parts of speech frequencies in 2013 (left) and 2018 (right)

behind adpositions, which rank 5th in the 2018 address. Let us now observe the frequencies of the most important word types, i. e. verbs, nouns and adjectives.

The top verbs in descending order according to the frequency of occurrence in the 2013 speech are listed in Table 1. The remaining verbs not shown in the table had frequency 2 or less. The usage of verbs in the addresses does not suggest much, since they are mostly not very specific.

The top verbs in 2018 address are shown in Table 2 (the remaining verbs not shown in the table had frequency 3 or less) and again do not seem very specific, but it is interesting, that ”mít” is listed as the first in the 2018 speech, with 30 occurrences, and not among the top verbs in the 2013 address.

Rank	Verb	Count	Percent
1	chtít (want)	7	5.6
2-5	dát (give)	4	3.2
2-5	muset (have to)	4	3.2
2-4	dovolit (allow)	4	3.2
5-7	dokázat (achieve)	3	2.4
5-7	říkat (say)	3	2.4
5-7	snažit (try to)	3	2.45

Table 1 Frequencies of verbs in 2013 speech

The word frequencies for nouns and then for adjectives are shown below in Figures 2 and 3. The most frequent noun in the 2013 address is ”president” and ”republika”, followed rather surprisingly by ”ostrov”. Rank 4-7 is ”deviace”, which may be rather unexpected in a presidential inaugural speech. The top three nouns in the 2018 address are ”strana”, ”občan” and ”prezident”. The top nouns in the 2018 speech seem quite common for a presidential speech.

The most frequent adjective in the 2013 address is ”český”, see Figure 3. For the 2018

Rank	Verb	Count	Percent
1	mít (have)	30	10.9
2-3	chtít (want)	9	3.3
2-3	být (be)	9	3.3
4	moci (can)	8	2.9
5-6	jmenovat (appoint)	6	2.2
5-6	myslit (think)	6	2.2
7-11	považovat (consider)	4	1.5
7-11	podařit (succeed)	4	1.5
7-11	připomenout (remind)	4	1.5
7-11	setkávat (meet)	4	1.5
7-11	jít (go)	4	1.5

Table 2 Frequencies of verbs in 2018 speech

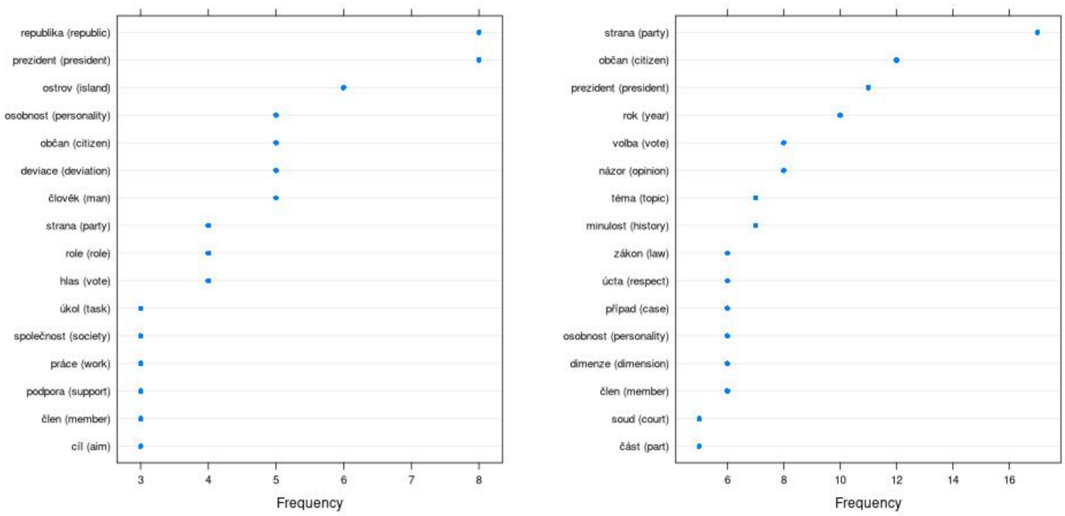

Figure 2 Frequencies of nouns in 2013 (left) and 2018 (right)

address, the most frequent adjective is the "rád". The adjectives used most frequently in the two addresses do not seem much unexpected in a presidential inaugural speech. The usage of the word "negativní" may seem interesting. The most frequent adjectives in 2013 speech include "zákonodárný", in the 2018 speech the most frequent adjectives include "ekonomický" and "sociální".

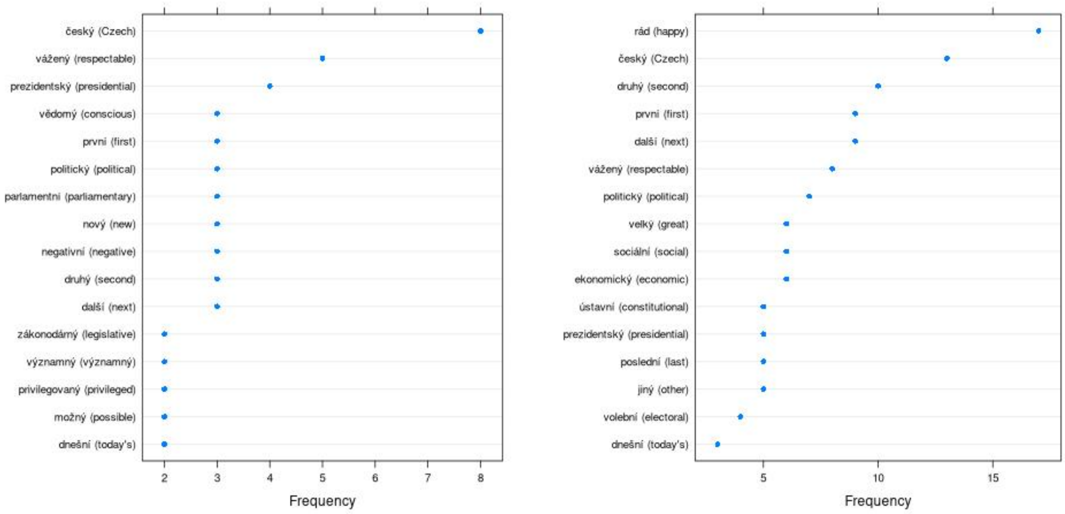

Figure 3 Frequencies of adjectives in 2013 (left) and 2018 (right)

Let us now search for co-occurrences, which may be more informative for analytical purposes then the frequency statistics of single words. We will find keywords which are a combination of nouns and adjectives following one another. The co-occurrences are displayed in Figures 4 and 5.

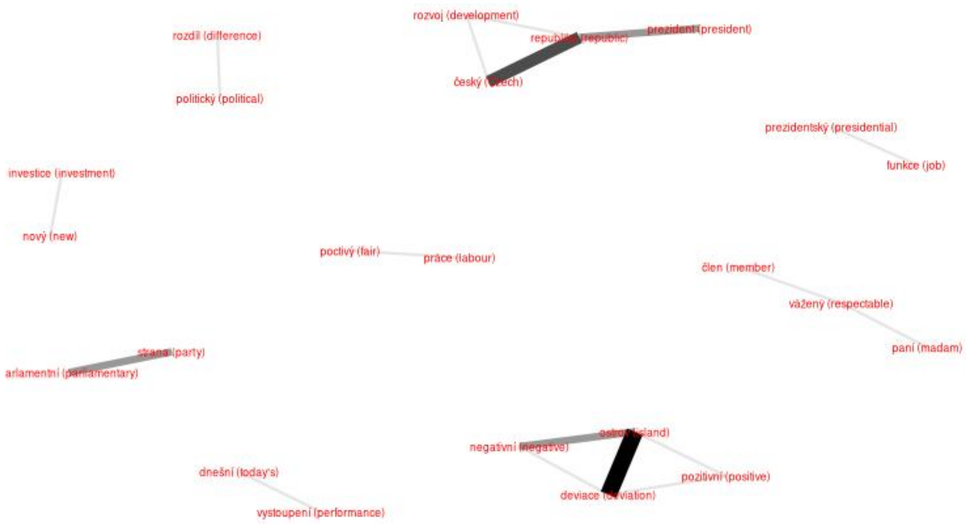

Figure 4 Co-occurrences in 2013 speech

The top co-occurrence in the 2013 speech is clearly ”ostrov + deviace”, both due to the highest frequency (5) and rather high specificity. Such co-occurence is rather rare in common inaugural addresses given by the presidents. ”deviace” and ”ostrov” have co-occurred with ”pozitivní” and ”negativní”. The co-occurrence ”český + republika” (occured 4 times) is not so unexpected, just like ”prezident + republika” and ”parlamentní + strana” (both pairs occurred 3 times).

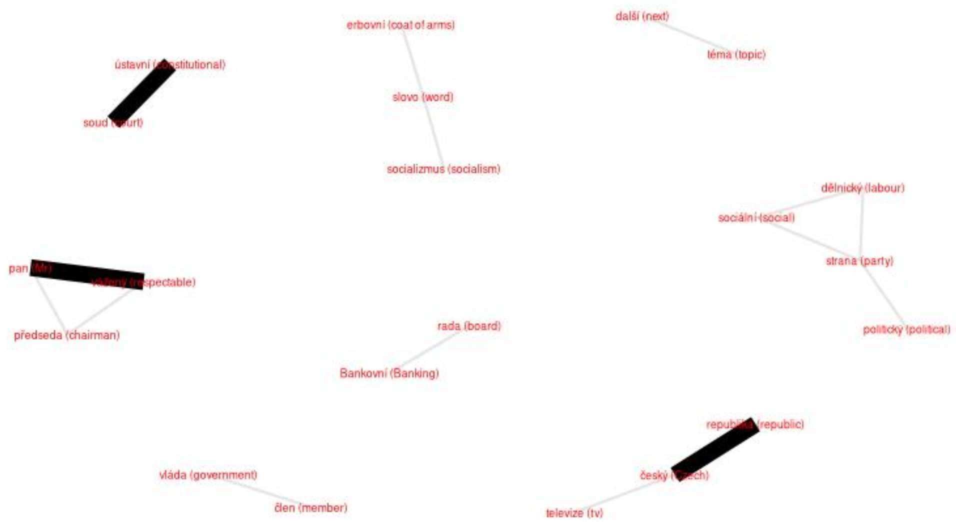

Figure 5 Co-occurrences in 2018 speech

The occurrences ”ústavní + soud”, ”český + republika” and ”vážený + pan” have all 4 co-occurrences in the 2018 address, the remaining twelve pairs shown in Figure 5 have 3 co-occurrences. Interesting co-occurrence is also ”bankovní + rada”, ”česká + televize”, the triangle ”dělnický - strana - sociální”. The pairs not shown in the plot had just 2 co-occurrences at most.

A sentiment analysis of the two speeches using the udpipe package (Wijffels, 2023) with the Czech Sublex dictionary (Veselovská and Bojar, 2013) shows that both 2013 and 2018 speech have positive polarity. The 2013 speech has score 13 and the 2018 speech has score 20.8. If we were interested in average polarity score per single term, then the second speech is slightly less positive (giving score 0.009 compared with 0.013 for the 2013 speech).

4 Conclusion

The formal analysis using basic NLP techniques is considerably faster compared with traditional reading and analysis by human reader even for texts which have lengths of several hundreds words. The drawback may be occasional errors in the automated transformations and classification of words in comparison with the human experts. Some of the results of the analysis of presidential inaugural addresses are interesting and show that the co-occurrences which have been found using NLP can be used as the proposed keywords. Careful reading of the two addresses by human can clearly reveal other relevant information, but for quick automated formal analysis, NLP techniques are hard to match.

Acknowledgements

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Comparing the performance of deep learning neural network architectures for predicting economic time series

Dmytro Kovalenko [1], Dusan Marcek [2]

Abstract. We propose two deep learning algorithms for neural network models. The first one the Long short-term memory model and the second one convolutional neural network architecture. These architectures were designed for predicting time series and are evaluated on daily historical stock price data for Apple Inc. The datasets collected from Yahoo Finance website were used as inputs. Both models were designed according to describing in theoretical background using toolkit of Keras and tested using RMSE, MAE. The achieved prediction accuracy obtained through the proposed deep learning convolutional neural network was much worse than long short-term memory model.

Keywords: Neural networks, RNN, LSTM, CNN.

JEL Classification: C13, C45, D81, G32

1 Introduction

Neural networks have already found their place among other approaches, models or paradigms of artificial intelligence. Unlike more conventional approaches based on the symbolic representation of the information, the knowledge of a neural network is spread units constituting elements, similarly as in biological neural networks. On the other hand, it is sometimes difficult to assess what knowledge has been acquired by the network since the analysis of the internal representation is difficult.

The recurrent neural networks (RNNs) have the biggest potential in predicting time series, which are applied very often in financial risk management. Later, for process data with spatiotemporal structure RNNs (see FIGURE 1) were suggested trained by common gradient descent techniques (Elman, 1990)

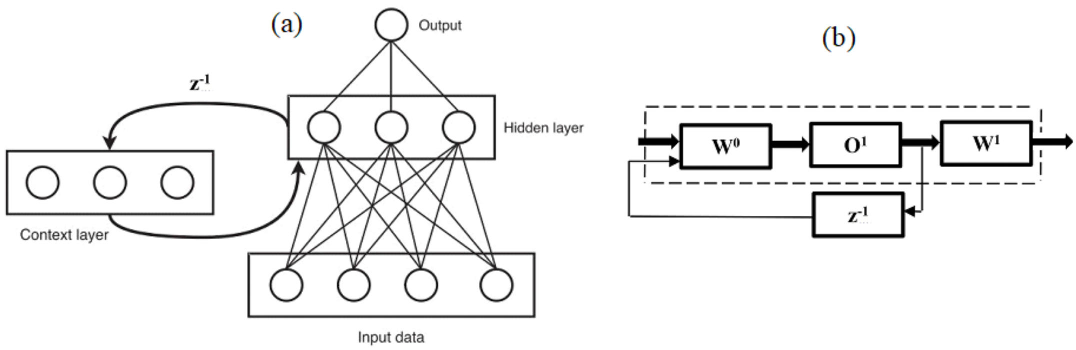

Figure 1 Simplified structure of the Elma´s RNN (a) and its block representation (b) [Torres et al., 2020]

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RNNs were successfully applied in many real-life applications where processing time dependent information was necessary. Unlike feedforward neural networks, units in RNNs are fed by activities from previous time steps recurrent through connections. In this way, contextual information can be kept in units´ activities, enabling RNNs to process time series. Common algorithms used for RNNs training are based on gradient minimization of the output error. Standard RNNs trained by common gradient descend techniques have problems with processing time series containing long-time dependencies. When propagating teaching signal, error tends to vanish or blow up (Hochreiter et al, 2001), see also (Čerňanský, 2006).

To overcome this limitation and to solve tasks traditional RNNs cannot solve, novel architecture was suggested. Long short-term memory (LSTM) networks are equipped with special units called constant error carrousels with self- recurrent feedback connection of constant weight set to 1 (Hochreiter and Smidhuber, 1997). In this way, error signal can span theoretically infinite time distances. LSTM architecture has further developed: forgetting mechanism was introduced (see Gers, Smidhuber, Cummins, 2000). Some attempts were made to use LSTM network in practical applications in robotics, see also Bakker (2002). The problem of time series forecasting is solved in LSTM with the help of a memory cell referred to as the LSTM cell. This type of network possesses the capability to learn long-term dependencies in data, which shows its applicability to a time series problem.

CNN is another deep learning algorithm applied in stock market prediction after LSTM. In study (Di Perisio and Honchar, 2016) CNN and RNN were applied to the forecasting of stock market price movements of the S&P 500 index. Experiments demonstrated advantages of CNN over other methods. Other experiments show that CNN plays an important role in the quality of the extracted feature set and the final prediction. For example, CNNs used in (Gunduz, Yaslan and Cataltepe, 2017) the data of 100 companies in Borsa Istanbul were utilized to produce technical indicators and temporal features. It was found out that CNN achieved better relative F-Measure values than other classifiers.

The main goal of this research is to investigate the ability of different ANNs architectures to enhance the accuracy of economic time series forecasting.

Sections 2 and 3 provide the basic methodologies of the deep learning for LSTM networks and CNNs respectively. Section 4 introduces the data for our research. The methods for implementing learning algorithms, as well as several commercial procedures and software are used and described in Section 5. Empirical comparison and discussion are given in Section 6. Concluding remarks are given in Section 7.

2 Theoretical background – LSTM model

LSTMs stands for Long Short-Term Memory and is a type of RNNs that are able to handle long-term dependencies between inputs. They use for various tasks such as speech and video recognition, natural language processing and time series forecasting such as stock price forecasting.

According to (Preeti, Rajni and Singh, 2019) LSTM network architecture is a sequential model based on two critical components states and three gates. The states include hidden state, which depicts the value of previous hidden layer and input state which is a linear combination of current input data and hidden state. The LSTM cell consists of gates that are input gate, forget gate and output gate, which named (i, f, o). Hidden state is output vector and named s. Each unit of LSTM cell network is consisted of these three gates and uses an optimizer function to update the weights associated with units of network. The forget gate, f_t is computed using Eqn. (1) to find which information from previous state to be kept for further computation.

$$F_t = \sigma(W_{fx}x_t + W_{fs}\text{f}\, s_{t-1} + b_f) \tag{1}$$

where, σ denotes the sigmoid activation function. After that, input gate is used to find an intermediate parameter it using Eqn. (2) and C_t using Eqn. (3) to decide whether internal state value serve as memory cell.

$$i_t = \sigma(W_{ix}x_t + W_{is}s_{t-1} + b_i) \tag{2}$$

$$c_t = \tan h(W_{cx}x_t + W_{cs}s_{t-1} + b_c) \tag{3}$$

Finally, the information to be kept is decided by merging input and forget gates output in Eqn. (4).

$$C_t = f_t \times C_{t-1} + i_t \times c_t \tag{4}$$

These sigmoid and tanh layers are used to compute new information being store in cell state. Then, output layer captures the output in Eqn. (5) which is used to give final output prediction st in Eqn. (6).

$$o_t = \sigma(W_{ox}x_t + W_{os}s_{t-1} + b_0) \tag{5}$$

$$\tilde{s}_t = o_t \times \tan(C_t) \tag{6}$$

where,$W_{fx}, W_{fs}, W_{ix}, W_{is}, W_{cx}, W_{cs}, W_{ox}, W_{os}, b_f, b_i, b_c$ and b_o are corresponding weights and biases used at different layers, respectively and $\tilde{s}_t$ denotes the output of LSTM network at time signal *t*.

3 Theoretical background – CNN model

Convolutional Neural Networks (CNNs) are used in image processing and have recently been applied to time series forecasting. CNNs are good for task as they are able to automatically extract features from raw data. The architecture of a CNN for time series forecasting is similar to architecture of CNN for image classification. The main difference lies in the input and output layers. In the context of time series forecasting, the historical values of the time series are transformed into a matrix, known as a tensor, and fed into the input layer of the network. The network then applies filters to the tensor, which serve as feature extractors. The filters are responsible for identifying patterns in the data, such as trends, seasonality, and anomalies. These patterns are then passed through multiple hidden layers, where the features are combined and processed to produce a prediction.

According to author´s Madera and Marcek (2023) all configurations of CNN are based on the classical feedforward artificial neural network and therefore adopt most of its basic principles of structure, training and inference. The configurations are built on the basis of the following three principles: weight sharing, local receptive field and subsampling. The result of sharing is a substantial reduction in the number of free parameters for the maintenance of the number of synapses affecting the network's ability. CNN configuration has types of layers:

- Input Layer: The input layer of the CNN accepts the raw data, such as images or time series data.
- Convolutional layer extractions of various features from the input feature map. This layer creates a convolved kernel with layer of input for creating a tensor of outputs.

$$Y_{i,j}^{y} = b^{l} + \sum_{h=1}^{H} \sum_{m=1}^{K} \sum_{n=1}^{K} X_{i+m,j+n}^{h} \times W_{m,n}^{h} \tag{7}$$

  where $x_{i+m,j+n}^{h}$is a point in the position in h input map, similarly, $Y_{i,j}^{l}$ is a point at a position (i,j) in the l output map, $W_{m,n}^{h}$ is the coefficient at the position (m,n) in the $(K \times K \times H)$ dimensional kernel used for the h input map and b^{l} is the bias for the l output map.

- Pooling layer, which performs the merge operation. This operation is essentially the same as in the case of convolutional weaving. The difference lies in the function that is used over a group of points in the local neighborhood. Merging leads to size reduction. In the case of the merging layer, the most used functions are average and maximum. Merging leads to a reduction in the dimensions of maps on other layers, a reduction in the number of synapsis and free parameters.

$$Y_{i,l}^{l} = f(X_{i,j}^{l}, X_{i+1}^{l}, X_{i,j+1}^{l}, X_{i+1,j+1}^{l}) \tag{8}$$

- Fully-connected layer performs the inner product of the input vector X and the transpose weight vector W' plus bias b_i, i.e.,

$$Y = X_{\ i}W' + b_i \tag{9}$$

  This layer serves as a classifier, where the input vector represents the vector of features extracted in previous layers.

- The rectified linear unit layer is vital in CNN architecture and is based on the nonsaturation 'activation function'. Without activating the fields of the convo layers, it increases the decision function's nonlinear properties by removing the negative values from the activation map and converting them to zero. For example, rectified linear unit $ReLU$ (10) speeds up network training and calculations.

$$ReLU(x) = \max(0,x) \tag{10}$$

- Dropout Layer: Dropout layer helps prevent overfitting. It randomly drop out a certain part of neurons in the network during training.
- Batch Normalization layer. It normalizes the activations of the previous layer, which helps speed up training and improve the generalization performance of the network.
- Output layer: The output layer produces the final predictions.

4 Used data and their pre-processing

In this paper, historical stock price data for Apple Inc. (AAPL) was obtained from Yahoo Finance (Yahoo Finance, n.d.). There are historical daily prices for Apple Inc. stocks on NASDAQ from December 12, 1980 till December 17, 2022. The data were presented initially in the format such on FIGURE 2.

The data about period of time and price by “Close” were used for forecasting. Therefor dataset was filtered by the indicators “Column” and “Date”. The time series plot for all period is shown on FIGURE 3.

Date	Open	High	Low	Close	Adj Close	Volume
1980-12-12	0.128348	0.128906	0.128348	0.128348	0.099722	469033600
1980-12-15	0.122210	0.122210	0.121652	0.121652	0.094519	175884800
1980-12-16	0.113281	0.113281	0.112723	0.112723	0.087582	105728000
1980-12-17	0.115513	0.116071	0.115513	0.115513	0.089749	86441600
1980-12-18	0.118862	0.119420	0.118862	0.118862	0.092351	73449600
...	...	...	...	...	...	...
2022-12-12	142.699997	144.500000	141.059998	144.490005	144.269730	70462700
2022-12-13	149.500000	149.970001	144.240005	145.470001	145.248230	93886200
2022-12-14	145.350006	146.660004	141.160004	143.210007	142.991684	82291200
2022-12-15	141.110001	141.800003	136.029999	136.500000	136.291901	98931900
2022-12-16	136.690002	137.649994	133.729996	134.509995	134.304932	160156900

10594 rows × 6 columns

Figure 2 Structure of initial dataset - preview of used data [Source: Yahoo Finance, n.d.]

Features of data was transformed by scaling to range (0,1) using MinMaxScaler. Dataset was divided on train data and test data with coefficients 0.8 and 0.2. The train data is shown in the FIGURE 3 in blue. The test data is shown in the FIGURE 4 in red. We used 60 days observations for CNNs models, therefor elements of the train dataset is a normalized time series with length of 60.

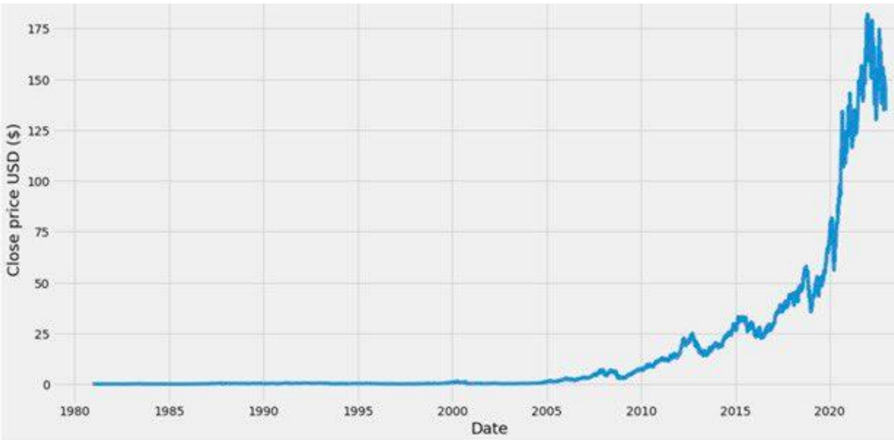

Figure 3 The time plot of daily prices for Apple Inc. stocks by “Close” from December 12, 1980 till December 17, 2022 [Source: own processing]

Figure 4 The data distribution for training and testing. Prediction values for the LSTM [Source: own processing]

5 Proposed solution

The basic models were built according to describing in theoretical background using toolkit of Keras and TensorFlow. According to Keras (n.d.) Keras is deep learning API written in Python, running on TensorFlow. Keras was developed with a focus on enabling fast experimentation. TensorFlow is an end-to-end platform that makes it easy for users to build and deploy Machine Learning models (TensorFlow, n.d.).

The basic LSTM model consists of the following components

2 LSTM layers with number of units as dimensionality of the output space is 50; 2 Dense layers with number of units is 25 and 1 respectively; optimizer Adam as a stochastic gradient descent method that is based on adaptive estimation of first-order and second-order moments (TensorFlow, n.d.); losses Mean Squares Error (MSE); number batch size is 1; number of epochs is 1.

The basic CNN model consists of the following components

1st Convolution 2D layer with number of filters is 8, kernel size as dimension of used matrix is 1x60, activation function is ReLU; 2nd Convolution 2D layer with number of filters is 1, kernel size 3x1, activation function is ReLU; 3rd Convolution 2D layer with number of filters is 5, kernel size is 3x1, activation function is ReLU; 2 Batch Normalization layers; 3 Max Pooling layers with pool size 2x1; Flatten layer; Dropout layer with drop value 0.1; Dense layer with 1 unit and Sigmoid activation function; number batch size of training examples is 1; number of epochs is 4.

6 Empirical comparison and discussion

The following statistical summary measures of model´s forecast accuracy were used: the root mean square error (RMSE) and the mean absolute error (MAE). The achieved accuracies of the models are listed in TABLE 1. The basic CNN model did not perform satisfactorily. The RMSE or MAE values are high as shown in TABLE 1. This gives an incentive to search for new solutions, e.g. using innovative convolutional models, to improve the performance of convolutional models. This will be the subject of further research.

Architecture/ Metrics	RMSE	MAE
LSTM	7.899	4.562
CNN	43.841	37.264

Table 1. The empirical statistical forecasting accuracy assessment of the presented CNN architectures (models)

7 Conclusion

We investigated the performance of CNN and LSTM networks for forecasting economic time series with the same set of input data and same accuracy metric. We used Apple's stock price from December 12, 1980 till December 17, 2022 as input data. We compared the results by metric RMSE and MAE. Our research demonstrated that accuracy of forecasting model based on LSTM is better than CNN for the Apple's stock closed prices.

Although we have obtained some interesting results, we are aware that prediction in complex and dynamic economic system is needed a very difficult task that calls on more advanced and sophisticated techniques of computational intelligence. In addition, how to incorporate qualitative data such as money, GNP, interest rate, inflation rates, political disturbances, moral hazard, into intelligent decision support systems remain an open question. We hope to conduct more research in this area in the future.

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Comparison of Communication Media Preferences for Generation Z in the gender context

Terezie Krestová[1],Lucja Matusiková[2], Kateřina Stanovská [3]

Abstract. In present times, many countries are fighting against disinformation. Therefore, it is important to get information from trusted sources. The nature of their ownership, i.e. their public or private character, may be an important factor when perceiving individual media. The aim of paper is comparison of Communication Media Preferences for Generation Z before the pandemic and after the pandemic in the gender context. We have compared the result of research from 2016 year and from 2022. The Pearson's chi-square test of independence served to confirm or reject the established hypotheses.

Keywords: Mass media, public, private, gender, generation Z.

JEL Classification: D70, J16

1 Introduction

Marketing communication is carried out via a lot of channels. Media are one of the possibilities how to address potential customers. The effect of advertising impulses of broadcast media, i.e. communication media, depends on a lot of factors. They include for example their credibility. And right the media credibility in the context of their ownership character became the essential research artefact. With respect to the fact that a clear specification of private and public media may be implemented only in the case of television and radio media, the results of the research activities will be intended right and only for them.

Generation Y and their relationship to the media is the subject of a number of publications, namely (Boughzala, 2014), (Duffet,2015), (Giovannini, 2015). The aim of paper is of Communication Media Preferences for Generation Z before the pandemic and after the pandemic. We have compared the results of research from 2016 year and from 2022. For the purposes of presenting the results of the present research, only one generation cohort is specified in detail, that is Generation Z (GZ). The generation Z are people born between 1991-2010.

Structure of this paper is following. Firstly, we define the basic terms and method. We use statistic, namely testing hypothesis. We analyze data in IBM SPSS Statistics. Next step, we present the results of Research.

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2 Definition of Basic Terms and methods

For the purposes of a correct interpretation of achieved results, we need to approach at least in basic dimensions the main notions that we will subsequently work with. Only the facts that are essential and more closely specifying or explaining individual concepts will be included.

2.1 Media

The Dictionary of Foreign Words (Linhart, 2008) defines the notion Medium as a mediation agent, environment, also as person arranging spiritistic information and, last but not least, as mass (collective) media printed (newspapers, magazines) as well as electronic (radio, television), mass medium.

The word medium is similarly characterized also by other authors (Jirák, Köpplová, 2003), who state that it is of the Latin origin and means a mediator, intermediating agent, that is anything that mediates, arranges something. Subsequently, the authors develop this idea with the fact that disciplines that deal with different manifestations of interpersonal, social communication mark the notion medium/media as something that mediates some information for somebody that is the communication medium.

The notion mass media, whose content is more specific, forms a separate chapter. “Mass media mean means of communication and institutions that are able to produce in the large scale public notification and distribute it towards the scattered, varied and individually unidentified public.” (Urban, Dubský, Murdza, 2011)

2.2 Public and Private Media

In the Czech Republic, following the European model, at the beginning of the 1990s, the so-called dual system of television and radio broadcasting was elected, that is the co-existence of the public and private sectors. Concurrently, the rights and obligations of the radio and television broadcasting operators, licence procedures and registration of the operators of the taken-over broadcasting were determined. This state is regulated by Act No. 231/2001 Coll., on Operating Radio and Television Broadcasting, as amended.

Yet, talking about public broadcasting, we mean the Czech Television Company and the Czech Radio Company. These institutions operate on the media market on the basis of separate laws. It is Act No. 483/1991 Coll., on the Czech Television Company and Act No. 484/1991 Coll., on the Czech Radio Company, always as amended. The public character of financing these institutions is implemented by Act No. 348/2005 Coll., on Radio and Television Charges, as amended.

The Czech Television Company and the Czech Radio Company are broadcasting opera-tors by law with specific tasks of the public service. Both the operators are independent of the state, they do not receive any state subsidies and their activity is financed by the income from radio and television charges and the income from their own business activity (above all, it is the sales of advertising time as well as the revenues from copyrights, leases of equipment, etc.) (The Ministry of Culture, 2012, [online]). The Czech Television Company and the Czech Radio Company fulfil their service for the public via own production and co-production and also by television and radio broadcasting and other services. Regarding the question of funding the Czech Television Company and the Czech Radio Company, the idea of financial security via the state budget was originally discussed. Yet, this idea was abandoned in connection with a threat of weakening the independence of the relevant medium of the state (Jirák, Köpplová, 2003).

2.3 Generation

According to the Dictionary of Foreign Words, the notion “generation” (Linhart a kol., 2008, p. 132) has a number of meanings. The generation is characterized first, that is a set of people born and living approximately at the same time. A generation sometimes means descendants of one pair of parents. The third semantic unit makes it possible to identify a generation as a specific set of concurrently living individuals of the same kind. A generation also means a membership of the type of technical equipment of a certain development stage.

From the viewpoint of perceiving communication media, we undoubtedly need to identify basic grounds that have had the impact on this age group of inhabitants, above all, from the sociological viewpoint. According to the Australian study of the labour market from 2007 (Bohutinská, 2008, [online]), currently, we may specify the following generationally differentiated groups of population:

Born before 1946	=	Pre Boomers
Born from 1947 to1960	=	Baby Boomers
Born from 1961 to1975	=	Generation X
Born between 1976 and 1990	=	Generation Y
Born between 1991 and 2010	=	Generation Z

As the Grail Research study states (Grail Research a Division of Integreon, 2011), the GZ representatives include young people whose date of birth is usually determined by the middle 1990s and year 2010, whereas it should be noted that different studies e.g. Howe, Strauss (1991) freely work with this time factor, when they include the GZ into the period from 2000 to the present time.

With respect to the method of communication (they are constantly on-line via their mobile phones, they share a lot of information via You Tube etc.) and the ability of both the intensive and extensive use of the state-of-the-art technologies. Their relation to technologies may be even characterized as a certain form of addiction. They seek more and more sophisticated devices and appreciate particularly their simple and interactive design. In spite of their currently low age in most cases, they appear to be socially more responsible than their predecessors. Owing to the sufficient amount of available information, far more intensively they are aware of the current problems, such as terrorism or climate changes.

If we summaries all the mentioned above, we may observe that the GZ is constantly on-line via a number of social networks and their decision-making processes are in many areas influenced by the ability to obtain information across the countries, cultures as well as religions.

2.4 Description of Used Methods – Testing hypothesis

At this point it should be emphasized (Matusiková, Kashi and Zelinková, 2016) that in terms of practical application of statistical methods in analyzing empirical data, statistical hypothesis testing represents one of the most important parts of all. One of the basic statistic methods for the assessment of set hypotheses, is the Pearson’s chi-square test of independence.

The role of hypothesis testing is to decide about the basis of information obtained from random samples, whether we accept or reject a particular hypothesis concerning the master sample. The statistical hypothesis (Marek et al., 2007) can be understood as any statement that may involve unknown parameters, set functions of the parameters, but also the shape of the distributions and other characteristics of the master sample. A decision rule by which we assign a decision on the validity or invalidity of the hypothesis is called a statistical test.

The first step in statistical testing is always a statistical hypothesis formulation, i.e. a formulation of a research question in the experiment in the form of a zero and alternative statistical hypothesis, which are asked when testing against each other.

The second step in testing statistical hypotheses consists in determining a significance level of the test (error α selected by an expert), which is the probability that the null hypothesis (H_0) will be rejected, although it is valid.

The formulation of the test conclusion is the last step in statistical hypotheses testing, which can be done in two ways, that is by comparing the calculated testing criterion with a critical value, which is determined in dependence on the selected significance level α. The *p*-value is used in statistical testing of the suitability of the model using different software. The *p*-value is the smallest level of significance α which we still reject H_0. If the *p*-value is smaller than α, we reject the null hypothesis H_0.

For nominal variables is used Pearson's chi-square test is used in this paper. Pearson's chi-square test is the basic and most used test of independence in the pivot table. The null hypothesis here is the statement that the random variables and are independent, which means that the probability of the occurrence of a certain variant of the random variable does not affect the occurrence of a certain variant of the random variable. For ordinal variables is used Spearman correlation test is used in this paper (Řezánková, 2011).

2.5 Concept of the Research, Determination of Objectives and Hypotheses

The following objectives were set as part of the research and corresponding descriptive analyzes and statistical tests are presented in the empirical part:

- ascertain how often the respondents follow the surrounding events in media;
- determine whether the respondents prefer a certain type of media and which type;
- determine whether the nature of the ownership is a factor that has impact on media credibility.

For the purposes of the research to preserve unambiguousness of terms, two types of media were used, namely radio and television. There we could compare the impact of the ownership on the medium perception. Therefore, ČT1, ČT2 and ČT24 television stations represent public media. All remaining tele-vision and radio stations are private. In their responses, the respondents were also offered a possibility to supplement additional radio and television stations that they follow. Such media as the internet, social networks and others were disregarded.

In this connection the following hypotheses were determined:

1) H_0 Within the sample, the respondents' gender does not have impact on their responses.
2) H_1 The respondents' gender have impact on their responses within the particular sample.

From the methodological viewpoint, it was proceeded from theory to practice, from general to specific. Retrospectively, the knowledge obtained in the primary and secondary research is applied in the theoretical grounds. The Pearson's chi-square test test of independence in the contingency table will be used to confirm or reject the established hypotheses. The test was carried out in IBM SPSS Statistics. Significance level (α)is 5 %.

3 Results and Discussion of Research

We have conducted the research by a questionnaire enquiry. The research before pandemic was carried out in the streets of the city of Ostrava during February and September 2016. The research after pandemic was provided during September and November 2022. The results of research before pandemic were published in 2017 (Matusiková, 2017).

The questionnaires were completed by the respondents via standardized anonymous face-to-face dialogues with the respondents in public. After the experience from the pilot part of the project, the enquirers were instructed to address the individuals, when the willingness to answer and the year of birth (1995 and more) were the decisive criteria for addressing respondents. The completed questionnaires were subjected to the optic inspection, subsequently they were rewritten into the data matrices in MS Excel and processed with the use of IBM SPSS Statistics. The questionnaire has 12 questions. Five questions are analysed in this paper.

The numerical representation of the enquired within genders in the form of the absolute value (hereinafter only A) and the percentage value (hereinafter only %) is shown in Table 1.

	GZ	Male	Female	Total
Before pandemic	A	96	118	214
	%	45%	55%	100%
After pandemic	A	82	109	191
	%	43%	57%	100%

Table 1 Division of Respondents according to Gender

In Table 2 is shown number respondents in the research before pandemic and after pandemic. In spite of the fact that due to a low number in individual categories the educational factor was not taken into account as an identification element.

The second question was of a closed character and the respondents needed to decide unambiguously for one of the options, which are shown in Table 2. The wording of the question was as follows:

Do you follow the surrounding events in media, for example the television, newspaper, radio (circle one response only)?

	Before pandemic		After pandemic	
	Male	**Female**	**Male**	**Female**
Daily	48%	39%	41%	43%
Several times a week	15%	37%	37%	39%
From time to time	27%	22%	12%	14%
I do not follow	10%	2%	10%	4%
***p*-value**	0,0768			0,08

Table 2 Frequency of Following Media and Confidence in them

We can see results of research in Table 3. The responses (before pandemic) show that almost 50% men and 40% women follow media daily. However, 41% of men and 43% of women watch the news daily after the pandemic. the biggest difference is for men. More than 15% men and almost 40% women decided for the response "Several times a week" before pandemic. Here you can also see the biggest change in men. after the pandemic, 37% of men and 39% of women watch the news several times a week. 30% enquired men and 22% women follow surrounding events in media "From time to time". 10% of men and 2% of women said they follow the news in the media.

The subsequent questions focused on following news at television stations. For the purposes of the research, only basic television stations were included in the offer, whereas the respondents had a possibility to supplement their preferences. Concurrently, the respondents could select from more options. For transparency, the results were adjusted according to the frequency of respondents' selective responses. The responses to questions or the frequency order are shown in Tables 3. We will perform a test on the independence of the variables Gender and TV station.

		ČT1	**ČT2**	**ČT24**	**Nova**	**Prima**	**Barrandov**
before pandemic	Male	1	5	3	2	4	6
	Female	2	5	4	1	3	5
	p-value		0.8087				
after pandemic	Male	1	5	3	2	4	6
	Female	2	5	4	1	3	5
	p-value		0.7007				

Table 3 Ratings of News at TV Stations

Whereas men watch news on ČT1 most often, women choose Nova. Concerning the station at which the news is watched the least, both women and men placed the ČT2 station last. The male selection for their number one may be the result of a habit, the female selection may arise from the NOVA station programme concept, when for example the series with a high share of female public are on prior to the main evening news. Nor in this case did the Pearson's chi-square test at the level of 0.8087 confirm dependence of respondents' replies on respondents' gender. It is shown in Table 4. The preferences of television stations are same after pandemic as before.

The last two questions were again of a closed character and the respondents needed to select unambiguously one of the options. The wording of the questions was as follows:

4) Do you have confidence in these news?

5) Is your confidence influenced by the ownership structure of the media (private, public)?

Question No. 4		**Male**	**Female**	**Question No. 5**	**Male**	**Female**
before pandemic	**Yes**	25%	46%	**Yes**	46%	35%
	No	46%	27%	**No**	46%	51%
	I do not know	29%	27%	**I do not know**	8%	14%
	***p*-value**	0.095		***p*-value**	0.81	
after pandemic	**Yes**	55%	50%	**Yes**	54%	40%
	No	26%	28%	**No**	30%	44%
	I do not know	20%	23%	**I do not know**	16%	16%
	***p*-value**	0.08		***p*-value**	0.71	

Table 4 Ratings of News at TV Stations

As Table 4 shows, there is not a considerable difference between the way men and women re-spond, in particular, as long as the confidence in media is concerned. Interesting is also the fact that almost 30% enquired men and women do not know whether they have confidence in these news. Simultaneously, more women think that they are not influenced in their decision by the ownership structure of the medium. We performed a test on the independence of the variables confidence in these news and Gender (question No.4) and a test on the independence of the variables confidence influenced by the ownership structure of the media and Gender (question No.5). In both the cases, although with a significant difference, the responses of the inquired were at the level that shows independence of the analyzed variables, which was proved by the Spearman Correlation test. Regarding Question No. 4, the *p*-value was 0.095 and for Question No. 5, it was 0.81.

4 Conclusion

In order to ensure a suitable way of communication with the client, by all means we need to utilize the most reliable communication medium. The ability of the medium to obtain credibility and maintain it may be characterized as a significant competitive factor.

On the basis of the questionnaire enquiry, we have ascertained that the addressed GZ sample has a relatively intensive interest in surrounding events. news viewing frequency has changed insignificantly for men. Before the pandemic, 48% of men watch the news daily, after the pandemic it was 41%. before the pandemic, 15% of men watched the news several times a week, after the pandemic it is 37%. there has been a significant increase here. We can state that the influence of the pandemic had an effect on the increase in news viewership among men. The hypothesis that there is a dependence of respondents's replies on respondents' gender was not confirmed.

When analysing the ratings of individual TV stations and related news at these stations, the GZ was able to unite across the gender in only the least followed stations in general as well as by news. The preference for watching news on TV stations has not changed after the pandemic.

The major areas of the research included news credibility in the followed medium and the impact of its ownership structure (private versus public) on such credibility.

If we review the GZ, then we may observe that credibility in the followed news was in the completely reverse order in the GZ men and GZ women. The percentage of the GZ women that have credibility in the followed news is identical with the percentage of the GZ men that do not have confidence in it. After the pandemic, confidence in news changed significantly for men.

So, what is the impact of the media ownership structure on their credibility? Regarding the GZ men, the same percentage of them decided for both “yes” and “no”. Regarding the GZ women, more than 50% of the enquired declared no effect of the ownership structure. On the other hand, more than 50% of men answered “yes” to the given question after the pandemic.

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Analysis of the efficiency of Czech breweries in the years 2016-2020

Martina Kuncová[1], Roman Fiala [2]

Abstract. The aim of this paper is to assess the efficiency of Czech breweries during the years 2016-2020 to see the situation in this sector. The research sample included around hundred companies. The data was exported from the Albertina CZ Gold Edition database. DEA models are used for analysis and comparison. Efficiency scores were calculated based on the CCR (Charnes, Cooper and Rhodes) and BCC (Banker, Charnes, Cooper) models with 3 and 2 inputs. The results show that the situation in all years was similar except for the year 2019 when more inefficient companies appeared.

Keywords: Czech breweries, beer production, efficiency, DEA models.

JEL Classification: C44

1 Introduction

The beer production has a long tradition in the Czech Republic. Information about brewing beer dates back to the early first millennium, with the earliest mention dating back to around 1088 (Danišová, 2020, Basařová, 1999). The development of brewing (in addition to the already existing monastic breweries) in the territory of today's Czech Republic is connected with the time of the founding of royal towns, especially the 12th and 13th centuries.). According to Danišová (2020), reports from the Provincial Statistical Office from the turn of the 19th and 20th centuries indicate that there was a significant decline in the number of breweries (from about 1000 in 1841 to half in 1925) and started a trend for a concentration of production in larger breweries. This decline in number of companies continued until around the 1960s, when the number of breweries fell below 100 firms. The number of industrial breweries has been relatively stable over the last 20 years. In 1999, there were 55 industrial breweries in the Czech Republic; in 2019, 52 breweries were operating on the Czech market. Industrial breweries are those that produce more than 10,000 hectolitres per year. There has been a significant increase in craft breweries from 27 in 1999 to 450 in 2019. (Tripes, 2019; Tripes and Dvořák, 2017). Nowadays there are almost 600 breweries in the Czech Republic again (see Table 1), which ranks the Czech Republic 7th in Europe in the number of active breweries (Statista.com, 2021).

year	**2016**	**2017**	**2018**	**2019**	**2020**
no. of breweries	398	450	488	617	599

Table 1 Number of breweries in the Czech Republic [The Brewers of Europe, 2022]

The highest beer production volume was achieved in 2019, when beer production exceeded 21.5 million hectolitres, with the most popular being lagers, i.e. bottom-fermented 11s and 12s, which account for more than half of total domestic production (Czech Statistical Office, 2019). As we see on the Figure 1, the year 2019 was the best in terms of production in the long term,

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so the COVID pandemic in 2020-2021 has clearly had an impact on the sector. Nevertheless, the Czech Republic remained among the top 10 European beer producer countries in terms of total production (Statista.com, 2022a). Annual beer consumption per capita has held steady at around 140 litres in recent 10 years (Czech Statistical Office, 2021), but fell to 129 litres after 2019, the fifth lowest level historically since 1950 – see Figure 2 (Czech Beer and Malt Association, 2021). Despite this significant decline, the Czech Republic retained its world leadership in average beer consumption per capita. The Czech Republic has held this position for the 29th consecutive year – since 1993 (Kirinholdings.com, 2022).

Figure 1 Volume of beer produced annually in Czechia from 2008 to 2021 [Statista.com, 2022c]

Figure 2 Average beer consumption per capita in Czechia from 2009 to 2021 [Czech Beer and Malt Association, 2021]

In terms of production and sales, the Belgian group Anheuser-Busch Inbev. is the global leader with sales of USD 54.33 billion in 2022 (among the Czech breweries, e.g. Pivovar Samson belongs to it), followed by the Dutch group Heineken Holding and the Japanese Asahi Group Holdings, which also includes the largest Czech brewery Plzeňský Prazdroj (Statista.com, 2022b).

The aforementioned shows that although the situation of breweries in the Czech Republic has slightly deteriorated in recent years, the number of breweries has rather increased.

Therefore, in this paper we want to focus on the efficiency of Czech breweries using DEA models and data from the Albertina database to see if there are any big changes during last years.

2 Efficiency and DEA models

Evaluating and measuring efficiency is nowadays a crucial topic for the proper functioning of a business, where based on the efficiency analysis, inefficient businesses can be examined, their weaknesses identified and eliminated. Farrell (1957) divides economic efficiency into two types namely technical efficiency and price (scale) efficiency. Being economically efficient requires having both technical and scale efficiency. Efficiency is usually measured by ratios, but most often we see the use of Data envelopment analysis (DEA) models.

2.1 DEA models

DEA models were first described by Charnes, Cooper and Rhodes (1978) based on the concept introduced by Farrell (1957). These methods and models belonging to the field of operations research are very often used to evaluate the performance of many different entities (countries, regions, companies, schools, hospitals, insurance companies, military units, etc.). The efficiency evaluation of decision-making units (DMUs) is calculated using DEA models and according to the efficiency score, two subsets - efficient and inefficient DMUs – are created. The main idea of DEA models is to estimate the efficient frontier, which is formed by the best relative ratios of inputs and outputs of the DMUs being compared. A DMU is considered efficient if it lies on the efficient frontier. Inefficient DMUs lie below the efficient frontier and their efficiency can be improved by changing inputs or outputs (Cooper, Lawrence, Zhu, 2004).

DEA models are a general tool for efficiency and performance evaluation of the set of n homogenous decision-making units (DMUs) that spend multiple (S) inputs and transform them into multiple (R) outputs. In general, the DEA models assume that the inputs are minimising, and the outputs are maximising. Let us denote $\mathbf{Y} = \left(y_{rj},\ r = 1,\ldots,R,\ j = 1,\ldots n\right)$ a non-negative matrix of outputs and $\mathbf{X} = \left(x_{sj}, s = 1,\ldots,S, j = 1,\ldots n\right)$ a non-negative matrix of inputs. The efficiency score of the unit under evaluation j_0 is derived as follows:

$$
\begin{aligned}
\text{Maximise} \quad & U_{j_0} = \frac{\sum_{r=1}^{R} u_r y_{r,j_0}}{\sum_{s=1}^{S} v_s x_{s,j_0}} \\
\text{subject to} \quad & \frac{\sum_{r=1}^{R} u_r y_{r,j}}{\sum_{s=1}^{S} v_s x_{s,j}} \leq 1, \quad j = 1, \ldots, n, \\
& u_r \geq \varepsilon, \qquad r = 1, \ldots, R, \\
& v_s \geq \varepsilon, \qquad s = 1, \ldots, S,
\end{aligned} \tag{1}
$$

where u_r is a positive weight of the r-th output, v_s is a positive weight of the s-th input, and ε is an infinitesimal constant, U_{j_0} is called the efficiency score for j_0-th unit under evaluation. The U_{j_0} equals 1 for the efficient units and lower than 1 for the inefficient units. The objective function in model (1) is not linear, and so two ways of linearisation depending on the orientation of the linear model are usually used: input-oriented model and output-oriented model. This article, as well as similar papers, is focused on the input-oriented models. The linearised version of the input-oriented model, often called the CCR model according to its authors Charnes, Cooper and Rhodes (1978), is as follows:

$$\begin{aligned}
&\text{Maximise} \quad && U_{j_0} = \sum_{r=1}^{R} u_r y_{r,j_0} \\
&\text{subject to} && \sum_{s=1}^{S} v_s x_{s,j_0} = 1, \\
& && \sum_{r=1}^{R} u_r y_{r,j} - \sum_{s=1}^{S} v_s x_{s,j} \le 0, \quad j = 1,\dots,n, \\
& && u_r \ge \varepsilon, \quad r = 1,\dots,R, \\
& && v_s \ge \varepsilon, \quad s = 1,\dots,S.
\end{aligned} \tag{2}$$

The dual formulations of the multiplicative DEA models are called the envelopment DEA models. The CCR input-oriented envelopment model is derived from model (2) and is following:

$$\begin{aligned}
&\text{Minimise} \quad && U_{j_0} = \theta_{j_0} - \varepsilon \left(\sum_{s=1}^{S} s_s^- + \sum_{r=1}^{R} s_r^+ \right) \\
&\text{subject to} && \sum_{j=1}^{n} x_{s,j} \lambda_j + s_s^- = \theta_{j_0} x_{s,j_0}, \quad s = 1,\dots,S, \\
& && \sum_{j=1}^{n} y_{r,j} \lambda_j - s_r^+ = y_{r,j_0}, \quad r = 1,\dots,R, \\
& && \lambda_j \ge 0, \quad j = 1,\dots,n, \\
& && s_s^- \ge 0, \quad s = 1,\dots,S, \\
& && s_r^+ \ge 0, \quad r = 1,\dots,R,
\end{aligned} \tag{3}$$

where $\boldsymbol{\lambda} = (\lambda_1, \cdots, \lambda_n)$, $\boldsymbol{\lambda} \ge \mathbf{0}$ is a vector of weights assigned to particular decision-making units, $\mathbf{s}^- = (s_1^-, \dots, s_S^-)$ and $\mathbf{s}^+ = (s_1^+, \dots, s_R^+)$ are vectors of slack/surplus variables, U_{j_0} is called the efficiency score for j_0-th unit under evaluation. The efficient units identified by this model have an efficiency score equal to one, and all slack/surplus variables equal to 0. The inefficient units have an efficiency score lower than one.

The CCR input-oriented models assume constant returns to scale (CRS), that is why they are sometimes named as CRS models. It means if the decision-making unit with an input/output combination $(\mathbf{x}, \mathbf{y})$ is efficient, then the unit with an input/output combination $(\alpha\mathbf{x}, \alpha\mathbf{y})$, where $\alpha > 0$ is also efficient. Another possibility of returns to scale is the variable returns to scale (VRS), which were firstly mentioned in Banker et al. (1984). The DEA models with the variable returns to scale are called VRS or BCC models, according to Banker, Charnes and Cooper. The multiplicative form of the BCC input-oriented model is following:

$$
\begin{aligned}
\text{Maximise} \quad & U_{j_0}^{V} = \sum_{r=1}^{R} u_r y_{r,j_0} + \mu \\
\text{subject to} \quad & \sum_{s=1}^{S} v_s x_{s,j_0} = 1, \\
& \sum_{r=1}^{R} u_r y_{r,j} - \sum_{s=1}^{S} v_s x_{s,j} + \mu \le 0, \quad j = 1,\dots,n, \\
& u_r \ge \varepsilon, \quad r = 1,\dots,R, \\
& v_s \ge \varepsilon, \quad s = 1,\dots,S,
\end{aligned} \tag{2}
$$

where μ is a free variable and $U_{j_0}^{V}$ is the efficiency score for j_0-th unit under evaluation. The $U_{j_0}^{V}$ equals one for the efficient units. The inefficient units have an efficiency score lower than 1. Similarly as in model (3), the envelopment BCC input-oriented model can be created.

The results of both CRS (CCR) and VRS (BCC) models can be put together. As Banker et al. (1984) mentioned, CRS provides global technical efficiency while VRS pure technical efficiency. The ratio between global technical efficiency and pure technical efficiency is called scale efficiency. In other words, technical efficiency can be obtained as the product of pure technical efficiency and scale efficiency (Banker et al, 1984).

2.2 DEA and breweries efficiency

The use of DEA models is very wide. Emrouznejad and Yang (2018) found 10300 articles focusing on DEA models in journals published between 1978 and 2016. In recent years, the increase in the use of DEA models in terms of number of articles has been exponential. Analyses in the field of business comparison are no exception, but brewing or brewery efficiency analysis directly are not mentioned very often. Bernetti et al. (2020) analyzed the performance of a sample of 163 Italian microbreweries. Their efficiency analysis was based on the input-oriented DEA models with 3 inputs (number of employees, debt/equity ratio, total debt) and 1 output (revenues from sales and services) considering both CRS and VRS models. Sellers Rubio (2018) estimated advertising efficiency in the Spanish beer industry. The input-oriented DEA models were used on the sample of 6 beer firms continuously operating from 2007 to 2014. To calculate advertising efficiency, 6 inputs (4 different advertising expenditures, number of employees, capital), and 2 outputs (total sales revenues, total beer sales) were used. Two-staged model which includes profitability and marketability functions was used for the DEA efficiency measurement of 500 beer production companies by Ezan (2015). The output variables from the profitability stage served as input variables to the marketability stage. Three indicators (total assets excluding financial investments and investment properties, stockholders' equity and total number of all employees), serve as input variables and revenue and profits from the operations serve as outputs in stage 1 and as inputs in stage 2. As the outputs in the stage 2 four indicators were used (earnings per share, average stock price, return on invested capital, net income). In addition to DEA models, econometric models, i.e. stochastic frontier production function models, were used to analyse the efficiency of breweries (Solomon, 2018).

Czech breweries were the subject of research by Kasem et al., who determined the efficiency of 14 breweries using indicators from the Global Reporting Initiative and Key Performance Indicators. Environmental, financial and sustainability report data sets were used in DEA models. The analysis was based on 4 inputs (number of employees, average employees' salary and bonus, amount of waste, percentage of women in supervising the company) and 2 outputs (cash flow, economic valued added EVA). Kasem and Trenz (2020) proposed three-phase system covering DEA models for both enterprise efficiency and sustainability value added calculation for sustainability assessment of 89 Czech brewery companies. The first phase was aimed at the data collection and SVA (Sustainability Value Added) calculation based on environmental, social and governance value added concepts. The second phase consists of DEA analysis and the sustainability assessment model. In the third phase, aimed to automate all the possible processes involved in the first two phases, the authors used the web portal Web Information System for Corporate Performance Evaluation and Sustainability Reporting – WEBRIS – for data extraction. Finally, the analysis based on questionnaires and data of 89 Czech breweries was carried out.

3 Data

To analyse the efficiency of Czech breweries, we chose a period of five years (2016-2020) in which there was both an increase and a decrease in beer production (see Figure 1), as well as an increase and a decrease in average per capita beer consumption (Figure 2). For the evaluation of the economic efficiency of breweries that operated (according to the classification of economic activities NACE) in the section 11-Manufacturing of bewerages, 1105-Manufacture of beer, data from the Albertina CZ Gold Edition database was used. After analyzing these data and based on similarly focused research, we included personnel costs, foreign resources, and equity as inputs, and profit/loss for the accounting period and sales of goods, products, and services as outputs to the DEA models. After removing the companies for which not all data were available, around 100 beer producers remained within each of the years under review (except for 2020, where only 77 remained – see Table 1). This is therefore approximately 15-25% of the Czech breweries operating in a given year. The main characteristics of the data set is in Table 1.

		Year	**2016**	**2017**	**2018**	**2019**	**2020**
	Number of companies		101	93	102	98	77
CZK thousands	**I1: personnel costs**	**avg.**	39038	38467	41304	46008	56876
		min.	70	56	80	20	25
		max.	1623000	1344000	1748000	1892000	1929000
	I2: foreign resources	**avg.**	304623	326109	261662	166187	260467
		min.	32	108	70	66	6
		max.	14237000	14216000	13429000	8001000	11934000
	I3: equity	**avg.**	297895	300967	266517	386812	442874
		min.	-54952	-24012	-17957	-19338	-19499
		max.	13444000	13309000	10462000	21200000	22007000
	O1: profit/loss	**avg.**	30327	36305	25378	63971	67747
		min.	-1673000	-135000	-2848000	-49494	-30409
		max.	3867000	2619000	4456000	4769000	3826000
	O2: sales	**avg.**	310107	290386	317100	341052	391975
		min.	260	298	128	642	270
		max.	14890000	12193000	16517000	17245000	15867000

Table 2 Data about breweries – main characteristics

4 Results

According to the previous description we conducted two analyses based on DEA CCR input-oriented models (CCR-I) and BCC input-oriented models (BCC-I) with 3 inputs and 2 outputs. The calculations were performed in Frontier Analyst, each year was evaluated separately. Table 3 describes the average efficiencies in all years for both type of models. Due to the nature of the models, it is common for BCC to have more efficient units than CCR. Since the efficiency scores take values from 0 to 1, we divided this interval into 5 segments of 0.2 and found the proportion of breweries in each year located in these intervals (see Figure 3). It is clear that the proportion of breweries with an efficiency greater than 0.8 exceeds 20% (except in 2019, when it is only 13%). We also determined the proportion of efficient breweries in each year (as the number of efficient breweries in a given year divided by the number of analyzed breweries) - see Table 4. Even here it is noticeable that this percentage has decreased in 2019.

year	2016	2017	2018	2019	2020
avg. CCR-I	0.543	0.571	0.574	0.417	0.516
avg.BCC-I	0.663	0.667	0.698	0.664	0.668

Table 3 Average efficiency of the DEA models results

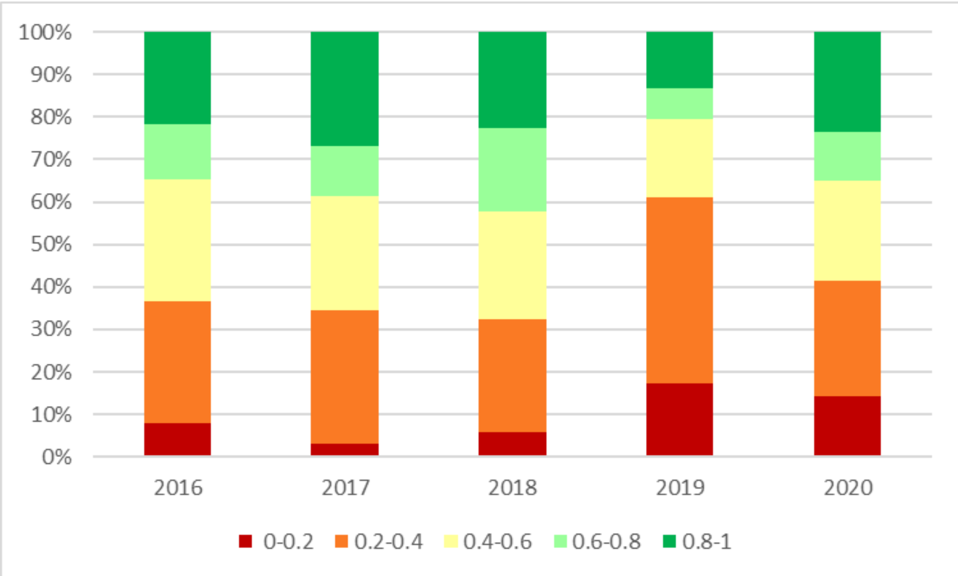

Figure 3 CCR-I results comparison – percentage of breweries with the given efficiency score

year	2016	2017	2018	2019	2020
CCR-I	16 %	14 %	13 %	11 %	16 %
BCC-I	28 %	28 %	32 %	27 %	31 %

Table 4 Percentage of efficient breweries in given year

With the exception of 2019, the results are therefore relatively stable in all years under review, and the impact of the constraints imposed by the COVID-19 pandemic is only visible in a decline in production, not in a significant change in efficiency. If we relate the observed average efficiency to the efficiency of the whole brewing sector in the Czech Republic, then it can be concluded that it is, for example, significantly higher compared to the accommodation and food service activities' sector (Kuncová et al., 2022). The year 2019 is noticeably different. It is the year with the highest beer production in the Czech Republic, at the same time, the highest number of breweries operated in the Czech Republic in this year and from the perspective of the monitored years, it had the second highest average beer consumption per capita and the highest export of beer with 5.3 million hectolitres of beer exported. Explaining all the reasons for this difference is beyond the scope of this paper, but the data suggest that more new firms entered the market in a given year, probably in anticipation of rising beer sales in the following years. These new breweries may then have caused lower efficiency compared to previous years. However, in 2020, due to the impact of the pandemic, there was no increase in sales and some breweries closed down. Thus, the average efficiency measured by the CCR-I model rose again. This situation may be also explained by The Law of Diminishing Returns (see more in Shephard and Färe, 1974). Tewari and Singh (2003, p. 96) define The Law of Diminishing Return as: ..when successive equal units of variable resource/input are added to a given quantity of fixed resources to produce a commodity, there will come a level of input beyond which the addition to total output of the commodity will start declining." Thus, in 2019, the firms analysed may have begun to enforce this law of diminishing returns.

The results show that the dynamics in this sector are big. Only one brewery was assessed as efficient in all the years under review by both models (CCR-I, BCC-I) - the largest Czech brewery Plzeňský Prazdroj in Pilsen. Two small breweries Gwern and Mandala CZ were among the most efficient in 4 years and both models. Zámecký pivovar Dětenice (Dětenice Castle Brewery) was rated as BCC-I efficient in 4 years (except 2019) and CCR-I efficient in 3 years. Similarly, Beskydský pivovárek was assessed as BCC-I efficient in 2017-2020, but only in 2017 and 2020 was it also CCR-I efficient. Finally, let's mention four breweries that were rated BCC-I efficient in all five years, but did not achieve CCR-I efficiency in any year. These breweries were: Budějovický Budvar (Budweiser Budvar), Chodovar, Heineken Czech Republic and Pivovar Nymburk (Nymburk Brewery). These results show that the size of the brewery does not play a big role in the efficiency evaluation.

5 Conclusions

The purpose of this paper was to measure the efficiency of Czech breweries in the period of 2016 to 2020 based on DEA CCR input-oriented models (CCR-I) and BCC input-oriented models (BCC-I) with 3 inputs and 2 outputs. The percentage of firms in all five segments is similar in all years analysed, except for 2019. In 2019, we uncovered a higher percentage of firms (compared to other years) that achieved efficiency scores below 0.2 and 0.4. On the other hand, a lower percentage of firms had efficiency scores higher than 0.6 and 0.8. In 2019, beer production in the Czech Republic reached its peak for the period from 2008 to 2021. The different efficiency score results in 2019 probably have multiple causes. One of them may be that more new firms entered the market in a given year, probably in anticipation of increasing beer sales in the following years. These new breweries could then cause lower efficiency compared to previous years. Another explanation can be found by The Law of Diminishing Returns. Of all the breweries evaluated (for which we had data in all years) only one was evaluated as efficient in all years for both models (CCR-I, BCC-I) - Plzeňský Prazdroj in Pilsen.

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Bankruptcy Prediction Using Neural Networks: The Case of Slovak Engineering and Automotive Industries

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Abstract. Prediction of company bankruptcy represents a relevant role in business management. In practice, companies should use only prediction models suitable for the conditions of the given country. This paper aims to create bankruptcy prediction models that can be used in Slovak businesses of engineering and automotive industries. Considering the growing influence of technologies, we use artificial neural networks (ANN-MLP) with back-propagation (BP) type of learning and feed-forwarded (FF) connections. We tested 54 prediction models on a sample of 2,210 enterprises from 2020, and 2,528 enterprises from 2021, while we used seven financial indicators that represent profitability, activity, indebtedness, and liquidity. All models achieved high accuracy. Results present the prediction parameters of the most optimal model in 2020 and 2021.

Keywords: bankruptcy prediction, artificial neural network, engineering industry, automotive industry, Slovakia.

JEL Classification: C45, C53, G33, L62, L69

1 Introduction

In the management of enterprises, the key task is to know the financial and economic situation and to react in time to the impending danger. An early warning system of impending bankruptcy can help management take measures to avert it. Various simple models, more complex statistical functions and, in recent decades, artificial intelligence have long been used to predict bankruptcy.

The existing models are created using a sample of data from different countries. Unfortunately, it is not possible to apply them in the Slovak conditions because they are designed for specific conditions of a given economy and period. Therefore, this paper aims to create bankruptcy prediction models that can be used in Slovak businesses of engineering and automotive industries.

One of the frequently used and successful techniques is an artificial neural network (ANN). Such a network has a non-linear characteristic and does not require normality or independence of the input variables (Jencova et al, 2020). Therefore, in this paper, bankruptcy prediction is performed based on an ANN.

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2 Literature review

In an increasingly dynamic and complex world, ensuring a business's financial stability and sustainability has become increasingly difficult. To measure firms' economic sustainability in this turbulent world, researchers need to connect traditional and modern metrics and create multidimensional models (Kral et al, 2018). In the beginning, scoring models included simple models. One of them is a univariate discriminant analysis applied by Beaver (1966). Altman (1968) used linear discriminant analysis based on five financial indicators. The next stage consisted of logistic regression (Ohlson, 1980) and probit statistical methods (Zmijewski, 1984). As current recent studies state (Tseng and Lin, 2005; Kitowski, 2022), the use of logistic regression for prediction is still frequently used. Youn and Gu (2010) and Peat and Jones (2012) compared logistic regression with neural networks.

With the gradual development of technologies, other methods based on artificial intelligence are coming. The ANN model is a simplified principle imitating the neural structure of the brain, whose learning consists in gaining experience. This schema can store information in the form of patterns. The basic unit of this network is an artificial neuron. The basic principle of a neuron is to receive input signals, combine them, perform a non-linear operation (activation function) and then produce an output signal. Neurons (nodes) that receive signals from the external environment are designated as input, those that produce output from the network as output, and all others form hidden nodes. By appropriately organizing the same nodes, layers (input, hidden, output) can be created, and they will form a network by interconnecting them. The network consists of one input layer, one output layer, and a certain number of hidden layers (possibly none) (Grumstrup et al, 2021; Sahoo and Pradhan, 2021).

A suitable type of structure for prediction is a multilayer perceptron (MLP). According to Karayiannis and Venetsanopoulos (1993), network involvement can be divided into three basic groups: FF–Feed-Forward (linear, non-linear), FB–Feed-Back (Boltzmann machine), SO–Self-Organizing. FF are layers connected without feedback, i.e., the information gradually passes through the individual layers only from the input to the output and does not get back. Conversely, FB also uses feedback (Kabir, 2021).

Based on publicly available information, FinStat (2022) evaluates the financial health of Slovak companies using its credit model for assessing the bankruptcy risk in the next accounting period, i.e., the FinStat score (accuracy 83%). The model includes total indebtedness, equity ratio, financial accounts to assets ratio, return on assets, and debt repayment period to sales. The value of the FinStat score ranges from 0% to 100%. The higher the value, the greater the bankruptcy risk of the company. If the value of the FinStat score is lower than 30%, the company is financially stable. A score higher than 70% indicates the company faces a high probability of bankruptcy. There is a grey zone between these limit values. In the accounting year 2021, 8% of companies (from 245,000) show a high probability of bankruptcy. Almost 64% of trading companies can be considered financially stable. 28% of companies are in the grey zone. Most of the financially stable companies are in public administration (88%), information technology (80%), healthcare (77%), design and engineering (76%), but also in education and training (75%). On the other hand, companies from the tourism sector and gastronomy (20%), food industry (13%), public administration (13%), retail (12%), and sale and maintenance of vehicles (10%) have high a probability of bankruptcy. 50% of companies from the automotive industry are in the grey zone. On the contrary, no company from the public administration is in the grey zone (Hrncarova, 2023). Compared to the FinStat score, we used a more modern and more accurate method based on artificial intelligence (artificial neural network) for bankruptcy prediction. The authors found the use of *ANN*-based prediction procedures to be better owing to their nonlinearity and ability to recognise complex relationships between indicators. Although classical prediction models are still used and justified, the estimate made by the artificial intelligence model may act as an indication of high potential risk; and thus initiate a more detailed analysis to confirm the adequacy of the suspicion of financial and economic problems.

3 Research methodology

This paper aims to create bankruptcy prediction models that can be used in Slovak businesses of engineering and automotive industries. The research sample consists of a set of 2,210 (in 2020) and 2,528 (in 2021) non-financial corporations in the Slovak engineering (European classification of Economic Activities – NACE Division 28, 30, and 33) and automotive industries (NACE Division 29). Specifically, the sample consists of 2,189 (in 2020) and 2,210 (in 2021) non-financial corporations from the engineering industry; and 339 (in 2020) and 328 (in 2021) non-financial corporations from the automotive industry.

We use the ANN to perform bankruptcy prediction of companies from two industries in Slovakia. The type of network was selected as MLP with feedforward connections only and backpropagation for learning. Due to the limited scope of the paper, we do not provide a detailed description of the method. For more information, see, e.g., Pozorska and Scherer (2018), Ptak-Chmielewska (2019), Gavurova et al (2022).

We used IBM SPSS Statistics, which includes neural networks (MLP) needed for our prediction issue. For the calculation, we used the financial ratios of non-financial corporations in the engineering and automotive industries. Financial ratios were calculated based on absolute indicators from the financial statements of non-financial corporations available from the Register of Financial Statements of the Slovak Republic. The choice of financial indicators is crucial for the results; therefore, we followed the literature on corporate failure prediction. During the search for the optimal model based on company data for 2020 and 2021, we considered all types of indicators. The stepwise method was used to construct neural network models.

We have chosen the following seven financial indicators as inputs for the ANN prediction model:

- x_1 – Return on Sales (*ROS*) = Earnings before interest and taxes (EBIT) / Sales
- x_2 – Total Indebtedness (*TI*) = Total Debt / Total Assets
- x_3 – Financial Leverage (*FL*) = Total Assets / Equity
- x_4 – Current Ratio (*CR*) = Current Assets / Current Liabilities
- x_5 – Return on Assets (*ROA*) = EBIT / Total Assets
- x_6 – Turnover of Assets (*TA*) = Sales / Total Assets
- x_7 – Net Working Capital to Assets ratio (*NWC/A*)

The dataset was split into several subsets (engineering industry without automotive, automotive industry, and both together), and each was used with scaling technique standardization. Standardization means eliminating the dependence on units and position parameters. It re-scales data to obtain a mean of 0 with a standard deviation of 1; and it is not impacted by outliers because the range of transformation is not defined.

The datasets for training and testing samples were divided with ratios of 80:20, 70:30, and 60:40. The transfer and activation functions were set to sigmoid. Extreme values in each subset were removed using the interquartile method. The adjusted database for 2020 consisted of 206 and 1,243 companies from the automotive and engineering industries. For 2021 it was 180 and 1,293 companies from the automotive and engineering industries.

The neural networks were assembled with one hidden layer (three, eight, or fifteen hidden nodes). The output of the neural network provided information on business bankruptcy (1) or not (0). We created 27 models for each year (i.e., 54 models in total).

4 Results and Discussion

We use the indicators of profitability (*ROS* and *ROA*), activity (*TA*), indebtedness (*TI* and *FL*), and liquidity (*CR* and *NWC/A*) to create an optimal neural network for 2020 and 2021. We constructed an optimal neural network for the automotive and engineering industries with these seven financial indicators on the input layer in combination with one hidden layer. This hidden layer has three, eight, and fifteen neurons.

Results show that each of the created models has a high predictive ability. The resulting accuracy for the training set of samples varied slightly between models (and was more than 99%). Furthermore, the number of hidden nodes had no significant effect on the result (the best average result was for eight nodes). When comparing the ratios of test and training samples (60:40, 70:30, 80:20), 70:30 appears to be the most optimal, although the differences are also very small. Table 1 shows the results of the prediction of the optimal models (8 hidden nodes, ratio 70:30). High accuracy can be achieved thanks to detailed pre-processing of the samples and a relatively short period of prediction (in the case of prediction several years in advance, the accuracy is significantly reduced).

Sample		**Automotive**			**Engineering**			**Both**		
		predicted			**predicted**			**predicted**		
		0	**1**	**Correct (%)**	**0**	**1**	**Correct (%)**	**0**	**1**	**Correct (%)**
2020										
Training	0	132	0	100.00	823	0	100.00	958	0	100.00
	1	0	9	100.00	0	40	100.00	2	55	96.49
	Overall (%)	93.62	6.38	100.00	95.37	4.63	100.00	94.58	5.42	99.80
Testing	0	57	0	100.00	355	0	100.00	409	0	100.00
	1	0	8	100.00	0	25	100.00	0	25	100.00
	Overall (%)	87.69	12.31	**100.00**	93.42	6.58	**100.00**	94.24	5.76	**100.00**
2021										
Training	0	126	0	100.00	872	0	100.00	973	0	100.00
	1	0	7	100.00	1	42	97.67	1	49	98.00
	Overall (%)	94.74	5.26	100.00	95.41	4.59	99.89	95.21	4.79	99.90

Testing	0	42	0	100.00	353	0	100.00	420	0	100.00
	1	0	5	100.00	0	25	100.00	0	30	100.00
	Overall (%)	89.36	10.64	**100.00**	93.39	6.61	**100.00**	93.33	6.67	**100.00**

Table 1 Prediction results (8 nodes, 70:30)

Table 2 shows the prediction parameters for 2021 for the overall industry (automotive and engineering together).

Parameter Estimates (2021, 8, 70:30)											
		Predicted									
		Hidden layer								Output layer	
	Predictor	H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	H(1:8)	[bankruptcy=0]	[bankruptcy=1]
Input layer	(Bias)	1.716	1.486	1.810	-0.201	1.095	1.273	1.344	1.530		
	ROS	-0.280	0.188	0.106	0.180	0.342	0.168	-0.298	-0.045		
	TI	-1.476	-1.098	-1.196	1.030	-0.879	-1.256	-1.045	-1.029		
	FL	1.329	1.456	1.502	-1.018	1.171	1.175	1.103	1.052		
	CR	0.107	0.045	-0.536	-0.136	0.051	-0.531	-0.096	0.051		
	ROA	0.164	-0.204	0.066	0.238	0.086	-0.032	0.413	0.272		
	TA	0.195	-0.058	0.092	0.310	0.236	-0.126	-0.037	-0.060		
	NWC/A	-0.152	-0.079	0.270	0.006	0.208	0.344	0.332	0.308		
Hidden layer	(Bias)									-3.199	3.401
	H(1:1)									2.508	-2.837
	H(1:2)									2.401	-2.454
	H(1:3)									3.016	-2.409
	H(1:4)									-3.158	2.954
	H(1:5)									1.731	-2.135
	H(1:6)									1.802	-2.165
	H(1:7)									2.047	-2.250
	H(1:8)									2.444	-1.890

Table 2 Prediction parameters of the model for 2021

Considering prediction parameters, *FL* and *TI* have the highest weights. These financial indicators have the highest informative value. The importance of using seven indicators in ANN follows from previous studies on company's financial aspects. First, the indebtedness indicators were represented by *FL* (see Purvinis, Virbickaite and Sukys, 2008; Kim and Kang, 2010), and *TI* (see Purvinis, Sukys and Virbickaite, 2007; Purvinis, Virbickaite and Sukys, 2008; Nyitrou and Virag, 2019). Second, *TA* represents activity indicators (see Purvinis, Virbickaite and Sukys, 2008; Kim and Kang, 2010; Nyitrou and Virag, 2019). *CR* and *NWC/A* belong to the liquidity indicators (Merkevicius, Gasva and Girdzijauskas, 2006; Kim and Kang, 2010). Finally, *ROA* and *ROS* are profitability indicators (Purvinis, Sukys and Virbickaite, 2007; Nyitrou and Virag, 2019).

5 Conclusion

In this paper, we constructed an optimal neural network for the automotive and engineering industries with seven financial indicators on the input layer in combination with one hidden layer (three, eight, and fifteen nodes). All networks were highly successful. We analyzed several combinations based on the belonging to the industries, and ratio of the sample distribution of the testing and training parts. Furthermore, models showed that the number of hidden nodes had no significant effect on the result. When comparing the ratios of test and training samples, 70:30 appears to be the most optimal, although the differences are also very small.

This study had several limitations. First, we analyzed only two years period and two industries. Repeating the analysis for an extended period can reveal more insight. Researchers can also use the regional segmentation of companies and other qualitative data. Second, we did not consider the heterogeneity of effects across firm sizes. Future research can divide the sample into small, medium, and large enterprises; and explore the differences among the results. Moreover, in addition to our method (ANN), we suggest using data enveloped analysis or panel regressions. Financial analysts should simultaneously use multiple methods to compare the results.

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Predicting Clearing Date of Account Receivables with Focus on Total Amount Paid

Jan Manďák[1], Markéta Šindlerová[2]

Abstract. The ability to predict the inflow and outflow of the money is crucial for many companies across various industries. Because each company has at least some control to choose when it will pay the debts (account payables), the tougher part is to predict the customer's behavior, so to predict when the company will receive the money due (account receivables). This study used 40,000 account receivables from year 2019 to train a Random Forest Regression model and 6,000 invoices from year 2020 to test the performance of the model. Sample weight parameter and also custom scoring function were tested to emphasize invoices based on the amount due. The best model with sample weight parameter was able to predict clearing date with mean absolute error of 3 days. The predictions were also aggregated to get weekly sums of amounts predicted to receive and amounts actually received. With the average percentage difference being 5.5 % it was proven that machine learning is able to accurately support financial experts managing cash flow.

Keywords: Account Receivables, Clearing Date, Random Forest Regression, Sample weights.

JEL Classification: M21, C88, C45

1 Introduction

Before we proceed to the description of account receivables management, it is necessary to start with cash flow. **Cash flow** in one of the indicators of a company's financial performance. It measures the money inflow to the company and money outflow from the company. Example of cash inflow can be receiving a payment for a goods/service from the customer, example of cash outflow can be payment for a goods/service to the supplier (Tracy & Tracy, 2012). It is important indicator for assessing of financial health of a company, which should be taken into account together with e.g. profit (revenues – expenses). If a company has profit, but struggles to receive money from their customers in time, then it doesn't have money to pay expenses and is not not financially healthy.

Then comes into the play two processes: **Order-to-Cash** and **Invoice-to-Cash**. As we can see from the Fig. 1, the whole Order-to-Cash proccess starts with checking of customer's credit, which is further followed by receiving, processing and fulfilling order (Wright). The **management of account receivables** is a sub-process of the Order-to-Cash process and can be defined also as an Invoice-to-Cash process. This process starts with sending invoice to customer and ends with incoming payment from customer.

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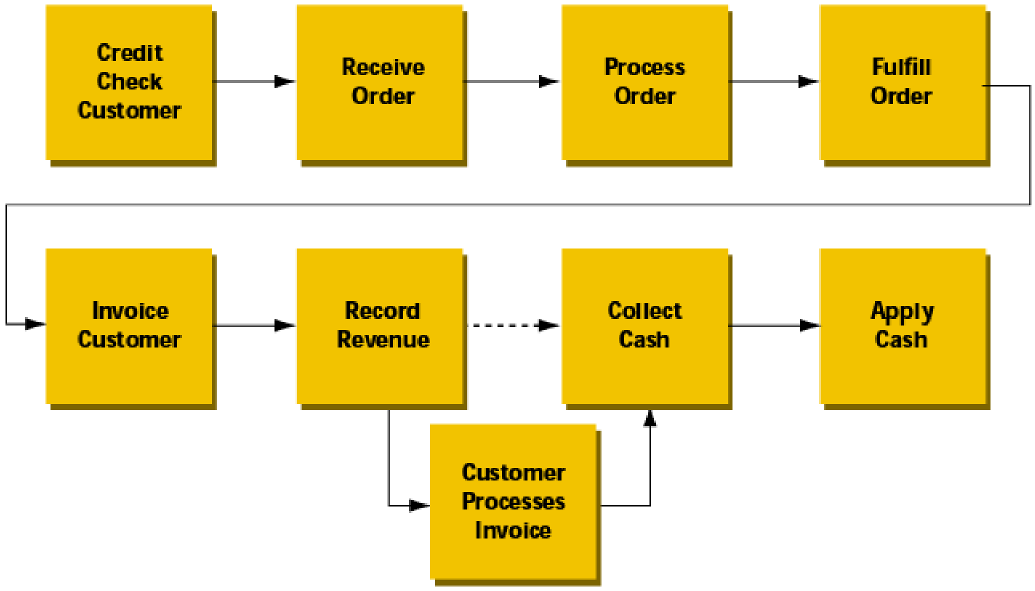

Figure 1 Order-to-Cash process (Wright)

We also shouldn't forget to define **account receivables**. It is the amount of money due to the company for goods or services delivered to customers but not yet paid by them (Hayes, 2022). A company gives to customers some time to pay for the goods and services already provided. This time is called **payment term** and is simply the number of days after the invoice was provided to pay the amount due. Usually this due date is 30, 45 or 60 days and this due date is the latest possible date of payment. It is no surprise and we will see it also in our dataset that the due date is the most frequent date of invoice payment. An **overdue** (**late**) invoice is an invoice paid after the due date, invoice paid **in advance** is an invoice paid before the agreed due date (Jones, 2018).

So far there were not much studies conducted to use machine learning for prediction of clearing date of account receivables, probably mostly due to the fact that this data are very sensitive and companies don't want to share it. There were studies, which classified invoice as on-time or delayed and were therefore focused on binary classification. Appel et al. (2020) presented a prototype for support of collections process in a multinational bank and reached up accuracy up to 81 %. They also proposed to multiply the probability of being late by amount of dollars due to prioritize invoices with higher value. Peiguang (2015) compared unsupervised and supervised machine learning methods to predict whether an invoice will be on-time or delayed (binary classification), and also used multi-class classification to predict 4 classes: on-time, within 30 days, between 30 and 90 days and more than 90 days. The best performing algorithm in their case was Random Forest for the two-classes with accuracy 81.6 %. In the multi-class case they noticed lower accuracy because of the class imbalance. Another study dealing with multi-class classification is a study of Zeng et al. (2008). They used C4.5 classification algorithm to predict if an invoice will be paid on-time, 1-30, 31-60, 61-90 or more than 90 days late. They achieved accuracy more than 77 %. We should also mention that SkywalkerHub (2021) predicts the delay in payment in days, so uses regression approach, but there are no performance metrics calculated and showed so we won't use this paper for comparison with our results.

This study tries to broaden the existing body of knowledge in the problem field of account receivables prediction by several aspects. The first one is that instead of classification it uses regression methods to predict exact number of days an invoice will be paid sooner or later in comparison to due date. Another one is that training of a machine learning model is done by minimizing custom metric which assigns more weights to the observations in the training data set with higher amount due. Because for the business users it is not so useful to know if an individual invoice will be paid in time or late, we also proposed an aggregation method to compare actual amount paid by customers in a given week of the year and the predicted amount.

2 Description of the input data

The data for this study are available for free download at SkywalkerHub (2021). The data are available for the whole year 2019 and for the first half of year 2020. Therefore authors decided to use data from 2019 to train machine learning models and leave data from 2020 to calculate performance metrics. For the model training there were 40,485 observations, for the model testing 6068 observations.

There are two types of features served to machine learning model, the original input variables already present in the dataset and engineered features. The original variables are described in the Table 1.

Variable	Description
business code	company code of the account
total open amount	amount due by the customer
invoice currency	the currency of the invoice amount in the document for the invoice
customer payment terms	business terms and agreements between customers and accounts on discounts and days of payment
due date	the date on which the customer is expected to clear an invoice
clear date	the date on which the customer clears an invoice, or in simple terms, they make the full payment
target	difference between clear date and due date in days

Table 1 Original input variables

Histogram in the Fig. 2 shows number of invoices according to the various values of target variable. As it was already stated in the introduction part, the majority of invoices are paid just on the same day when they are due. There is also a substantial amount of invoices paid 1-5 days ahead, it can be associated with some discounts provided to customers when payment is done early. There are also a lot of invoices paid after the due date, but almost all of them are cleared within one week after due date.

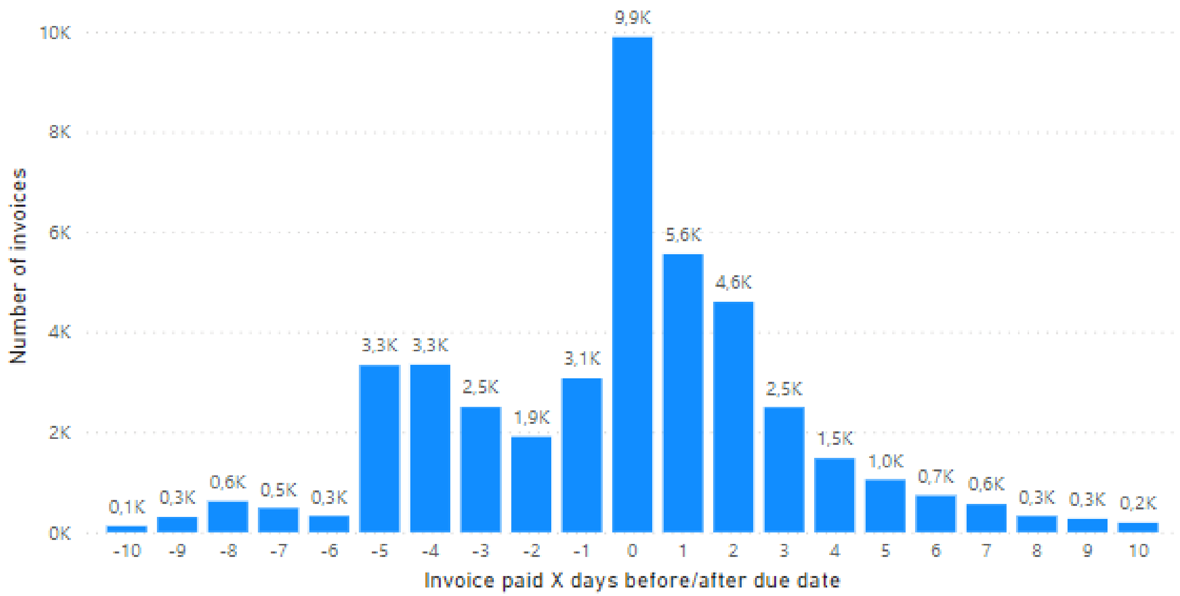

Figure 2 Histogram of invoices paid in time or late

The second part of input variables are the so called engineered variables, all of them are calculated with a purpose to capture customer behavior. These features are listed in the Table 2. It is evident that these variables are calculated from the historical invoices and for new customers with just a small amount of invoices the values won't be as reliable as for stable customers with many invoices. Relationship between total number of invoices and prediction error will be examined in the section Results.

Variable	Description
total late payments	total number of invoices paid late
total payments	total number of invoices
ratio late	percentage of invoices paid late
amount paid late	sum of the amounts of invoices paid late
amount paid in time	sum of the amounts of invoices paid in time
mean target	average number of days invoice was cleared prior/after the due date
last target	days prior/late to the due date of the latest invoice cleared

Table 2 Customer behavior variables

3 Regression Analysis

Because the dependent variable is of continuous nature, regression analysis will be used. The focus should be more on the invoices where the total open amount is high, therefore possibilities of assigning weight to these invoices will be tested. Three scenarios were compared:

1) Initial model without sample weights and custom metric.
2) Model with sample weights.
3) Model with custom metric.

As the goal of the study is not to provide a comprehensive comparison of performance of various machine learning models, but rather to test the introduction of weights applied to each observation in the training data set, there is just one state-of-the-art machine learning model selected for regression analysis – random forest regressor. The RandomForestRegressor estimator from the Scikit-learn Python package is used. The algorithm behind RandomForestRegressor is the following: a defined number of decision trees is estimated on various sub-samples of the train dataset, then the results are subsequently averaged to prevent over-fitting (Pedregosa et. al., 2011).

The base estimated model was fitted with the use of GridSearchCV Scikit-learn method to find optimal hyperparameters across 5 folds with scoring metric to optimize *neg_mean_absolute_error*. The optimized hyperparameters were *n_estimators* (the number of trees in the forest) and *max_depth* (the maximum depth of the tree, number of edges from the root node to the lowest target node). The Scikit-learn API (Pedregosa et. al., 2011) provides user-friendly function to easily accomplish it:

```
# Import of necessary classes
from sklearn.model_selection import GridSearchCV
from sklearn.ensemble import RandomForestRegressor

# Define model and hyperparameter grid
model = RandomForestRegressor()
param_grid = {'n_estimators': [10, 50, 100], 'max_depth': [None, 5, 10]}

# Create grid search object
grid_search = GridSearchCV(model, param_grid, scoring='neg_mean_absolute_error', cv=5)

# Fit grid search
grid_search.fit(X_train, y_train.values)
```

To emphasize invoices with higher amounts in the learning process of the algorithm, two scenarios were tested. The first one is usage of sample_weight parameter within the fit method of the RandomForestRegressor class, as it can be seen in the chunk of code below. The values of hyper parameters *max_depth* = 10 and *n_estimators* = 100 were used from the previous GridSearchCV function.

```
# Sample weight parameter in model fitting
clf = RandomForestRegressor(max_depth = 10, n_estimators= 100)
RF_weights = clf.fit(X_train, y_train.values, sample_weight=X_train['Amount_EUR'])
```

The second one is usage of custom scorer defined in scikit-learn and optimizing the learning process based on this custom scorer. It is necessary first to define function which is then provided to custom scorer:

```
# Define custom function to calculate weighted mean absolute error
def WMAE(y_true, y_pred, sample_weight):
    loss = 0
    for i in range(len(y_true)):
        loss += sample_weight[i] * abs(y_true[i] - y_pred[i])
    return loss / sum(sample_weight)

# Creation of a custom scorer
from sklearn.metrics import make_scorer
sample_weight = X_train['Amount_EUR'].values
scorer = make_scorer(WMAE, greater_is_better=False, sample_weight=sample_weight)
```

Two classical performance metrics were used to assess the quality of the machine learning models - mean absolute error (MAE) and root mean squared error (RMSE). MAE calculates average absolute difference between actual and predicted values and is defined as follows (1):

$$MAE = \frac{\sum_{i=1}^{n} | y_i - \hat{y_i}|}{n}, \tag{1}$$

where y_i is the actual value and $\hat{y}_i$ represents the predicted value (James et. al, 2013). Root mean squared error is the square root of the average squared difference of actual and predicted values. RMSE is calculated as (2)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y_i})^2}{n}}. \tag{2}$$

Third performance metric is called weighted mean absolute error (WMAE) and is an enhanced version of MAE, where the weights are equal to the min-max scaled total amount of the invoices. WMAE is defined as (3):

$$WMAE = \frac{1}{\sum w_i} \sum_{i=1}^{n} w_i \, |y_i - \hat{y_i}|, \tag{3}$$

where w_i corresponds to the weights, which are in our case total amounts of invoices.

Another metric which was compared is the metric most important for the business users. It is average weekly percentage difference between amounts predicted to be received in a given week and amounts actually received in a given week (AWPE). The whole aggregation process is as follows:

For each payment in the test data set:

1) predict target,
2) add predicted target (in days) to the due date → predicted clearing date,
3) calculate sum of the amounts for the actual and predicted clearing date,
4) aggregate to weekly sums,
5) compare the weekly sums of amounts.

4 Results

Comparison of the performance metrics of three selected approaches is visible in the Tab. 3. According to RMSE, MAE and also WMAE, the best performing model is the model with sample weights. The difference compared to the base model and model trained using custom metric is clear. Interestingly the model trained to optimize WMAE is the worst even for the metric it was trained to. On the other hand the differences in RMSE, MAE and WMAE seems to be eventually flattened for the AWPE metric, the best model is the base model with value 5.46 %, the second one is the model with sample weights parameter with value 5.51 % and the third one is model with custom metric (5.61 %). These three approaches are also compared with a naïve approach where the prediction is equal to the mean delay in payment from the whole training data set. This approach is obviously the worst one.

Model	**RMSE**	**MAE**	**WMAE**	**AWPE**
Mean value	12.687	5.857	4.765	0.1130
Base	8.416	3.515	2.833	0.0546
Sample weights	7.842	3.044	2.442	0.0551
Custom metric	8.444	3.517	2.831	0.0561

Table 3 Performance results comparison

As it was mentioned in the data description part, the relationship between prediction error and total number of payments for a given customer needs to be examined. We assumed that the predictions will be more accurate for the customers with higher number of total payments. This hypothesis is not confirmed, because the correlation coefficient between total payments and the prediction error is close to zero and equal 0.015. Also scatter plot in the Fig. 3 does not imply any dependency of prediction error on total payments.

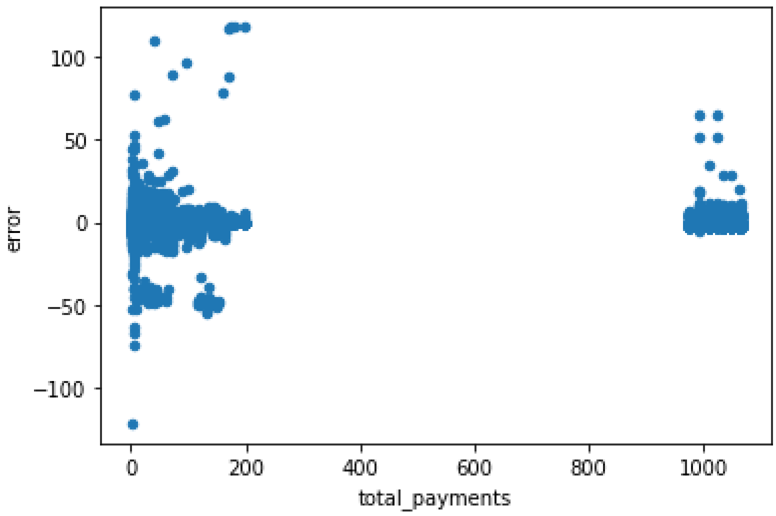

Figure 3 Relationship between total payments and prediction error

Besides of the overall comparison on the whole testing data set, it is important to provide also comparison of results based on weekly basis. This type of comparison is interesting for the business users, who don't care much about individual predictions. As we can see from the Fig. 4 with first 10 weeks of the year 2020, the predicted amounts are quite close to the reality.

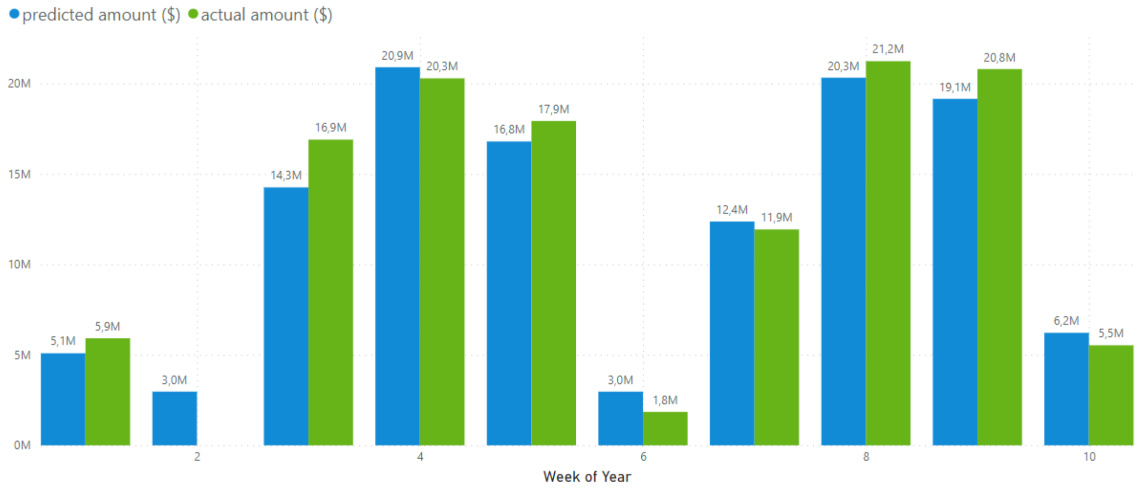

Figure 4 Comparison of predicted and actual amounts

After estimation of any machine learning model it is important to look also at feature importance to see variables with the biggest role in the prediction. Gini importance and permutation feature importance were used for this purpose. The in-built feature importance of RandomForestRegressor is Gini importance, where the importance of a feature is computed as the (normalized) total reduction of the criterion brought by that feature (Pedregosa et. al, 2011). In permutation feature importance algorithm (Breiman, 2001) each column is randomly shuffled and difference in predictive score between original model and model with corrupted data is computed.

For all three models these charts look very similar, so only feature importance for the best model with sample weight is shown. According to Gini importance, there are two variables playing the biggest role – mean target, so average value of all historical differences between clearing date and due date for a given customer, and last target, the difference between clearing date and due date for the last receivable. The major influencer is again mean target by the permutation feature importance, but there are also other important variables – customer payment terms, ratio of invoices paid late and total number of payments, see Fig. 5.

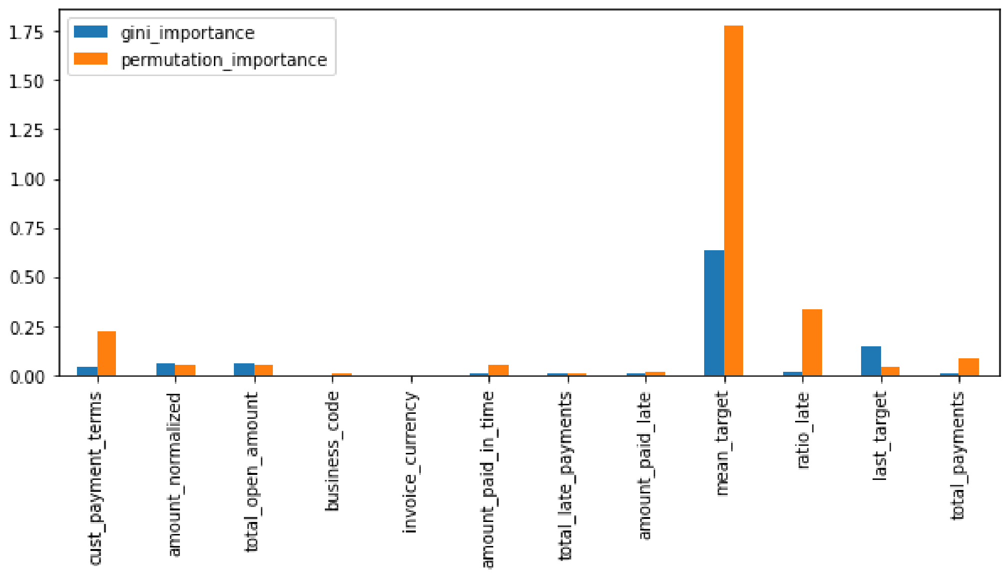

Figure 5 Gini and permutation feature importance

If we are to compare these results with the results of similar studies, e.g. Appel et al. (2020), Peiguang (2015) or Zeng et al. (2008), it would be very difficult, because they all used either binary or multi-class classification models, whereas in this paper regression analysis was utilized. It always depends on the business case behind such analysis, but it is evident that classification models cannot provide such detailed results, which can be immediately started to be used in cash-flow management.

5 Conclusion

This study has proven that it is possible and beneficial to use machine learning for prediction of clearing date of account receivables. Regression analysis, specifically random forest regression algorithm, seems to provide highly accurate prediction of clearing dates. For the best model with sample weights the MAE was equal 3, what means on average the model predicted clearing dates with 3 days deviation from the actual clearing date. We have shown that also inclusion of sample weight parameter had a positive effect on WMAE, metric which reflects also amounts being due by the customers. Also the weekly predicted received amounts are very close to the real ones, making this model a useful support tool for finance practitioners.

It is clear that there is always some space to make the model work better. In our case several possibilities could be tested, e.g. the input data to the model could be first prepared on a weekly basis and then a machine learning model could be trained to optimize average weekly percentage error. It was visible in our case when the best model with sample weights was the best according to MAE, RMSE and also WMAE, but the AWPE, average weekly percentage error was despite this fact the lowest for the base model without any weights. There is also a possibility to engineer more explanatory variables and give the model possibility to learn more patterns from the data and last but not least there are many more machine learning models that could be tried.

Acknowledgements

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Several Recommendations for Optimizing the Size of the Power BI Datasets

Vítězslav Novák [1]

Abstract. Power BI is a business intelligence cloud analytics service from Microsoft. It aims to provide interactive visualizations and business intelligence features with an interface simple enough for end users for creating their own reports and dashboards. These reports are published to the Power BI Service, but the dataset size must not exceed 1 GB, this applies to Free and Pro licenses. Although dataset data is highly compressed, there is a risk of exceeding the allowed dataset size. In such a case, it is necessary to proceed with further optimization of the data model. This article should show a few selected options for optimizing the Power BI data model, which should result in a reduction of the dataset size.

Keywords: Microsoft Power BI, VertiPaq, optimizing, data model, dataset, column compression, column cardinality.

JEL Classification: M15

1 Introduction

Power BI is a business intelligence cloud analytics service from Microsoft. It aims to provide interactive visualizations and business intelligence features with an interface simple enough for end users for creating their own reports and dashboards. These reports are published to the Power BI Service, but according to Microsoft (2022) the dataset size must not exceed 1 GB, this applies to Free and Pro licenses. There is also a 10 GB data limit for workspaces where reports are published to. Although dataset data is highly compressed, there is a risk of exceeding the allowed dataset size. In such a case, it is necessary to proceed with further optimization of the data model.

The purpose of this article is not to optimize the Power BI data model to increase the performance of Power BI reports. This article should show a several selected options for optimizing the Power BI data model to reduce its dataset size because the dataset size is limited for publishing to Power BI service as it is mentioned in Microsoft (2022).

In the following chapters, the principles of column data compression will firstly be described, as this has a large effect on the resulting size of Power BI datasets. As Mladenova, Kalmukov, Marinov and Valova (2021) write, data compression highly improves system performance in terms of storage saving. Regardless of the used compression, or the lack of it, the time for selecting thousands of rows does not change in noticeable manner.

The measurement of the optimization of the Power BI datasets size will be carried out using the VertiPaq Analyzer tool what is according to SQLBI (2023) a tool useful to analyze VertiPaq storage structures for a data model in Power BI and SQL Server Analysis Services Tabular, and views called Dynamic Management Views, specifically the DISCOVER_STORAGE_TABLE_COLUMNS view providing metadata about the tables and

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their columns and according to the methodology described in SQLBI (2017). This methodology says that to get correct dictionary measures from VertiPaq Analyzer, it is necessary to connect VertiPaq Analyzer just after opening a Power BI file, without hitting Refresh or modifying any calculated table expressions. If this happens, then it is necessary to save the file, close Power BI, and open the file again in Power BI before running VertiPaq Analyzer again over it.

2 Types of Column Compressions

The Power BI data model data is processed by the VertiPaq database engine. According to Russo and Ferrari (2017), VertiPaq is an in-memory columnar database. Being in-memory database means that all the data handled by a data model reside in operating memory. This has a huge effect on the speed of calculations processing.

The speed of the calculations processing is also affected by the fact that the VertiPaq is a columnar database. According to Candel, Sevilla Ruiz and García-Molina (2022), in columnar databases, data is structured in a similar way to relational databases. Each table has a name, and it is organized in rows and columns, but rows have a more complex structure than in relational tables because they are organized in column families. On this data structure, the aggregation of values in the column is much easier because database engine does not have to scan other columns, what is needed when using relational database, as Durán-Cazar, Tandazo-Gaona, Morales-Morales and Cardoso (2019) write.

The quantum of size occupied by each column depends on the data type of the column. As Khalwadekar and Gogate (2022) confirms, the Vertipaq engine is best suited for working with columns having numeric data types. If the column data type has a non-numeric or string datatype, then the Vertipaq engine needs to perform hash-encoding to assign a numeric identifier for every unique text value.

To improve performance, VertiPaq tries to reduce the data reading time for column. According to Russo and Ferrari (2015), the reducing of memory access time at the expense of increasing CPU speed can be tolerated, because with modern computers it is always easier and cheaper to increase CPU speed than to reduce the memory access time. If a column is compressed, the engine will scan less RAM to read its content and it results in better performance. So, the rate of column compression has a great influence not only on the resulting size of the dataset, but also on the performance of the database.

The VertiPaq engine uses for column compression three possible algorithms, which will be described in the following subsections. The resulting compression rate is often determined by combination of several of these algorithms.

2.1 Value Encoding

The compression algorithm called Value Encoding is used to reduce the number of used bits of individual column values and only in integer columns. The principle consists in finding a mathematical operation that will allow to reduce the number of bits of individual values, e.g. subtracting a constant from all values, when the opposite mathematical operation can be used to return the individual column values to their original size at any time.

2.2 Dictionary Encoding

The Dictionary Encoding compression algorithm is used for columns with values of all data types. This algorithm creates a dictionary of unique column values, assigns them an integer index, and then replaces the values in the column with that index. This procedure has the following advantages:

- After the algorithm is executed, all columns of the table contain only integer values, allowing the VertiPaq engine to optimize the internal code more easily.
- If the number of items in the dictionary is low, only a low number of bits is sufficient to create the dictionary index. If, for example, the compressed column contains only 4 different text values, then only 2 bits are sufficient to create a dictionary index.

The resulting size of the column is not determined by the number of values in the column or the data type of the columns, but by the number of unique values in the column - the so-called cardinality. The smaller the column cardinality is, the smaller its dictionary is.

2.3 Run Length Encoding

The principle of the Run Length Encoding (RLE) compression algorithm is to reduce the size of the dataset by eliminating repeated values. If one value from a limited set of values is repeated in a column on many continuous rows, then RLE tries to avoid storing repeated values by replacing them with a more complex structure that contains each column value only once supplemented by the number of rows in which finds a continuous block of repeating values.

However, usually not just one compression algorithm is used to compress a column, but the combination of several algorithms. VertiPaq usually first decides, e.g. according to the data type or cardinality of the column, whether to use Value Encoding or Dictionary Encoding algorithm for column compression, and if it is appropriate, it will supplement the selected compression with the RLE algorithm.

3 Individual Recommendations for Optimizing the Size of Power BI Datasets

It is clear from the previous chapter that the size of the columns after compression and thus the total size of the dataset is most affected by the cardinality of the columns. Therefore, most of the following recommendations for optimizing the Power BI dataset size will try to reduce the cardinality of individual columns by modifying the columns using Power Query and its M language during data import or SQL commands directly in the data source.

3.1 Recommendation 1: Store Only the Necessary Columns in the Appropriate Data Type

If it is necessary to reduce the size of the Power BI data set, it is necessary to mention in the first place a very simple but absolutely essential recommendation, which says that only those columns that are really needed for data analysis should be imported from the data source, especially columns with high cardinality.

We should consider importing mainly the following types of columns:

- Primary and other candidate keys of tables in data sources that will not be used to create relationships in the data model. An example could be a unique identifier in the Sales table. The Sales table as a fact table will be on the N-side of relationships with other dimensional tables, so the Sales table does not need to have a primary key to create the relationships. Moreover, the cardinality of such columns is very high.
- Non-numeric primary keys that will be used to create relationships should be replaced with numeric ones, because the Vertipaq engine is best suited for working with columns having numeric data types.
- For quantitative attributes, it is possible not to import columns that provide redundant information or that can be calculated from other columns. An example can be the Profit column, which can be calculated from the Quantity and Unit Price columns.
- Descriptive or technical attributes, such as the Description column in the Product table or date and time columns of the last modifications of records in transactional database tables, are often completely unnecessary for data analysis.

3.2 Recommendation 2: Minimize Column Cardinality When Designing Data model

As explained in the chapter describing the Dictionary Encoding algorithm, the size of the dictionary and thus the size of the entire dataset depends on the cardinality of the column. It is true that the smaller the column cardinality is, the smaller the dictionary is. This direct relationship will be demonstrated in the following example.

Let us have a table with a million rows with six text columns all with a text length of 7 characters. So, these columns do not differ in size, they only differ in cardinality. The columns have a cardinality of 1, 10, 100, 1000 and million respectively, see the following figure:

Text1	Text10	Text100	Text1000	TextN
T000000	T6000000	T000009	T000162	T000001
T000000	T3000000	T000083	T000668	T000002
T000000	T6000000	T000064	T000277	T000003
T000000	T9000000	T000066	T000980	T000004
T000000	T9000000	T000050	T000757	T000005

Figure 1 Example of a table with columns of different cardinality [source owns].

If this table were a relational database table, all columns would have the same size according to the column data type. If using char(7) data type, it would be 7 B per data, i.e. 7 MB per column. In the Vertipaq database engine, however, the situation is different, column compression takes care of a very significant reduction in their size depending on their cardinality.

Row Labels	Rows	Cardinality	Dictionary Size	Columns Total Size	Database Size %	Encoding_
'MinimizeCardinalitySheet'[TextN]	1 000 000	1 000 000	28 190 996	38 857 716	96,43%	HASH
'MinimizeCardinalitySheet'[Text1000]	1 000 000	1 000	41 256	1 382 640	3,43%	HASH
'MinimizeCardinalitySheet'[Text100]	1 000 000	100	19 496	20 352	0,05%	HASH
'MinimizeCardinalitySheet'[Text10]	1 000 000	10	17 356	17 492	0,04%	HASH
'MinimizeCardinalitySheet'[Text1]	1 000 000	1	17 120	17 192	0,04%	HASH

Figure 2 Example of column size dependence on column cardinality [source owns].

It is clear from the measurement of the columns' size of the above-mentioned table that the smaller the cardinality of the column is, the smaller the dictionary and the smaller the total size of the column are. Therefore, it is advisable to think about the possibilities of reducing the cardinality of individual columns when designing a data model.

3.3 Recommendation 3: Optimize Data Model Using Column Splitting

By splitting a column into multiple columns, you can reduce the cardinality of the columns. For example, let us have a 10-character PersonalID text column, which we want to split into a left part with 6 characters and a right part with 4 characters. This operation can be executed e.g. with the following SELECT command of the SQL language:

```
SELECT
     LEFT(PersonalID, 6) AS PersonalIDLeft,
     RIGHT(PersonalID, 4) AS PersonalIDRight
FROM …
```

Splitting the PersonalID column into two columns will reduce the cardinality of the new columns and thus the total size of the dataset, see the following figure:

PersonalID	PersonalIDLeft	PersonalIDRight
1727889915	172788	9915
1238858046	123885	8046
6926849339	692684	9339
5195385004	519538	5004
6366752194	636675	2194

Row Labels	Rows	Cardinality	Columns Total Size	Encoding_
'PersonalID'[PersonalID]	1 000 000	999 939	40 035 239	HASH
'PersonalID'[PersonalIDLeft]	1 000 000	600 608	22 632 771	HASH
'PersonalID'[PersonalIDRight]	1 000 000	8 889	1 975 255	HASH

Figure 3 Example of column size dependence on text column split [source owns].

However, numerical columns in principle cannot be split into their left and right parts using text functions, for their splitting it is necessary to use mathematical operations. E.g. an integer column with values between 0 and 100,000,000 can be split into two halves by the following operations:

```
SELECT
     Number / 1000 AS Left,
     Number % 1000 AS Right
FROM …
```

Even in case of splitting an integer column, there was a significant reduction in the cardinality of the columns, see the following figure:

Number	Left	Right
49940624	4994	624
98576505	9857	6505
25566375	2556	6375
39313516	3931	3516
2883627	288	3627

Row Labels	Rows	Cardinality	Columns Total Size	Encoding_
'SplitIntegers'[Number]	1 000 000	995 054	7 980 384	VALUE
'SplitIntegers'[Right]	1 000 000	10 000	2 308 456	HASH
'SplitIntegers'[Left]	1 000 000	10 000	2 178 600	HASH

Figure 4 Example of column size dependence on integer column split [source owns].

In case of a column with decimal numbers, the most appropriate way to split the column seems to be to split it into columns with the integer and the decimal parts of the number, e.g. using the following operation:

```
SELECT
     FLOOR(Number) AS Integer,
     Number - FLOOR(Number) AS Decimal
FROM …
```

Also in this case, there was a significant reduction in the cardinality of the columns and thus also a reduction of the dataset size, see the following figure:

Number	Integer	Decimal
801,5115	801	5115
561,7413	561	7413
492,1754	492	1754
655,3633	655	3633
493,8428	493	8428

Row Labels	Rows	Cardinality	Columns Total Size	Encoding_
'SplitDecimal'[Number]	1 000 000	951 800	7 807 368	VALUE
'SplitDecimal'[Decimal]	1 000 000	10 000	2 382 496	HASH
'SplitDecimal'[Integer]	1 000 000	1 000	28 736	HASH

Figure 5 Example of column size dependence on decimal column split [source owns].

However, DateTime columns are particularly dangerous. Not only the cardinality of the DateTime column is very high, but it continues to grow as the days in the column increase. It is therefore very important to divide such columns into two columns: one with the date part, the other with the time part, e.g. using the following operation:

```
SELECT
     CAST(DateTime_ AS DATE) AS Date_,
     CAST(DateTime_ AS TIME) AS Time_
FROM …
```

E.g., let us have random dates for 10 years in a column of DateTime type in the table. The following figure shows how the cardinality of the columns is reduced after splitting into two columns of the DATE and TIME type and thus how the size of the dataset is reduced:

DateTime_	Date_	Time_
21.5.25 11:48	21.05.2025	11:48:04
27.11.30 12:26	27.11.2030	12:26:41
4.7.24 13:28	04.07.2024	13:28:44
9.11.31 13:42	09.11.2031	13:42:21
10.12.25 10:29	10.12.2025	10:29:57

Row Labels	Rows	Cardinality	Columns Total Size	Encoding_
'DateTime'[DateTime_]	1 000 000	999 992	52 615 736	HASH
'DateTime'[Time_]	1 000 000	86 400	6 173 856	HASH
'DateTime'[Date_]	1 000 000	3 652	716 152	HASH

Figure 6 Example of column size dependence on datetime column split [source owns].

Very often you do not even need time values for data analysis, but only date dimensions such as year, quarter, month and day are sufficient. In that case, do not use the time from the DateTime column at all.

3.4 Recommendation 4: Avoid DAX calculated columns

Using the DAX language, it is possible to calculate new measures or columns from existing data model columns. However, unlike SQL queries or DAX measures, DAX calculated columns are according to Microsoft (2023) computed during database processing instead of computation in query time and they are stored in data model. Because computed columns are stored in the data model, they take some space in the data model. Moreover, a calculated column is not as optimized as a native column. It can have a lower compression rate compared to native columns of the table because it does not take a part in the heuristics that VertiPaq executes to find the optimal sort of data.

By storing a DAX calculated column in the data model, its data is available for further calculations much faster than if the calculated column was only calculated at query time, which can increase Power BI report performance. But if you need to optimize the data model in terms of dataset size, then try to avoid calculated columns. E.g. if you have Quantity and Unit Price columns in the Sales table and you need to calculate the total Profit, you do not need to create a calculated column, which is then added using a measure:

```
ProfitColumn = Sales[Quantity]*Sales[Unit Price]
ProfitMeasure = SUM(Sales[ProfitColumn])
```

You can directly create the Profit measure without having to create a calculated column as an intermediate calculation:

```
ProfitMeasure = SUMX(Sales,Sales[Quantity]*Sales[Unit Price])
```

DAX measures are calculated at query time and are not stored in the data model, so when using a DAX measure, the size of the data model does not change.

4 Conclusion

This article aimed to show which factors most significantly affect the size of the Power BI data model, and also tried to outline some recommendations for optimizing the data model in terms of reducing its size. As measured, the factor that most affects the size of a Power BI data model is column cardinality, i.e. the number of unique values in the column. In order to reduce the size of the Power BI data model, it is necessary to either completely omit the columns with high cardinality or try to reduce the cardinality of the columns, e.g. by splitting the column into multiple columns.

Nevertheless, the mentioned recommendations for optimizing the size of the data model of Power BI can affect report performance. E.g. calculations of the original values from the split columns will increase the demands on the computing power of the hardware. Therefore, it is definitely a good idea to measure the performance of Power BI reports to see if there will be significant performance degradation by performing optimization focused on the size of the Power BI dataset.

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Virtual reality as a tool for creating a parallel environment of an educational institution

Petr Rozehnal[1], Petr Gurný[2], Jozef Hvorecký[3]

Abstract. Dynamically developing virtual reality technologies advance the possibilities of application in the creation of a virtual environment that complements or replaces the real environment of the organization. In the field of education, great application potential appears not only in educational processes, but also in other activities related to the operation of schools. In the paper we discuss key characteristics of the virtual environment, which is supposed to serve as a parallel virtual world for the school's activities. We defined the characteristics on the basis of experience with the virtual reality environment created and applied as part of the project solution dealing with the influence of virtual reality technologies on university students.

Keywords: virtual reality, environment, education.

JEL Classification: M15, O33, I29

1 Introduction

Virtual reality (VR) technologies are currently a rapidly developing area that finds application in many fields. This also applies to the field of education. (Martín-Gutiérrez et al., 2017; Abulrub et al, 2011; Choi, 2016). However, VR in education can be applied and understood from different perspectives. In the paper, we address a selected topic in connection with a project where VR is understood as an environment accessible via the Internet, where the interface is a screen and no additional hardware or software equipment is required. It is a virtual space accessible to the user, which can be configured and supplemented with content elements that convey information. With regard to flexibility and scalability, the environment can also be used as a platform for a parallel, virtual campus. As far as the authors are aware, the issue of the parallel virtual world at educational institutions has not been generally described and formalized so far. Therefore, the goal of the paper is to define the general characteristics of virtual reality environment (VRE) when replicating the real physical environment of an educational institution into a parallel virtual world.

The aim of the project is to verify the benefits of teaching in a virtual environment, which is developed as part of the project. To evaluate the impact of VRE on student results and their work (Korenova et al., 2022). Based on the progress and results of the project, in the contribution we deal with the deployment of VR technology in the environment of an educational institution. With regard to the key properties of the virtual environment (VRE), the initial idea is based on the application of VRE as a parallel world - a virtual campus as a supplement to the real, physical world. The motivation for the topic is also the fact that we encountered several cases (e.g. participating in a trade fair in VRE mode) where the event was

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promoted as a virtual environment, although the application ended up not showing the essential characteristics of what the term "virtual" currently means commonly thought.

VRE as a platform where both teaching and related activities are implemented, copies the real operation of the school for selected agendas. If VRE is implemented for educational processes, the application in a broader concept that includes non-teaching activities is a concept that moves the use of VRE to a qualitatively higher level.

The operation of the school does not only include the direct aspect of teaching. It also includes non-pedagogical processes, which represent, for example, the agenda of the study department, events for the public and others. And the field of pedagogy often includes elements of cooperation, communication outside of the actual teaching (with students, but also teachers), access to school equipment (e.g. laboratories with specific equipment). The concept of a virtual, digital campus as a complement to the real world thus opens up the possibility of providing another platform for meeting and communication. It does not have to be a complex implementation that we discuss in the paper, but also partial applications. The application of augmented reality on part of the campus states (Tabuse and Tada, 2014) or VR for a selected area (Jalil, 2022) and many others.

The period of the pandemic related to the disease Covid accelerated the need to create an environment that could be used as a substitute for the real world. During the time of restrictions and closed schools, various applications were used to enable and support the organization of the teaching process. We are talking about elements such as class, subject, user account and the processes of sharing teaching materials, communication between teaching actors. Application features such as video calling, instant messaging, screen sharing and more are coming to the fore.

If we talk about VRE, it is obvious that the above-mentioned properties, which are already common today, must be overcome in a significant way, more precisely, they must be supplemented with other properties that expand their use. In VRE, these are mainly elements associated with interactivity, visualization, the possibility to use the element of space (3D), immersion in the action of in-depth learning activities (Peng, Liu and Liu, 2016) and others. As a result, advantages such as greater student interest, the ability to learn based on experience, to create an illusion of reality (simulators, virtual equipment – machine, models) are expected.

2 Virtual campus concept

The concept of VRE as a virtual campus is simple. Let's present a model situation and compare three solution variants. The default is a situation where a student needs to arrange a certain matter with study department officer. Let's think about agendas that are not available directly in digital form in information systems (IS), that is those that are handled by the student directly, physically on the school campus.

First, let's use the classic communication technologies that have been used for decades, www and email.

1) The student is looking for a worker who takes care of the agenda (probably via the website), he tries to solve the matter by email.

In the newer concept, they try to solve it in the form of a video call or chat in the environment of the respective application.

2) The first step is again to find the person responsible for the agenda (again probably through the website) and then contact in the application for real time communication, video call (chat). Here, he already gets in direct contact with the person responsible for the given agenda, for example in the form of a video call.

3) In the VRE campus concept, the student would go through the visualization of the campus (it is possible in the implementation of the visualization identical to the actual layout of the campus) to the study department and after entering it would be possible to initiate communication directly with the person responsible for the given agenda (chat, call, video call).

The application of 3D VRE will allow the process to be essentially identical to the situation in the real physical environment. Spatiality, visualization, common form of communication are applied.

It is obvious that the deployment of VRE can be a partial issue connected to a selected subject (there are a number of applications on the market focused on specific content), a teacher or an agenda, but also a complex issue that affects many areas of the organization. In the paper, we further classify the basic functionalities of using the environment, which was created as part of the project Improving the quality of learning and strengthening students' motivation to learn by deploying a 3D virtual university campus based on virtual and augmented reality technologies in the teaching process. This VRE is the default test platform for the mentioned usage models.

3 Virtual reality application

With regard to different perceptions and concepts of the term virtual reality, let us state that the environment under discussion belongs to multi-user virtual environments (MUVEs), as defined by (Liu et al., 2017): „*Multi-user Virtual Environment (MUVE) interfaces offer students an engaging Alice-in-Wonderland experience, going "through the screen" to a simulated setting in which their digital avatars convey psychological immersion in a graphical, virtual context. The participant represented by the avatar feels remote presence inside the virtual environment: the equivalent of diving rather than riding in a glass-bottomed boat*".

It is beyond the scope of the paper to pay more attention to individual types of applications or environments that are generally discussed in connection with the term VR (e.g. augmented reality, mixed reality), here we refer to (Liu et al., 2017).

The environment we use is fundamentally based on the use of the screen and common peripherals as an interface for visual communication and application control (no special hardware equipment such as glasses, etc. is required). We emphasize this aspect with regard to the implications for implementation. Whether it's about limits (e.g. in the area of experiences) or benefits (no problems with technical equipment).

An essential part of the use of VRE are its properties, which determine the behavior of users. Babich (2018) suggests benefits as follows:

- Visualization – learning by visualization. Visualization helps in comprehension and understanding of context. As mentioned above, this is an element that could not be fully developed in the applications used so far.
- Better sense of place – the student identifies with the environment and this makes his behavior more natural (also see the example above).
- Virtual laboratories – use of simulation where students can test the situation and gain practical experience.
- Learning by doing, Learning through activities – students are directly involved in activities of a different nature and thus acquire knowledge or skills.
- Support development of creativity – education is not only consumption of content but often content creation.
- Emotional reaction – students' interest increases due to emotional reactions that are more natural in VRE compared to a regular computer application.

The author adds five fundamental characteristics of VR apps for education: Immersive, Easy to use, Meaningful, Adaptable, Measurable.

Essentially similar characteristics affecting user psychology are mentioned by (Liu et al., 2017, p. 5) when they talk about nesting – Actional Immersion (motivation, experience), Symbolic/Narrative Immersion (emotion, association), Sensory Immersion (feeling of reality, visual learning) and Social Immersion (social aspects, cooperation and communication).

4 3D VRE as a parallel environment

If VRE is to serve as a parallel environment, it must have selected functionalities that allow simulating real conditions. The illusion of a real space must be created, where the actor will be able to behave - perform activities that are common in the ordinary world (mainly social interaction, communication, but also, for example, movement in space).

In the project, such an environment was created and tested. We present a brief description of the VRE concept and its key features and functionalities.

It is a Software as a Service (SaaS) application, accessible to users via the Internet and a web browser. From an implementation point of view, the process of environment preparation and management can be briefly summarized as follows:

1) Creation of an organization instance - this is access for the administration of the environment for the account/user who initiated the creation.

The creation of the environment is conceived as so-called rooms (whether it is a partial, one room or a complex area). These spaces are created using templates (immediately available) or it is possible to develop a customized environment (customization is a matter for developers and therefore the whole process is significantly complicated).

2) Configuration of the environment. It can be defined as: 1) environmental modifications, i.e. space and its design; 2) modification of the content elements of the environment (informational content, the environment is intended for education; it includes the addition of images, textual content, linked videos, 3D content).
3) Using the environment in different modes (modes can be applied to selected rooms). It is thus possible to create an environment available 24/7 or only at selected times.

Access can be set for individual users who will work in the environment alone or in a multiuser variant where many users can be present (see MUVEs above).

The environment is available to the user via a URL link. This is an excellent prerequisite for integration into other digital structures of the organization (for the education segment, typically into LMS, Intranet, etc.).

The user moves in the environment as a so-called avatar. In this form he is visible to other participants. Movement in the environment is an important element of the actor's behavior. Users also have visual feedback on the movement of other actors. In this way, the innovative element of spatiality is applied. This is supported by the possibility of applying 3D content. The behavior and activities of VRE participants are complemented by functionalities such as chat, video call, screen sharing and others.

The mentioned properties enable the application of 3D VRE in the scope discussed in the introduction of the paper. A virtual environment is available - a campus with a space where it is possible to move and interact with other participants. The concept allows for scalability and flexibility.

VRE can be deployed as follows:

- VRE as a complex environment, a virtual campus where it is possible to communicate, which has a spatial character, is supplemented with additional content. In an extreme case, it can be a twin of a real campus.
- VRE as a partial space, a room, which is accessible for a selected purpose (event/action) supplemented with its own content. In this way, several purpose-defined spaces with specific content can be created, which are not part of a complex space. They can be accessed via separate lines or linked by a teleportation function.

Both variants are available in defined times (specific time period or 24/7). Both can be available as single-user or multi-user environments.

As mentioned, the implementation of the environment is primarily based on pre-prepared templates that can be further configured. In two levels. First, configure the space by editing selected elements, changing the color scheme, etc. Second, by adding information elements, content (text, images, video, 3D elements). A more demanding matter would be to create an environment completely according to the client's disposition, therefore with complete development (space and visualization).

5 Results and discussion

Based on the experience and results of the project solution, we can derive the following key characteristics for the creation of a parallel environment in an educational institution. Let's emphasize that the following properties are also based on the basic characteristics of VRE (and their effect on actors in the environment), which were mentioned above.

5.1 Key features of 3D VRE to create a parallel environment

An overview of the key features of 3D VR.

Openness – in the sense of connection to other systems that are already used in organization. Let's realize that a certain form of parallel functioning is common in modern organizations. It is implemented by information systems that cover the company's functions. IS contains data reflecting actual real-world activities. The ability to connect VRE with these systems and generally other content on the Internet is essential.

ERP systems cover a range of business management agendas and are the repository of data that represents these agendas. Similarly, other classic types of IS such as CRP, LMS and others. Another example would be directory services, typically including user information.

3D Environment – 3D space is the basis for VRE and forms the virtual world where the user exists and in which he occurs and behaves. Spatiality significantly affects the immersion of the actor in the situation and changes the way of orientation (both in space and information content).

The **existence of users** in the form of avatars that represent them to other actors. This is especially important in a multi-user environment where visibility of other actors is essential.

The **movement of actors** - avatars - follows the spatiality and form of the actor's existence. It brings a shift in that we do not go through information content structured by a selected form of navigation: menus, links, web pages, etc. The concept is used where a person goes through an environment (3D) that includes information content. VRE thus naturally replaces elements of navigation and orientation.

Communication – actors must be given the possibility of communication that is normal in everyday life. Within VRE, typically a call, video call or chat.

Identification of users – follows on from the element of actor representation. This aspect has a number of consequences from 1) **authentication** of actors and their 2) **authorization** for activities in the environment (e.g. Can they edit content elements?), to 3) identification for assignment to a specific real-world person. **Recognizability** for other actors.

It is obvious that the problem of identification is closely related to the question: how should the environment really work? Let's give an example. Typically, any person can enter the school's campus, e.g. to attend a lecture (so it is in anonymous mode for others - we do not know who it is, the person is not identified), but the moment a person wants to participate in an exercise class or complete a specific agenda, that is the moment when authentication occurs.

Interactivity - a certain degree of interactivity of the actors is assumed in principle for the VR environment. We have already mentioned some forms of interactivity - movement and communication. Other forms are connected to a specific situation and thus it is possible to prepare for them (e.g. machine control in the laboratory is determined by the properties of the machine-model, file uploads to external systems is set according to user authentication and authorization, etc.)

Time – management of VRE availability in time (from non-stop 24/7 mode to defining time restrictions).

Environment configuration – is another aspect that is interesting for the field of VR. In the virtual environment, the configuration will mainly concern 1) the configuration of the space (including the layout of the space), 2) the configuration of the content (information elements that are in the space).

Ad 1) If we are discussing in the context of creating a virtual twin, we can limit the modifications in the same way as we have them limited in the real environment. We are not able to modify the space - the building. On the contrary, we are able to modify the properties of selected elements: e.g. lock the door, add information content, etc.

Further customization of the environment beyond the mentioned modifications is certainly possible in the virtual environment, but it will be based on cooperation with the developers (similarly to the modification of the layout of the physical building, it is solvable, but we have to contact the builder).

Ad 2) Content management is one of the basic features. It is the possibility of inserting 2D content (texts, images, videos) and 3D content (3D models). The very existence of a 3D space carries with it certain information "about the space".

It is worth adding that certain modifications can be achieved in VR by appropriate environmental settings. For example: locked doors outside the working hours of the study officer are not solved by locking, but by unavailability of the room (service) at defined times. It is therefore an adjustment made through time disposition. Similarly, in the VR environment, the authorization of the actor will occur automatically (by logging in), although in the real world it would be proven with a personal document only at the moment related to the given activity.

5.2 The pros and cons of 3D VRE

It is clear that each of the above points would be appropriate for a more in-depth discussion. The aspects were derived from experiences based on real VRE deployment. The initial idea for the contribution is the possibility of using VRE as a parallel, digital environment to the real environment. The mentioned aspects - the properties of the VRE are essential. Without them, it is not possible to talk about VRE as a digital world alongside the physical world.

Let's list the pros and cons of running VRE as a parallel environment.

Positive matters:

- The options for presenting content (information) are more flexible. It is not primarily about the variability of forms and formats, but about their structuring into space, combination and connection.
- The way in which the content (information) can be available from the perspective of the actors is closer to the natural environment.
- Use of 3D space - represents a different way of perception and orientation, which is reflected in work with content, communication with other actors.
- Communication - although it is basically built on options that have already been used for a long time (call, chat, etc.), in combination with orientation in space and representation of other users, it comes significantly closer to communication in the physical world.

Negative matters:

- The difficulty of preparing 3D VRE. Despite the simplification with the use of templates, default configurations, etc. As a rule, further modifications are needed and it is true that if we deviate from the pre-prepared spaces, these are interventions that cannot be implemented by an ordinary user.
- Higher Demands on hardware and software resources (on the user side it is mainly hardware). No special equipment is needed, but the user's end device should have sufficient performance.
- For participants on the provider side, it is another environment where they fulfill their role. It is therefore a question of whether and how they will function in the physical world. On the client side, it's more about choice.
- In addition to participants (see point above), this is generally another environment for providers that needs to be managed. In general, operation requires additional costs, usually higher compared to, for example, LMS systems.

6 Conclusion

In the paper, we defined the basic characteristics of VRE in a situation where we try to use this environment to copy the real, physical environment of an educational institution and for a situation where the interface is traditional equipment (screen, keyboard, mouse).

The above-mentioned characteristics are mainly based on two requirements that we want to achieve: user immersion and improve the transmission and especially the perception of information by users.

The properties and functionalities of VRE, which create prerequisites for embedding the user in the environment and the actions in it, raise the overall properties of the environment to a qualitatively higher level compared to traditional types of software (web pages/intranet, traditional types of IS) and naturally support the sharing of information and their perception between actors.

Part of the activities that are part of the life of educational institutions (not only teaching, but also others) can currently be transferred to 3D VRE.

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On choosing a trading strategy in (in)efficient markets

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Abstract. The information efficiency of stock markets is often statistically tested and verified. If the given stock market is evaluated as inefficient, it is logical to design and apply a suitable trading strategy that would lead to higher than average yields. Given that the information inefficiency of stock markets is usually caused by nonlinear dependence in returns, it is advisable to apply a trading strategy that is based on nonlinear relationships. The goal of this article is not to provide statistical evidence of the efficiency or inefficiency of the given market, but only to propose the principle of this trading strategy and show illustrative example on real data. The trading strategy proposed in this paper is based precisely on nonlinear dependencies in the time series of returns. Buy or sell signals are generated using the *k*-nearest neighbor (*k*-NN) method. This method is based on similar principles as the nonlinear BDS test. The *k*-NN method will be applied in the Python programming language.

Keywords: BDS test, efficient market hypothesis, nearest neighbor, nonlinear dependency, Python, trading strategy.

JEL Classification: C22, C38, C53, G14

1 Introduction

Investors usually choose their trading strategies on the basis of their attitude toward risk, investment horizon, and also how they believe in the hypothesis of an efficient market (Urquhart and McGroarty, 2016). It is obvious that some market participants often act irrationally. Behavioral financial economists and psychologists have presented evidence of systematic errors that some investors made. Rational investors have two basic options when choosing their trading strategies. Passive management could still be an appropriate strategy even if markets are inefficient, because it is a zero-sum game. Obviously, all stocks have to be held by someone, and while some investors achieve above-average returns, other investors must underperform. When accounting for the additional costs of active management, most investors may not outperform the market average so passive investors may thus achieve better results. If some market is inefficient, it is possible to use fundamental and technical analyses. Of course, it is also possible to apply more sophisticated rules or models (Pagan and Sossounov, 2003).

Many empirical studies confirmed that returns are conditionally predictable (Seďa, 2020). Linear dependencies in financial time series returns have rarely been identified in the scholarly literature. The only exceptions are ultralow and ultrahigh frequencies (Christoffersen and Diebold, 2010). Potential nonlinear dependencies are often considered too complex to be

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accurately specified. Therefore, practitioners often focus on the use of artificial intelligence and data mining methods that do not require the analyst to define precisely the relationships in the time series. Thus, many data mining methods, such as neural networks, nearest neighbor, classification trees, random forests, etc., have been used to predict the future values of financial time series (Calvacante et. al. 2016).

The practical challenge is to design a trading strategy that would be based on nonlinear relationships in returns and thus combine data mining methods with modern programming tools. The goal of this paper is to propose the principle of a trading strategy that is based on nonlinear dependencies detected in returns by the *k* nearest neighbor (*k*-NN) method using Python programming language and show an illustrative example on a real data sample.

The added value of this paper consists of the following two aspects:

- the connection between the nonlinear BDS test results and trading strategy will be shown;
- the possibility of using the Python programming language to detect signals for selling and buying generated by the *k*-NN method will also be demonstrated.

This article is organized as follows. In the introduction the motivation was explained, a short overview of the literature and current level of knowledge was given, and the added value of this paper was highlighted. The second chapter delivers a theoretical background of investigated problem. A relation between the efficient market hypothesis (EMH), adaptive market hypothesis (AMH) and BDS test is briefly described. The third chapter provides a description a trading strategy that is based on the results of the BDS statistical test using the Python programming language and the nearest neighbor method. Additionally, an illustrative example comparing the results of three trading strategies is delivered. The results of this paper are summarized and discussed in the conclusion.

2 Conditional predictability of returns based on nonlinear dependencies

The practical application of trading strategies in inefficient or efficient markets is fundamentally related to the results of statistical tests that investigate whether returns are conditionally predictable or not. However, conditional predictability is not statistical proof of the efficiency or inefficiency of the market. According to the AMH, (in)efficiency changes and develops over time. As market agents adapt to changing market conditions, they often rely on heuristics to select investment opportunities. Lo (2004) states that the degree of market predictability changes over time as market conditions may change. Conditional predictability in the asset returns can be investigated using statistical tools.

One of the empirical features of informationally efficient markets is the randomness of price changes. Therefore, price developments should not be predictable in efficient markets. Several linear and nonlinear statistical tests have been defined in the literature to verify randomness of returns. The BDS test is one of the strongest nonlinear tests of the random walk hypothesis of the first type (Seďa, 2020). The BDS test of independence is a non-parametric test of the null hypothesis that the data are independent and equally distributed (Brock et al., 1996). The test is based on the concept of the correlation integral. The BDS test is sensitive to a wide set of alternative hypotheses. It can identify different types of processes that are not independent and equally distributed such as non-stationarity, chaos or nonlinear stochastic processes (Seďa et al, 2021). When having a series of logarithmic returns r_t that includes *n* observations, one can write the correlation integral for *m* dimensions:

$$C_{m,n}(\varepsilon) = \frac{2}{(n-m+1)\cdot(n-m)} \cdot \sum_{s=1}^{n-m} \sum_{t=s+1}^{n-m+1} \prod_{j=0}^{m-1} H_\varepsilon(r_{s+j}, r_{t+j}), \tag{1}$$

where *ε* represents a small enough preset distance, *m* means a nesting parameter and *H* is the Heaviside function, for which the following formula holds:

$$H_\varepsilon(r_i, r_j) = \begin{cases} 1 \text{ if } |r_i - r_j| \leq \varepsilon \\ 0 \text{ for other cases.} \end{cases} \tag{2}$$

Brock et al. (1996) defined test statistics as follows:

$$W_{m,n}(\varepsilon) = \frac{\sqrt{n-m+1} \cdot \left[C_{m,n}(\varepsilon) - \left(C_{1,n-m+1}(\varepsilon)\right)^m\right]}{\hat{\sigma}_{m,n}(\varepsilon)} \sim N(0,1), \tag{3}$$

where $\hat{\sigma}_{m,n}(\varepsilon)$ represents an approximation of the asymptotic standard deviation.

3 Proposal of a trading strategy

Considering the results presented by Seďa et al. (2021), when it was found that returns are predictable rather based on the results of the nonlinear BDS test, it is rational to propose a trading strategy based on the existence of nonlinear relationships in returns.

3.1 *K*-nearest neighbor method

The *k*-NN method appears to be a suitable method for generating buy or sell signals. This method is based on selecting geometric segments of historical time series values that are similar to the last segment preceding the observation to be predicted (Fernández-Rodríguez, Sosvilla-Rivero and Andrada-Félix, 1999). Indeed, the *k*-NN method selects relevant previous observations based on their levels and geometric trajectories, not their location in time. Prediction using the *k*-NN method can be described using several steps. The time series x_t, where $t = 1, \dots, n$, must be transformed into a series of segments of the same length, which have the form of vectors $x_t^{m,\tau}$ and contain m sample observations of the original time series at intervals $\tau \in N$:

$$x_t^{m,\tau} = (x_t, x_{t-\tau}, \dots, x_{t-(m-1).\tau}), \tag{4}$$

where $t = 1 + \tau \cdot (m-1), \dots, n$, *m* represents the nesting dimension, while *τ* is the delay parameter. These *m*-dimensional vectors are referred to in the literature as *m*-histories, while the *m*-dimensional space R^m is the phase space of the time series. The proximity of two *m*-histories in the phase space of the time series R^m can be characterized as nearest neighbors in the dynamic behavior of two segments in the time series x_t.

The prediction of the time series x_t, where $t = 1, \dots, n$, is based on the analysis of the historical paths of the vectors around the last vector $x_n^m = (x_n, x_{n-1}, \dots, x_{n-(m-1)})$. In the next step, segments with similar dynamic behavior are detected and these are then used for prediction. In order to obtain a time series prediction, it is necessary to consider a total of *k* *m*-histories

$x_{i_1}^m, x_{i_2}^m, x_{i_3}^m, \ldots, x_{i_k}^m$,, which are most similar to x_n^m. In order to identify the nearest neighbors of x_n^m, it is necessary to identify the nearest k vectors in the phase space of the time series R^m. Identification consists in finding the highest serial correlation of all *m*-histories x_i^m with the last vector x_n^m. The prediction of the time series x_{n+1}^f using the NN method consists of the application of linear autoregression, the coefficients of which are estimated by the method of least squares. This is a regression in total of *k m*-histories $x_{i_1}^m, x_{i_2}^m, x_{i_3}^m, \ldots, x_{i_k}^m$.

It is essential that the prediction by the *k*-NN method depends on the value of the nesting dimension *m* and also on the number of points closest to *k* in the phase space of the time series R^m. To determine these two parameters, it is possible to apply, for example, some heuristic methods. However, the most suitable is the use of genetic algorithms, which enable the simultaneous determination of the optimal values of *m* and *k*. Genetic algorithms represent a class of adaptive search and optimization techniques that have the advantage of being able to evaluate the loss functions associated with the predictor parameters without assuming continuity or differentiability of the loss function (Holland, 1992). In addition, the application of genetic algorithms is also advantageous because it eliminates the problem of data snooping. The sample is divided into training and test sets. However, before using the *k*-NN method, it is advisable to verify the existence of nonlinear dependence in the time series of returns. The proof of nonlinearity would confirm the correct direction of our reasoning about the application of the *k*-NN method. The most appropriate test seems to be the BDS test, which has a similar logic.

3.2 Nearest neighbor algorithm in Python

Python is a high-level programming language that offers dynamic control of data types and supports a variety of programming paradigms, including object-oriented, imperative, or functional. Python is developed as an open-source project that offers free installation packages for most common platforms (Unix, MS Windows, macOS, Android). Currently, the Python programming language is also very popular in the field of applied finance.

The *k*-NN, algorithm in fact creates an imaginary boundary for data classification. When new data points come in, the algorithm predicts it to the nearest boundary line. Thus, a larger value of the parameter *k* implies a damping of the separation curves, leading to less complex models. While a smaller value of the *k* parameter tends to overfit the data and result in complex models. To sum up, it is very important to choose the right value of the *k* parameter to avoid overfitting or underfitting the data set.

The nearest neighbor algorithm should run in the following several steps in Python:

- Import the *k*-NN algorithm from the scikit-learn package;
- Create feature and target variables;
- Split the data into training and test data sets;
- Generate a *k*-NN model using the neighbor's value;
- Train or fit data into a model;
- Predict the future values.

The crucial question is how to determine the value of the k parameter for a data set. At first glance, it is obvious that we need to get knowledge of the data sample to obtain the range of the expected k-value. To get an accurate k-value, we need to test the model for each expected k-value. An example of Python code is shown in Figure 1.

```
# Import necessary modules
gdf from sklearn.neighbors import KNeighborsClassifier
from sklearn.model_selection import train_test_split
from sklearn.datasets import load_SP500return
import numpy as np
import matplotlib.pyplot as plt
SP500returnData = load_SP500return()
# Create feature and target arrays
X = SP500returnData.data
y = SP500returnData.target
# Split into training and test set
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size = 0.2, ran-
dom_state=42)
neighbors = np.arange(1, 9)
train_accuracy = np.empty(len(neighbors))
test_accuracy = np.empty(len(neighbors))
# Loop over K values
for i, k in enumerate(neighbors):
    knn = KNeighborsClassifier(n_neighbors=k)
    knn.fit(X_train, y_train)
       # Compute training and test data accuracy
    train_accuracy[i] = knn.score(X_train, y_train)
    test_accuracy[i] = knn.score(X_test, y_test)
```

Figure 1 Example of testing the accuracy of *k*-nearest neighbor model in Python

3.3 A trading strategy based on *k*-NN method

The proposed trading strategy is based on simple market timing, which consists of investing in the stock market (index or asset) or a risk-free asset. Forecasts obtained on the basis of the *k*-NN method are applied to classify the following trading day into two options. The first option means the presence of the investor in the market (it will bring a market return), and the second one means the absence of the market and an investment in a risk-free asset (it will bring a risk-free return). The trading strategy specifies the position for the next trading day, considering the current state (presence or absence in the market) and generating buy or sell signals using the *k*-NN method. If under conditions of market presence, prices are expected to fall based on the prediction using the *k*-NN method, the asset is sold and the funds are invested in a risk-free asset. On the contrary, in the case of absence in the market, price growth is expected in the near future based on the *k*-NN method, and a signal to buy the asset is generated. The risk-free asset is sold and the funds are invested in the market. In the case of the other two options, the current status is preserved.

When applying the trading rule for the entire trading period from time 1 to time *T*, the yield *r*, can be written in the following way:

$$r = \sum_{t=1}^{T} r_m(t) \cdot I_b(t) + \sum_{t=1}^{T} r_f(t) \cdot I_s(t) + n \cdot \log \frac{1-c}{1+c}, \tag{5}$$

where $r_m(t)$ is the market return, $I_b(t)$ and $I_s(t)$ are indicator variables equal to the value of one if the *k*-NN method generates a signal for buying or selling, respectively, or to the value of zero in other cases. The condition $I_b(t) \cdot I_s(t) = 0, \forall t \in (1, T)$ must be met, *n* is the number of transactions, and the value of *c* means transaction costs expressed as a share of the price.

When using this strategy, it is convenient to modify a simple rule for buying or selling with a filter that reduces the number of false signals for buying or selling, if the prediction at time t is close to the value of the closing price at time t-1. The filter can be interpreted as the risk that the investor is willing to transfer. The filter rule will generate buy (sell) signals at time t if the expected value obtained by the k-NN method is greater (lesser) than the closing price at time t-1 adjusted by the percentage δ of the standard deviation σ of the price differences on the interval from 1 to t -1. If $\widehat{P}_t$ is the predicted value of the price P_t, then if $\widehat{P}_t > P_{t-1} + \delta \cdot \sigma$ and at the same time the investor is not present in the market, a buy signal is generated. Assuming a presence in the market, we should not leave the market. On the contrary, if $\widehat{P}_t \leq P_{t-1} + \delta \cdot \sigma$ applies and at the same time the investor is present on the market, a sell signal is generated. Assuming no presence in the market, we should continue to hold the risk-free asset.

3.4 Illustrative example on US data sample

It would be appropriate to compare the proposed k-NN trading strategy with other strategies. Due to the limited length of this article, only an illustrative example will be given. Trading strategies based on Relative Strength Index (RSI) and Relative Momentum (RM) (Edwards, Magee and Bassetti, 2018) will be chosen for comparison.

Considering that the k-NN method is based on the existence of non-linear relationships in returns, it is advisable to verify the non-linearity of the data sample using the BDS test. The BDS test statistic is based on asymptotic estimates. However, it can lead to erroneous conclusions (Richardson and Stock, 1989). To avoid this problem, the bootstrap method was used. This method involves computing individual and combined statistical tests using samples of T-observations generated by weighing the original data. Bootstrapped p-values are calculated directly from the fraction of replications that fall outside the limits defined by the estimated statistics. The number of replications was set at 2500.

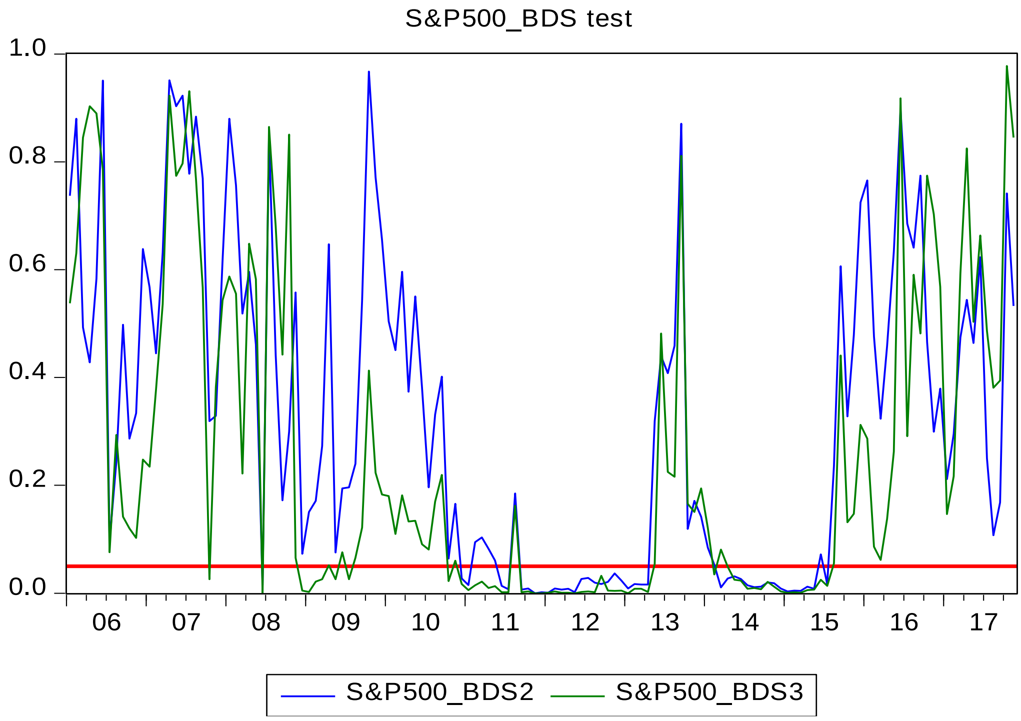

Figure 2 Bootstrapped p-values of the BDS test with nesting dimensions 2 and 3

In this article, the daily returns of S&P 500 index were chosen. Figure 2 shows the evolution of the *p*-values of the non-linear BDS test statistics for the S&P 500 index returns in 2006-2017. The values of BDS statistics were calculated for nesting dimensions 2 and 3 (marked by the symbols BDS2 and BDS3). The statistical significance of BDS tests will be evaluated on the 5% significance level, which is indicated in the graphs by a red horizontal line. The *p*-values were obtained on the basis of time series lasting 20 months. So, for example, the *p*-value for October 2008 corresponds to the data sample for the period from February 2007 to September 2008. Figure 2 shows that the null hypothesis of independence of returns was rejected in the years 2011-2012 and 2014-2015.

The daily closing rates of the S&P 500 index for the four-year period from January 1, 2011, to December 31, 2014, adjusted for dividends, became a basis for the calculations. This period was chosen on purpose. According to the results shown in Figure 2, the null hypothesis of independence was often rejected by the BDS test in that period. The data were obtained from http://finance.yahoo.com. A 3-month U.S. Treasury bill was chosen as a risk-free asset. Transaction costs c were chosen at the level of 5% of the price. The percentage δ of the standard deviation σ of the price differences was set at 5% as well (Georgiev, Kim and Stoyanov, 2015). The 14-day indicator for RSI calculation is recommended as the most suitable time period. The same frequency was therefore chosen for the RM indicator, when a value from the interval of 5-25 trading days is usually chosen (Veselá, 2019).

Table 1 shows a summary of the results of all 3 trading strategies. The profitability indicator shows the percentage of profitable trades out of the total number of trades made. The average return of each trading strategy represents the most important characteristic and is given in percentage. The results show that in the test period the *k*-NN strategy slightly outperforms the other two alternatives when considering the average yield. Of course, this is only an illustrative example of using historical data samples without actually investing money.

Strategy	**Profitability**	**Average yield**
k-NN strategy	84%	57%
RM 14 strategy	69%	48%
RSI 14 strategy	86%	53%

Table 1 Summary results of trading strategies

4 Discussion and conclusions

In this paper, the trading strategy based on the *k*-NN method was proposed. However, the aim of this paper was not to test that strategy on real data samples and thus provide statistical evidence of the effectiveness or ineffectiveness of the given market. The goal of this paper was to propose only the principle of a trading strategy that is based on nonlinear dependencies detected in returns, utilize Python programming language, and show an illustrative example on a real data sample. Buy or sell signals of the proposed strategy are generated by the nonlinear *k*-NN method. The *k*-NN method is based on similar principles (correlation integral and nesting dimensions) as the nonlinear BDS independence test. Therefore, one can see a direct connection between the results of statistical tests and the proposed trading strategy. Moreover, the article shows the direct utilization of the *k*-NN method in the Python programming environment, which is an increasingly popular tool also in empirical finance. The profitability of the proposed trading strategy was tested on real data from the US stock market in the period 2011-2014 when the results of the BDS test often confirmed non-linear dependencies in returns. Subsequently, the *k*-NN strategy was compared with trading strategies based on RSI and RM. Empirical results slightly favor a strategy based on the *k*-NN method. The proposed *k*-NN strategy should also be tested on data from other markets, for different types of assets, at different stages of market development, for different data frequencies, in subperiods of different lengths, and compared to other types of strategies as well. It would also be appropriate to verify statistically whether the profitability of the *k*-NN strategy is related to the results of the BDS test.

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Innovation project management: How to ideally adapt the project lifecycle to current challenges?

Michaela Staníčková[1], Lukáš Melecký[2]

Abstract. Requirements for project management skills and competences have been steadily on the rise across the majority of economic sectors, and demand for project managers is expected accelerate more than any other professions. The principles of project management are applied to the development activities facing most organizations today. Quality project management is a tool to successfully implement major changes in the life of a company, organization or public administration entity. Focused on the achievement of established goals and priorities, this method of management concentrates knowledge and skills for planning, organizing the preparation and subsequent implementation, securing and effective use of resources of all kinds. These processes are based on project management standards, i.e., methodologies for how projects are designed, managed, implemented and maintained. The question is whether the common and widely applied project management standards meet the needs of today's project management and project management. The aim of this paper is thus to present an alternative approach to project management in the form of the AIDIC model – one of the outputs of InnoPro project and practical courses for the Ministry of Regional Development of the Czech Republic.

Keywords: AIDIC Model, Innovation, Project Management, Skills, Tools.

JEL Classification: H43, M11, O22

1 Introduction

Requirements for project management skills and competences have been steadily on the rise across the majority of economic sectors, and demand for project managers is expected accelerate more than any other professions, according to the Project Management Institute (PMI). However, education of future project managers fails to fully meet the current requirements of the labor market and scientific research environment. The main motivation of the course entitled Innovation Project Management (InnoPro) is to enhance the professional competence of the target groups participating in the course in the area of project and innovation management. Within the Erasmus+ project InnoPro have been created the course with the new model of project management. The course places emphasis on the interconnection of knowledge in the fields of study of innovation and project management by defining a set of tools, templates and concepts to support project management work. Students will also improve a number of management skills (especially critical thinking, decision-making, planning, oral and written communication), as well as their preparedness for future career in both universities/research centers and the industry/companies. This will increase their employability on the labor market, attract young people to innovation, and support the utilization of R&D results in economies at

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the same time. The paper aims to introduce own approach to project management – AIDIC model.

2 Methodology

Two things are needed to create a new, innovative or alternative project management model. Firstly, knowledge of project management, orientation in existing approaches and applied standards, the overview and summary of which can be prepared on the basis of a literature search. And the second, perhaps far more fundamental, is practice - one's own project practice and personal activity and experience as a project manager – one could speak of field research.

For the first point, the above mentioned is realized through the method of literature review. A literature review is a survey of scholarly sources on a specific topic. It provides an overview of current knowledge, allowing identifying relevant theories, methods, and gaps in the existing research. A good literature review doesn't just summarize sources – it analyses, synthesizes, and critically evaluates to give a clear picture of the state of knowledge on the subject. Such a result of the literature review is part of the preparatory phase – especially literature review about project management approaches worldwide and the EU context, EU project management methodology, tools and techniques were analyzed, the most relevant ones were compared and evaluated, including partial specifications and advantages and disadvantages of each of them. This comparison is made on the basis of the comparative method. Comparative research is a research methodology in the social sciences that aims to make comparisons across different topics and areas of research interest. Comparison is a fundamental tool of analysis. It sharpens powers of description, and plays a central role in concept-formation by bringing into focus suggestive similarities and contrasts among cases.

For the second point, after we have set the problem and aim, we should also think about what methods and techniques of “data” collection we will use in the field research. The use of qualitatively oriented methodological approaches is particularly significant for this research, as they can capture the phenomenon under study in more depth. First of all, this involves participant observation, various types of interviews, content analysis of documents, but it can also be quantitative research in the form of a questionnaire. Of course, it is good to choose the methods according to the nature of the research problem in advance, but even here the methods may change in the course of the solution, i.e., during the fieldwork. The methodology applied is the so-called field research. Field research – also field investigation, field study – these are terms used either as synonyms of empirical research, or to denote the field phase of empirical research, also in the sense of research in natural conditions in opposition to experimental investigation, or in the sense of field work. Sometimes field research, and more likely its synonyms, is associated with case study and direct observation. In this sense, it is particularly typical of social and cultural anthropology (Soukup, 2017). The paper is thus based on personal experience, i.e., field research and knowledge gained through several years of conducting seminars for the Ministry of Regional Development of the Czech Republic, whose focus is the education of applicants and beneficiaries of EU Funds. “Data”, resp. not only the own experience, but also the experience of wide group of project managers, are obtained on the basis of personal involvement, i.e., lecturing seminars for Ministry of Regional Development. Specifically, the seminars are EU Grants and Project Management, EU Grants and Financial

Management, and EU Grants and Cost-Benefit Analysis. The seminars thus cover a wide range of project manager activities and are a relevant platform for setting up innovative project cycle management model.

3 Innovation Management System – Theoretical Base

The *Oslo Manual* (OECD, 2018) defines **innovation management** as *all systematic activities to plan, govern and control internal and external resources for innovation. This includes how resources for innovation are allocated, the organisation of responsibilities and decision-making among employees, the management of collaboration with external partners, the integration of external inputs into a firm's innovation activities, and activities to monitor the results of innovation and to support learning from experience* (OECD/Eurostat, 2018, p. 91). In parallel with work to produce the fourth edition of the Oslo Manual, the OECD established a relationship with the International Organisation for Standardisation's (ISO) Technical Committee (TC) on Innovation Management, responsible for developing standards for the Innovation Management ISO 56000 series, whose secretariat is held by AFNOR, ISO's member for France. The ISO 56000 family of standards is integrated by the following published documents:

- ISO 56000: 2020, Innovation management – Fundamentals and vocabulary.
- ISO 56002: 2019, Innovation management – Innovation management system Guidance.
- ISO TR 50004: 2019, Innovation management assessment – Guidance.
- ISO 50003: 2019, Innovation management – Tools and methods for innovation partnership - Guidance.

It also has several standards in development, including:

- ISO 56005, Innovation management – Tools and methods for intellectual property management – Guidance.
- ISO 56006, Innovation management – Strategic intelligence management – Guidance.
- ISO 56007, Innovation management – Idea management.
- ISO 56008, Innovation management – Tools and methods for innovation operation measurements – Guidance.

An **innovation management system** is a set of interrelated and interacting elements, aiming for the realisation of value. It provides a common framework to develop and deploy innovation capabilities, evaluate performance, and achieve intended outcomes (see Figure 1). The elements can be gradually adopted to implement the system according to the particular context and circumstances of the organisation. Full benefits can be gained when all the elements of the innovation management system are adopted by the organisation (ISO, 2019). Ultimately, the effective implementation of the innovation management system relies on the commitment by top management and the ability of leaders to promote innovation capabilities and a culture supporting innovation activities. These activities are usually organised and managed through well-defined projects. Following ISO 21500: 2012, **a project** can be defined as a *unique set of processes consisting of coordinated and controlled activities with start and end dates, performed to achieve project objectives* (ISO, 2012, p. 3), while **project management** – which constitutes the main objective of this course – is *the application of methods, tools, techniques and competencies to a project* (ISO, 2012, p. 4).

The structure of the guiding standard for innovation management ISO 56002: 2019 covers seven key elements:

- **Context**: The organisation should track external and internal issues and trends, e.g., user preferences, technology developments, and internal capabilities, in order to identify opportunities and challenges that can trigger innovation activities.
- **Leadership**: Based on the understanding of the context, top management should demonstrate leadership and commitment by establishing an innovation vision, strategy, and policy, including the necessary roles and responsibilities.
- **Planning**: Innovation objectives, organisational structures, and innovation portfolios, i.e., collection of innovation projects that are grouped together to facilitate their effective management in order to meet strategic goals, should be established based on the direction set by top management and the identified opportunities and risks.
- **Support**: The support necessary for innovation activities should be put in place, e.g., people with the right competences, financial and other resources, tools and methods, communication and awareness creating activities, as well as approaches for intellectual property (IP) management.
- **Operations**: Innovation initiatives should be established in line with the strategies and objectives. Innovation processes should be configured according to the types of innovations to be achieved, namely opportunities identified, concepts created and validated, and solutions developed and deployed.
- **Evaluation**: The performance of the Innovation Management System as a whole should regularly be evaluated to identify strengths and gaps.
- **Improvement**: Based on the evaluation, the system should be improved by addressing the most critical gaps with regards to the understanding of the context, leadership, planning, support, and operations.

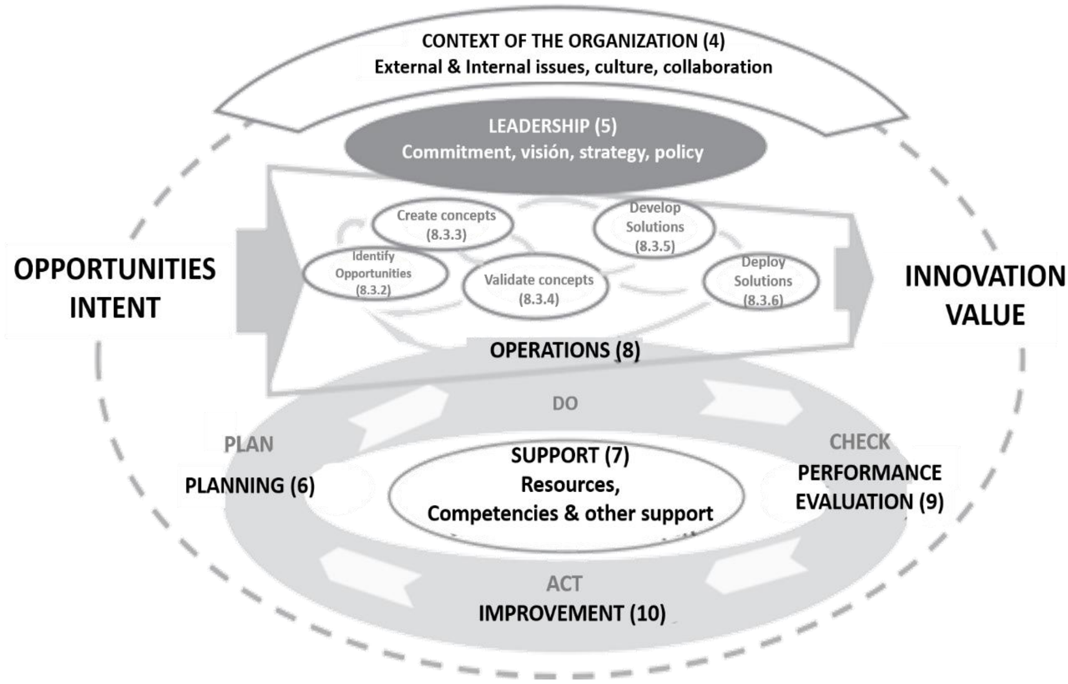

Figure 1 Framework of the Innovation Management System with References to the Clauses of ISO 56002:2019 [ISO, 2019]

4 InnoPro Course – AIDIC Model – Concept, Basis and Structure

The course InnoPro gathers the key elements of innovation, innovation processes and innovation management systems developed by means of the **AIDIC** (**A**ssessment-**I**nitiation-**D**esign-**I**mplementation-**C**losure) model, which represents a unique approach in the general project cycle methodology, described in Module 2 and developed in detail in stages 1 (Assessment) to 5 (Closure). The InnoPro course provides an overall understanding of innovation project management from a wider perspective.

The concept of the AIDIC model aims to provide an overall understanding of successful project management and project implementation. This module captures the key elements of project management, project implementation, project management information systems, security, safety and ethical issues. It deals with project management from a wider perspective and defines a set of approaches and concepts to support future projects and the delivery of day-to-day project management work.

The AIDIC model may be read from cover to cover to learn about the methodology, or it may be used as a reference in the process of familiarisation with the project cycle. It represents a simple, easy-to-implement methodology which project teams can tailor to their specific needs. AIDIC model is fully supported by a comprehensive training programme (including workshops and e-learning sessions) and documentation of all model outputs, materials and activities within online course on the LMS Moodle platform. The AIDIC model concept incorporates elements from a wide range of globally accepted project management best practices, captured in standards and methodologies. Its development has also been influenced by operational experience on various projects both within the European Union (EU) Institutions and external bodies.

4.1 AIDIC Model Description

At the start of a project, the amount of planning and work required can seem overwhelming. There may be dozens or even hundreds of tasks that need to be completed at just the right time and in just the correct sequence. Seasoned project managers know it is often easier to handle the details of a project and take steps in the right order when the project is broken down into phases. Dividing project management efforts into these five phases can help give efforts structure and simplify them into a series of logical and manageable steps.

There are many different models for the phases a project goes through during its life cycle. At the simplest level, a project has a beginning, middle, and end. During the course, a more complex approach is adopted, using the life-cycle model and terminology which is shown in **Table 2**, although other versions can be equally valid. The AIDIC model of project lifecycle presented in our Innovation Project Management course is based on the basic concept of the project cycle within the well-known **IPEC model** (**I**nitiate-**P**lan-**E**xecute-**C**lose) mainly based on *Project Management Institute* (PMI) methodology but has been organically adapted to the needs of this course.

Based on the PMI methodology, a Project Management Process Group is a logical grouping of project management processes to achieve specific project objectives. Process groups are independent of project phases and steps. Project management processes of IPEC model are usually grouped into the following five Project Management Process Groups (PMI, 2017):

- **Initiating Process Group:** Those processes performed to define a new project or a new phase of an existing project by obtaining authorisation to start the project or phase.
  - **Project Initiation:** Initiation is the first phase of the project lifecycle. This is where the project's value and feasibility are measured. Project managers typically use two evaluation tools to decide whether or not to pursue a project:
    - *Business Case Document* – this document justifies the need for the project, and it includes an estimate of potential financial benefits.
    - *Pre-feasibility Study* or *Feasibility Study* – this is an evaluation of the project's goals, timeline and costs to determine if the project should be executed. It balances the requirements of the project with available resources to see whether it is sensible to pursue the project.
  - Teams abandon proposed projects that are labelled unprofitable and/or unfeasible. However, projects that pass these two tests can be assigned to a project team or a designated project office.
- **Planning Process Group**: Processes required to establish the scope of the project refine the objectives and define the course of action required to attain the objectives that the project is to achieve.
  - **Project Planning:** Once the project receives the green light, it needs a solid plan to guide the team, as well as keep it on time and budget. A well-written project plan or design gives guidance for obtaining resources, acquiring financing and procuring required materials. The project plan gives the team direction for producing quality outputs, handling risk, creating acceptance, communicating benefits to stakeholders and managing suppliers.

    - Project plan also prepares teams for obstacles they may encounter throughout the project and helps them understand the cost, scope and timeframe of the project.

- **Executing Process Group**: Processes performed to complete the work defined in the project management plan to meet project requirements.
    - **Project Execution/Implementation:** This project phase is most commonly associated with project management. The execution consists in building deliverables that satisfy the customer. Team leaders make this happen by allocating resources and keeping team members focused on the assigned tasks.
    - The execution relies heavily on the planning phase. The work and efforts of the team during the execution phase are derived from the project plan.

- **Monitoring and Controlling Process Group**: Those processes required to track, review, and regulate the progress and performance of the project; identify any areas in which changes to the plan are required, and initiate the corresponding changes.
    - **Project Monitoring and project control:** Monitoring and control are sometimes combined with execution because they often co-occur. As teams execute their project plan, they must constantly monitor their progress.
    - To guarantee delivery of what was promised, teams must monitor tasks to prevent scope creep, calculate key performance indicators and track variations from the allotted cost and time. This constant vigilance helps keep the project moving ahead smoothly.

- Closing Process Group: Processes performed to formally complete or close the project, phase, or contract.
    - **Project Closure:** Teams close a project when they deliver the finished project to the customer, communicating completion to stakeholders and releasing resources to other projects. This vital step in the project lifecycle allows the team to evaluate and document the project and move on the next one, using previous project slips and successes to build stronger processes and more successful teams.

4.2 AIDIC Model and Parallel Approaches: Breakdown and Structure

The project management processes are linked by specific inputs and outputs where the result or outcome of one process may become the input to another process that is not necessarily in the same Process Group. Although project management may seem overwhelming at times, breaking it down into these five distinct cycles can help the team manage even the most complex projects and use time and resources more wisely.

Based on the common methodology of the *European Commission – Centre of Excellence in Project Management*, the IPEC project lifecycle has four phases with a different type of activity predominant in each phase (i.e., initiating activities are predominant in the Initiating phase, etc.), as shown in Figure 2. However, while phase-related activities peak in terms of effort during a specific phase, activities of this type can also be executed during neighbouring phase(s) (e.g., planning activities are also repeated in the Executing phase). A project moves on to the next phase when the goals of its current phase have been deemed achieved as the results of a formal (or less formal) phase-exit review.

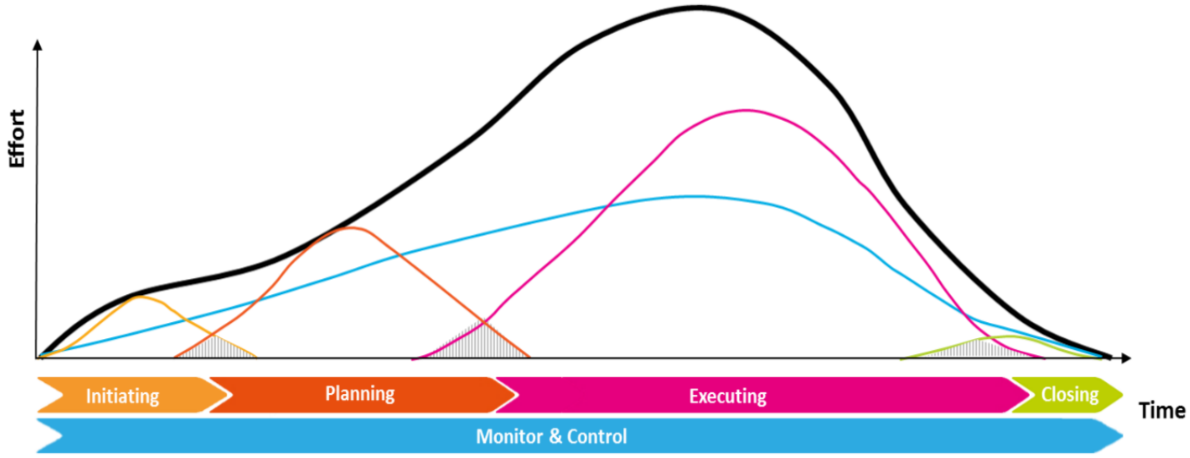

Figure 2 The IPEC Project Lifecycle based on PM² Project Management Methodology [European Commission. Centre of Excellence in Project Management, 2018]

The focus of a project shifts from initiating and planning activities at the beginning to executing, monitoring and controlling activities in the middle, and acceptance, transitioning and closing activities at the end. Description of the individual phases is given in Table 1.

Phase	Description
Initiating	Define the desired outcomes. Create a Business Case. Define the project scope. Get the project off to a good start.
Planning	Assign the Project Core Team. Elaborate on the project scope. Plan the work.
Executing	Coordinate the execution of project plans. Produce deliverables.
Closing	Coordinate formal acceptance of the project. Report on project performance. Capture Lessons Learned and post-project recommendations. Close the project administratively.
Monitoring and Controlling	Oversee all project work and management activities throughout the project: monitor project performance, measure progress, manage changes, address risks and issues, identify corrective actions etc.

Table 1 Description of Project Lifecycle Phases based on PM² [European Commission. Centre of Excellence in Project Management, 2018]

Inexperienced project teams sometimes underestimate the importance of the work done in the initial project phases and start working on deliverables that are inadequately defined or planned. This results in the delivery of outputs which are of poor quality and little value to end-users. This is a common and costly mistake, which is often the root cause of overall project failure and the failure to realise the intended benefits of the project.

In the case of the AIDIC model, presented in InnoPro course, it is noticeable that every project begins as a concept, which is always “fuzzy” and that the project team must formalise the definition of the job before doing any work.

The AIDIC model is created based on the following project management methodologies and approaches:

- *The Project Management Institute (PMI)* – The Project Management Body of Knowledge (PMBOK® Guide).
- *The International Project Management Association (IPMA)* – Individual Competence Baseline (ICB 4.0).
- *The European Commission Centre of Excellence in Project Management (CoEPM²)* – PM² Project Management Methodology.
- *The European Commission EuropeAid Cooperation Office (EuropeAID)* – Project Cycle Management (PCM) Guidelines.

The AIDIC model includes the following project cycle stages:

- **A**ssessment.
- **I**nitiation.
- **D**esign.
- **I**mplementation.
- **C**losure.

In line with practice and international standards. Being able to plan and manage a project properly and well is a master skill. It is always a combination of experience, skills and knowledge. Perhaps the InnoPro project, its course and the AIDIC model developed could help. Breakdown and structure of the AIDIC Model displays Figure 3.

STAGE	GENERAL DESCRIPTION	SUB-STAGE	STEPS	PROJECT OUTPUTS	TOOLS and TEMPLATES
ASSESSMENT	• The organisation defines needs and commissions the project to meet it	• Assessment of the problem, need or opportunity to start a project • Innovation opportunities analysis	• Formalisation of problem, need or opportunity to start a project • Innovation prospective	• Project Initiation Request (PIR) • Innovation project report	*Tools:* • PIR Form *Templates:* • Mindtools.com
INITIATION	The tasks required to authorise, fund and define the project, generally on the organisational level (above the project)	• Project identification and definition • Initial project budget allocation • Primary project stakeholder's identification • Fundraising	• Project Purpose • Project Goals/Questions • Project Scope • Project Deliverables • Project Stakeholders • Grant Resources • Instruments for financing innovations • Public procurements	• Project Initiation Plan • Project Charter • Project Scope Statement • Stakeholder Analysis • Grant Resources Analysis	*Tools:* • Mind Map • Logical Framework Matrix (LFM) • Project Charter Template • Grant Resources Analysis *Templates:* • Coggle.it • Carleton.ca • Easyproject.com • Smarthseet.com • Vertex42.com • Logframer.eu
DESIGN	• The project management team define how the project will be carried out, who will do the work, how long it will take, and so forth • The planning phase defines the project in sufficient detail that all stakeholders' expectations are understood	• Creating of workflow project • Estimating project time and budget • Gathering resources • Risk assessment • Project communication • Monitoring & Controlling	• Scope of Work • Project Milestones • Project Scheduling • Project Budgeting • Resource Plan • Identification and management of project risks • III.7: Communication requirements and rules • III.8: Monitoring of project performance and progress, managing changes, addressing risks	• Statement of Work • Gantt Chart • Project Plan (Success Factors, Deliverables, Schedule, Budget, Human resource, Quality management) • Risk management plan • Procurement management plan • Project status report and project change documentation	*Tools:* • Work Breakdown Structure • Organisation Breakdown Structure • Responsibility Assignment Matrix • Gantt Chart • Cost Breakdown Structure • Resource Breakdown Structure • Risk Assessment Tool • Communication Matrix *Templates:* • Easyproject.com • Smarthseet.com • Vertex42.com • MS2021+ (for the Czech Republic)

Figure 3a Breakdown and Structure of the AIDIC Model [Own elaboration, 2022]

STAGE	GENERAL DESCRIPTION	SUB-STAGE	STEPS	PROJECT OUTPUTS	TOOLS and TEMPLATES
IMPLEMENTATION	• The project work is completed and the final product or service is achieved while secondary stakeholder requirements are satisfied • Concurrent to the project work the project management team monitors and controls all aspects of the project – schedule, cost, stakeholder's requirements, etc. • If problems are encountered, changes to the project plan are made	• Briefing team members • Monitoring quality of work • Validity and up-to-date innovations • Managing budget and earned value • Monitoring & Controlling	• Kick-off meeting • Project status • Change request • Prospective and technology watching • Project outputs handovers • Acceptance of project implementation • Monitoring of project performance and progress, managing changes, addressing risks	• Kick-off meeting minutes (agenda) • Project status report • Status updates and project change documentation • Stakeholder communication • Earned value analysis (EVA) • Project checklist • Technology watching report and business plan	*Tools:* • Kick-off Meeting Template • EVA Template • Project Checklist Template • Change Management Document Template • Progress Project Report Template • Business plan template *Templates:* • Easyproject.com • Smarthseet.com • Vertex42.com • MS2021+ (for the Czech Republic)
CLOSURE	• The project has completed its product or service, and the necessary documentation and administrative work must be done to close the project • Exploitation of results	• Project reporting • Analysing project and team results • Project documentation closure • Project evaluation • Intellectual and industrial property aspects • Monitoring & Controlling	• Public Procurement procedures evaluation • Instruments of industrial and intellectual property protection • Final beneficiary and subsidy provider acceptance • Project archiving • Lessons learned • Monitoring of sustainability of project outputs, managing changes, addressing risks	• Project checklist • Patents, utility models and/or industrial design • Project final report • Accounting report • Project sustainability report	*Tools:* • Final Project Report Template *Templates:* • Easyproject.com • Smarthseet.com • Vertex42.com • MS2021+ (for the Czech Republic)

Figure 3b Breakdown and Structure of the AIDIC Model [Own elaboration, 2022]

5 Conclusion

Project management has become a core competency, and nearly every manager is involved in managing one or more projects. Moreover, the role of projects in organisations is receiving increasing attention. Today, project management can be seen as a professional discipline with its own body of knowledge and skills. Project management expertise can benefit any kind of organisation. In order to focus on how projects, contribute to the strategic goals of an organisation, a holistic, integrative view of project management provides the most value. This view should also include the process of selecting projects that can provide the best support for a particular organisation's strategy. Moreover, several project management models exist.

Everyone manages projects, even if not everyone realizes it. In fact, the project is a fundamental tool for managing the changes that happen to all of us. But everyone - individual and company alike – has different needs. A small team or individual handling units of projects at the same time needs a simpler tool to keep track of tasks, time worked and project income and costs; on the other hand, a company with 50 or 100 employees handles dozens or hundreds of smaller or larger projects simultaneously – some at a strategic level, others at an operational level. Here, prioritization of projects is already necessary, linked to resource utilization and capacity management – ideally all transparent through the whole company, otherwise it is common that operational issues eat up resources for strategic projects, which then do not move forward, and the company loses competitiveness. And that's not all, these activities are commissioned, coordinated, communicated by someone – person – project manager. Clearly, you need to know and, more importantly, be able to apply both the hard and soft competencies of a project manager, and ideally all of them and combine them well, i.e., a mix.

In conclusion, although this is obvious and familiar, it is not too much to repeat: How do we know if we have set up announced project cycle correctly? By successfully completing the project that: met its objectives; met a predetermined measurable purpose; is not over budget; met the schedule; eliminated potential risks; made effective use of all resources; and has a positive impact on society. Generally, for all projects and times. And what is a recipe for successful project management? Trust in the team and accountability of individual members is an essential ingredient for a long-lasting team. In addition, need to think about regular feedback to help the team move forward in reality of project management practice.

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Ecological-economic Efficiency Analysis of EU Pulp and Paper Manufacturers Participating in the EU ETS

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Abstract. The paper industry is not even under the pressure of digitization disappearing. The industry is just transforming and developing, which is associated with a higher production of CO2 emissions. The companies in the EU ETS need to deal with limited number of emission allowances to achieve climate neutrality in the EU by 2050. The goal of the paper is to assess the performance of the EU paper manufacturers in terms of the efficiency. To do this, a hybrid PROMETHEE – DEA method is used. The presented model contains both economic and environmental indicators. The results show that only 2 companies behave efficiently, and the rest should improve their performance.

Keywords: Eco-Efficiency Analysis, PROMETHEE, DEA, EU Emissions Trading System, Carbon allowances.

JEL Classification: C61, H21, O44, Q56

1 Introduction

Paper industry is heavily impacted by digitization, but it does not mean, that the paper and forest-products industry is disappearing. On the contrary, the industry is growing, because other products are filling the gap left by the graphic paper. For example, packaging is growing all over the world. The paper industry is also far from disappearing, it is just changing and developing.

The development of the segment is also associated with a higher energy use and production of CO2 emissions. The pulp and paper industry is among the top five most energy-intensive industries globally and is the fourth largest industrial energy user. The pulp and paper sector was responsible for about 190 Mt of CO2 emissions in 2021, about 2% of all emissions from industry (IEA, 2022; Berg and Lingqvist, 2019).

In 2021, the European Commission adopted a series of legislative proposals setting out how it intends to achieve climate neutrality in the EU by 2050, including the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030.

The overall volume of greenhouse gases that can be emitted by industry factories covered by the EU Emissions Trading System (EU ETS) is limited by a 'cap' on the number of emission allowances. Within the cap, companies receive or buy emission allowances, which they can trade as needed. The cap decreases every year, ensuring that total emissions fall (European Commission, 2021).

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The aim of the performed analysis was to evaluate companies in the paper industry from an environmental but also economic point of view, taking into account also the allocated allowances. Their efficiency was evaluated based on several comparative criteria. For the analysis was used the hybrid PROMETHEE – DEA method introduced by Ishizaka (2018).

Peng et al. (2015) analyse the negative factors in the pulp and paper sector by calculating energy efficiency from the lengthways time and investigating the gap between China and foreign countries through a horizontal comparison. Pandey and Prakash (2018) present energy auditing of a paper industry (Orient Paper Mills) in India.

Vershinina et al. (2020) present the results of analysing the efficiency of the following five fuel types: dry coal, wet coal processing waste, coal–water slurry, and two waste-derived slurries. They employed 16 criteria related to the energy industry, economy and also the environmental protection and they analysed three countries: Japan, China and Russia. The total performance indicator was calculated using three multiple-criteria decision analysis techniques: weighted sum method, weighted product method and analytic hierarchy process.

The paper is organized as follows. The information about the methodology and applied methods are in Section 2, followed by description of input data and comparison criteria in Section 3. In section 4, results of the analysis are presented. There is also the graphical representation of results clearly illustrates a company’s position relative to its competitors. Article is finished with the concluding messages in Section 5.

2 Methodology

The efficiency evaluation can be done using various quantitative methods. The main 3 possibilities are as follow:

- Stochastic Frontier Analysis (SFA),
- Data Envelopment Analysis (DEA),
- Multi-attribute decision making methods (MADM).

All 3 mentioned approaches have advantages as well as drawbacks. SFA is a parametric approach which require the definition of the functional form and, moreover, it allows to work with only one systems output. Therefore, SFA is not suitable in this paper. DEA is probably the most popular approach; it allows to set any number of inputs and outputs (under assumption of sufficiently great number of evaluation units). However, many situations (negative and zero values, missing data, desirable inputs and undesirable outputs, etc.) require to use special models which makes the application less user-friendly. MADM methods were not originally aimed at efficiency evaluation, but their extensions allow it. In this paper, the hybrid combination of PROMETHEE MADM method together with the additive DEA model is used. This method proposed by Ishizaka, Resce and Mareschal (2018) do not suffer from the drawbacks mentioned for DEA because the performance is evaluated using the PROMETHEE MADM method. The additive DEA model is used to quantify the inefficiency of the units.

The algorithm of the PROMETHEE method, which has been introduced by Brans and Vincke (1985), was described many times in the literature. Therefore, the algorithm is provided in this text very briefly, in a very short manner, and with the understandable focus on efficiency measuring.

Let us assume the set of m inputs I and k outputs O, and n units to be evaluated. Then, let x_{ij} be the performance of the unit i in terms of factor (input or output) j. The evaluation is done using the so-called preference function P^I and P^Oassigned to each input and output. The preference function must be non-decreasing, with range from 0 to 1, with zero functional value for arguments less than or equal to 0. This function is applied to the difference in performance of each pair of evaluated units i,j in terms of each factor k: $\Delta x_{ij}^k = x_{ik} - x_{jk}$ if the greater values of the factor k are preferred over lower values, and $\Delta x_{ij}^k = x_{jk} - x_{ik}$ vice versa. The original ranking PROMETHEE algorithm assumes the weights w assigned to criteria. For the efficiency evaluation, we consider equal weights for all inputs $w_i^I = \frac{1}{m}$ and outputs $w_j^O = \frac{1}{k}$. Then, the aggregated performance of unit y in terms of inputs and outputs is given by:

$$\phi_{Iy} = \frac{\sum_{j\neq y}^{n} \sum_{i=1}^{m} w_i^I \cdot P_i^I(\Delta x_{yj}^i)}{n-1} - \frac{\sum_{j\neq y}^{n} \sum_{i=1}^{m} w_i^I \cdot P_i^I(\Delta x_{jy}^i)}{n-1} \tag{1}$$

$$\phi_{Oy} = \frac{\sum_{j\neq y}^{n} \sum_{i=1}^{k} w_i^O \cdot P_i^O(\Delta x_{yj}^i)}{n-1} - \frac{\sum_{j\neq y}^{n} \sum_{i=1}^{m} w_i^O \cdot P_i^O(\Delta x_{jy}^i)}{n-1} \tag{2}$$

Using (1) and (2), each unit is given by a tuple $[\phi_{Iy}, \phi_{Oy}]$, which enters the DEA model.

To make the differences among units as great as possible, the linear preference function is used in this study, see Brans and Vincke (1985). Namely, the settings with the increasing part for Δx_{ij}^k between 0 and the range of the performance values for the given factor k (input/output) across all units.

The additive DEA model measuring the distance of the unit k from the efficient frontier by changing the performance in inputs is as follows (Ishizaka, Resce and Mareschal, 2018):

$$\begin{aligned} \max \quad & \Delta\phi_{Ik} \\ \text{s. t.} \quad & \Phi_{Ik} = \sum_{j=1}^{n} \Phi_{Ij}\lambda_j - \Delta\Phi_{Ik} \\ & \phi_{Ok} \geq \sum_{j=1}^{n} \phi_{Oj}\lambda_j \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \lambda_j \geq 0; j = 1, \dots, n \\ & \Delta\phi_{Ik} \geq 0, \end{aligned} \tag{3}$$

where $\Delta\phi_{Ik}$ is the input distance to the frontier for the actions k under evaluation, λ_j is one element of the intensity vector.

Similarly, the following optimization model has to be solved for each DMU k to measure its distance from the efficient frontier.

$$\max \quad \Delta\,\phi_{Ok} \tag{4}$$

$$
\begin{aligned}
\text{s. t.} \quad & \phi_{Ik} \geq \sum_{j=1}^{n} \phi_{Ij}\lambda_j \\
& \phi_{Ok} = \sum_{j=1}^{n} \phi_{Oj}\lambda_j - \Delta\phi_{Ok} \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0; j = 1, \dots, n \\
& \Delta\phi_{Ok} \geq 0,
\end{aligned}
$$

where $\Delta\phi_{Ok}$ is the output distance to the frontier for the actions k under evaluation.

The minimum distance to the frontier is quantified by the PPA_k measure, see (5).

$$PPA_k \;= \min\,[\Delta\Phi_{Ik}, \Delta\Phi_{Ok}] \tag{5}$$

3 Input data

The paper producing EU companies are used as DMUs in the model. Companies, covering 90% of paper production for which the input data are available, are used.

	Company		**Company**
DMU1	Stora Enso	**DMU11**	Lenzing
DMU2	Smurfit Kappa Group	**DMU12**	Fedrigoni Group
DMU3	Sappi	**DMU13**	Kemira
DMU4	SCA – Svenska Cellulosa Aktiebolaget	**DMU14**	Arctic Paper
DMU5	Mondi	**DMU15**	Grupo Empresarial Ence
DMU6	Metsä	**DMU16**	Mercer International
DMU7	Norske Skog	**DMU17**	Savon Sellu
DMU8	Munksjö	**DMU18**	Trierenberg Holding
DMU9	Cascades	**DMU19**	Arjowiggins
DMU10	Holmen Paper	**DMU20**	Heinzel Group

Table 1 Compared alternatives

Alternatives were compared according to 8 criteria, divided into inputs and outputs, see Tables 1 and 2.

Inputs	Units
Allocated allowances	Tonnes of CO2 equivalent
Number of employees	Number of employees

Table 2 Inputs

Outputs	Units
Production of greenhouse gas emissions	Tonnes of CO2 eq.
Net profit	EUR
Earnings Before Interest, Taxes, Depreciation and Amortization	EUR
Paper production	Tonnes
Return on capital employed	%
Personnel expenses	EUR

Table 3 Outputs

The set of factors was compiled so that the alternatives can be evaluated both, environmentally and economically. Factors were divided to 2 inputs and 6 outputs. As inputs enter the criteria *Allocated allowances* and *Number of employees*. Both inputs have a key value in evaluating efficiency of companies in the EU ETS trading system, in which is limited number of emission allowances to achieve climate neutrality. The rest of criteria are the outputs. *Production of greenhouse gas emissions* is, due to the analysis evaluating the environmental impacts, indispensable factor. The other outputs are more economical, but also very important when evaluating efficiency. *EBITDA (Earnings before interest, taxes, depreciation, and amortization)* is an alternate measure of profitability to net income. By stripping out the non-cash depreciation and amortization expense as well as taxes and debt costs dependent on the capital structure, EBITDA attempts to represent cash profit generated by the company's operations. It is widely used measure of corporate profitability and that is why it has its place also in this paper. The indicator ROCE is important in company's efficiency evaluation as well because it measures the company's profitability after factoring in the capital used to achieve that profitability. The criterion *Personnel expenses* was added to the analysis to check, if the inefficiency of the units is not caused by too high employee costs, instead of low turnover.

All information about companies was found in their official reports published on their websites.

4 Results

Based on the analysis, 2 effective units were determined, namely DMU7 and DMU18 (see Figure 1). The red line represents the PPA frontier. Table 4 provides the list of the alternatives sorted by their efficiency.

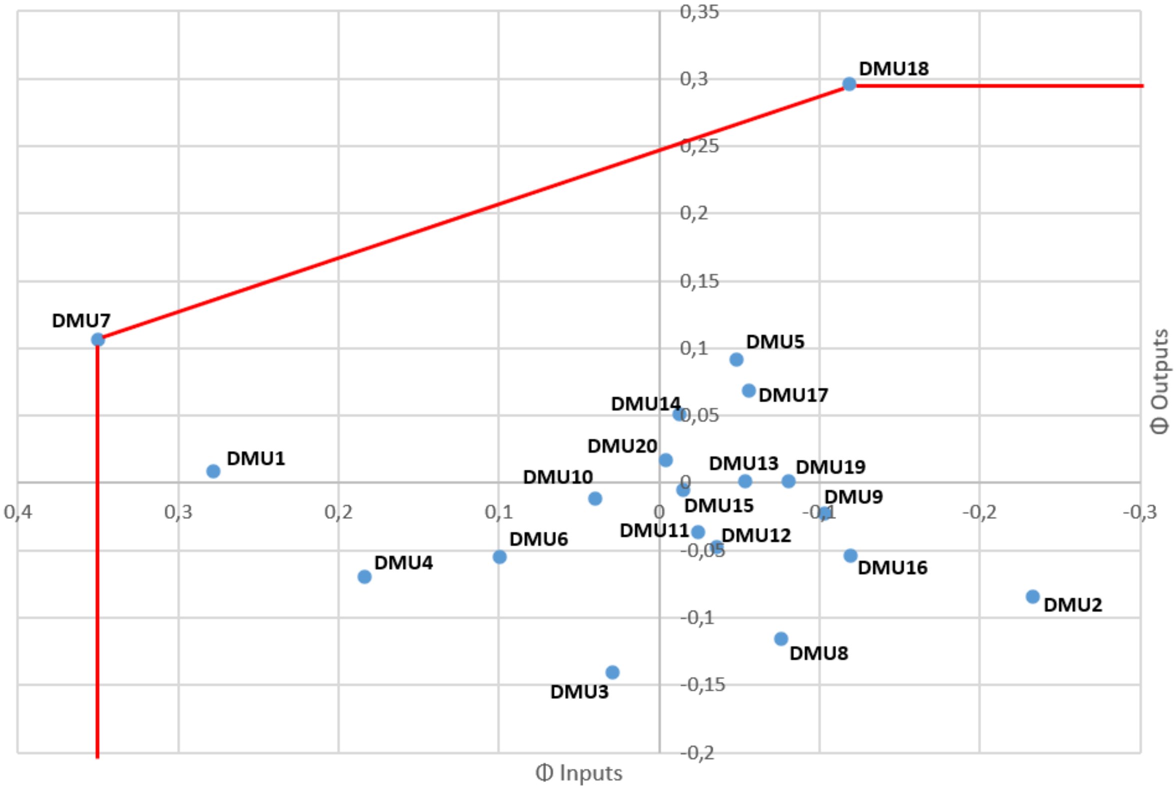

Figure 1 Efficiency frontier

5 Conclusion

In this paper, we have used the combination of multi-attribute decision making method PROMETHEE and DEA to evaluate the performance of the companies in paper industry in EU. The issue of air pollution caused by excessive emissions of greenhouse gases is not only a question for ecologist but also for economists. Within this work, the analysis was performed, taking into consideration both environmental criteria and economic factors.

According to the analysis result are efficient only 2 companies, namely the Norske Skog (DMU7) and the Trierenberg Holding (DMU18). According to the amount of the allocated allowances were with significantly difference best rated two companies, the effective one DMU7 and the DMU1, which is approaching the efficient frontier. The DMU18 was very well evaluated according to 3 of outputs, Net profit, EBITDA and Emissions production. No wonder it stands out significantly above the rest of DMUs.

DMU	Φ_I	Φ_O	$\Delta\Phi_I$	$\Delta\Phi_O$	PPA_k
DMU7	0.2781	0.0088	0.0000	0.0000	0.0000
DMU18	-0.2329	-0.0843	0.0000	0.0000	0.0000
DMU1	0.0291	-0.1405	0.0719	0.1263	0.0719
DMU4	0.1839	-0.0695	0.1661	0.2428	0.1661
DMU6	-0.0485	0.0912	0.2503	0.1705	0.1705
DMU5	0.0997	-0.0548	0.3985	0.1764	0.1764
DMU14	0.3499	0.1059	0.3623	0.2016	0.2016
DMU17	-0.0757	-0.1153	0.4062	0.2021	0.2021
DMU20	-0.1032	-0.0223	0.3538	0.2327	0.2327
DMU10	0.0397	-0.0115	0.3102	0.2433	0.2433
DMU15	-0.0239	-0.0366	0.3653	0.2579	0.2579
DMU13	-0.0360	-0.0471	0.4037	0.2687	0.2687
DMU19	-0.0537	0.0010	0.4303	0.2793	0.2793
DMU11	-0.0124	0.0513	0.3739	0.2942	0.2942
DMU12	-0.0153	-0.0050	0.3860	0.3096	0.3096
DMU9	-0.1197	-0.0540	0.4531	0.3121	0.3121
DMU3	-0.0563	0.0687	0.3209	0.3766	0.3209
DMU16	-0.1185	0.2960	0.4696	0.3500	0.3500
DMU2	-0.0803	0.0012	0.5829	0.3802	0.3802
DMU8	-0.0039	0.0168	0.4256	0.3940	0.3940

Table 4 Emotional intelligence

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Discovery of Company-related Hashtags using Association Rules Mining

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Abstract. Data analysts spend a significant amount of time with data collection. Reducing the time required for this activity by at least a bit by automation could reduce the total costs of data analysis projects. In this paper, we examine possibilities of such automation process in terms of Twitter-based user input. We focus on a single task: detection of hashtags related to a specific company. Inclusion of posts containing such hashtags may lead to improvements in tasks such as sentiment analysis. We propose an association-rule based approach for automatic discovery of such related hashtags. Experiments show that the suggested solution provides useful results, although requiring some manual post-processing. The most significant downside of the method is the inclusion of hashtags that are too general. We attempt to mitigate this issue by defining *specificity ratio* for each hashtag identified as related by the association-rule mining algorithm. The problem of hashtag generality as well as other limitations and proposals for future research are further discussed.

Keywords: hashtag discovery, association rule mining, Twitter responses mining.

1 Introduction

Data scientists spend a significant amount of time collecting data relevant to their studies and models. According to CrowdFlower (2016) this activity represents about 19 % of their workload. This ratio is slightly lower in a more recent work presented in Hayes (2019) according to which, the average fraction of time spent by gathering data is 16.8 %. A survey results in CrowdFlower (2017) also show that about 51 % of the data analysts' time is spent by "collection, labeling, cleaning and organization of data". Hence, we assume that even partial automation of the data collection tasks might help to reduce the total costs of some data science projects and potentially improve the quality of the results as well.

This paper examines the possibility of such partial automation in context of Twitter data. Twitter is a popular source of data among analysts and researchers. Google Scholar reports more than 6.9 million search results for the term "twitter data" and more than 350 000 results for "twitter sentiment" as of time of writing.

Twitter users frequently use hashtags to signal the relationship between their post and some broader topic discussed on the social network. In many research use cases, hashtags can be utilized to identify posts, often referred to as *tweets*, that are relevant to a certain study. Identification of relevant hashtags is, therefore, required before the data is be collected.

We propose a semi-automated method of relevant hashtag discovery for a specific use case:

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analysis of sentiment expressed towards a certain company. For such use case, one would naturally expect relevant tweets to contain a hashtag written as the company name, e.g., $\#microsoft$ or $\#google$. However, one tweet might be related to a given company without explicitly mentioning its name. Instead, the tweet might refer to that company's product or to an event the company is organizing. In the case of Microsoft, such tweets might contain hashtags such as $\#msbuild$, $\#surface$ or $\#azure$, etc.

The presented approach proposal is based on the application of association-rule mining method. The use of this method for solving of similar problems was previously examined by a number of researchers. In Tsantarliotis (2015), the author applies association rule mining in order to discover hashtags related to a specific event. The application of association rules in the context of Twitter hashtags was also studied in Adedoyin-Olowe et al. (2014). A more general study of hashtag uses in various cases is presented also in Bansal et al. (2022), Kim and Seo (2020) and Cantini et al. (2021).

The rest of this paper is organized as follows: in section 2 we describe the methodology we follow in the manuscript. Next, in section 3 we describe the experiments performed in order to test the proposed approach. Section 4 describes so-called *specificity ratio* that is used to further improve the results. Finally in section 4 we conclude with a discussion on the limits and issues related to our proposed approach as well as on the potential of future research.

2 Methodology

In this chapter, we first describe briefly the Apriori algorithm for association rule mining and after that, we describe the proposed approach which leverages principles of teh Apriori algorithm for hashtag discovery.

2.1 The Apriori algorithm of association rule mining

Association rule mining or frequent item set mining is a popular machine-learning technique. Its application leads to the discovery of associations and correlations among items in large transactional or relational data sets Han et al. (2011). Let $I = \{I_1, I_2, I_3, ..., I_n\}$ be an item set and D a set of database transactions (e.g., sales transaction or similar data sets) where each transaction $\mathfrak{T}$ is a nonempty itemset such that $T \subseteq I$ - each transaction should be identified by a transaction identifier (*tid*). The resulting association rule is then an association implication, i.e., that $X \rightarrow Y$, where $X \subset I$, $Y \subset I$, $X, Y \neq \emptyset$ and $X \cap Y = \emptyset$.

In the proposed approach, we will apply standard association rule quality measures, i.e. support and confidence. The rule $X \rightarrow Y$ holds in the transaction set D with support s, where s is the probability $P(X \cup Y)$ (i.e. percentage of transactions containing items from both co-occurring sets X and Y). The rule $X \rightarrow Y$ has confidence c in the transaction set D, where c is the conditional probability $P(Y|X)$ (i.e. percentage of transactions containing X that also contain Y).

Minimum support and confidence levels (thresholds) will be an important aspect of the proposed hashtag discovery approach described further. Generally, rules that satisfy minimum support threshold and minimum confidence threshold are considered strong rules. An idea of closed frequent item set mining Han et al. (2011) is adopted further in the manuscript, since deriving all frequent item sets is a problem that is too complex and in most cases also unnecessary to solve (due to implicitly high computing resources demands).

The *Apriori* algorithm was first proposed in Agrawal and Srikant (1994) for mining frequent item sets to derive Boolean association rules. The algorithm requires prior knowledge of frequent itemset properties and employs iterative approach known as level-wise search, where k-itemsets are used to explore (k+1)-itemsets (this aspect is relevant for the proposed approach as well). The limitations of the algorithm is that each step requires a full scan of the database of transactions, therefore search space pruning is advised to lower computation-time demands.

In general, a set of frequent 1-itemsets (itemsets that contain only 1 item) is first discovered by scanning the database to accumulate the count for each item, and collecting those items that satisfy minimum support. The resulting set is the used to find frequent 2-itemsets and so on until no more k-itemsets can be found in the database. If an item set I does not satisfy the minimum support threshold then I is not a frequent itemset. We use the described association-rule mining procedure in the proposed approach to discover hashtags related to a given company.

2.2 Hashtag discovery approach

The proposed approach is based on two assumptions:

- *A1:* One initial hashtag is provided by the user to initialize the process. In many cases, this hashtag can simply be the name of the company in question, e.g. $\#microsoft$ or $\#google$.
- *A2:* Some tweets contain multiple hashtags, one of which is the initial hashtag.

Assumption *A2* implies the tweets can be treated as transactions T containing multiple items I, i.e., hashtags and as such, the *Apriori* algorithm can be applied on Twitter data. Hence, given a level of minimal support and confidence, association rules, i.e., set of hashtags that are often used together can be extracted. For now, the association rules size is limited to 2 items.

Assumption *A1* allows the user to put limits on the search space size as only tweets containing the initial hashtag need to be considered. At the same time, the initial hashtag can be used to filter detected association rules under the assumption that only these rules contain additional hashtags of interest.

The process of hashtag discovery can be summarized as a sequence of the following 4 steps:

1) extraction of hashtags from tweets,
2) removal of items not containing the initial hashtag,
3) application of the *Apriori* algorithm to discover association rules,
4) search for association rules containing the initial hashtag.

Steps 2 and 4 might seem redundant. The reason why both steps are included in the process is that the number of hashtags contained in a single tweet might be greater than 2. Therefore,

Google	Microsoft	Intel	AMD	Total
162024	100103	9309	8007	**279443**

Table 1 Number of tweets by company in the dataset

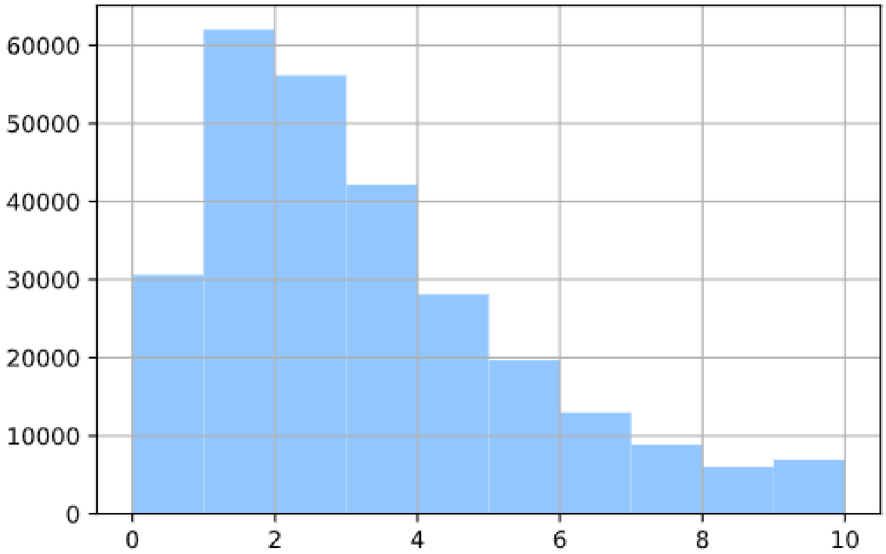

Figure 1 Distribution of number of hashtags in a single tweet

there is a possibility that some of the 2-item association rules detected in step 3 might not include the original hashtag.

3 Experiments and results using the proposed approach

To test the proposed approach, a set of experiments was performed in attempt to discover hashtags related to 4 companies: Microsoft, Google, Intel and AMD.

The set of tweets used during the analysis was gathered using the free version of Twitter API. Through the *search* endpoint, tweets containing the name of the company in a hashtag form, i.e., $\#microsoft$, $\#google$, $\#intel$ and $\#amd$ were collected. The publication date of these posts range from Jan. 16, 2020 to Apr. 29, 2020. Table 1 shows the total number of tweets collected for each company. Twitter API, by default, provides tweet texts trimmed to 140 characters - presented experiments are performed on such shortened texts.

Figure 1 shows the distribution of number of hashtags in a single tweet obtained from the dataset. On average, a single tweet contains 3 tweets, with standard deviation of 2.61. This provides evidence for the validity of assumption A2.

The association-rule mining algorithm (we used an implementation in the Python programming language) was then executed separately on subsets of tweets related to a given company. The aforementioned company name hashtags were used as the starting point.

We further examined combinations of 3 different levels of minimal support - 1 %, 0.5 %, 0.25 % - and 3 different levels of minimal confidence - 0.85, 0.75, 0.65. Quality of each configuration was measured as a simple ratio of correct relevant hashtags. The definition of *correct* was based on the subjective opinion. In majority of cases, this lead to the exclusion of hashtags

Google		**Min. confidence level**		
		0.85	**0.75**	**0.65**
Support	**1 %**	1 (100 %)	2 (33.3 %)	2 (25 %)
	0.5 %	2 (33.3 %)	3 (20 %)	3 (13.6 %)
	0.25 %	10 (50 %)	12 (29.3 %)	13 (25.5 %)
Microsoft		**Min. confidence level**		
		0.85	**0.75**	**0.65**
Support	**1 %**	4 (80 %)	7 (50 %)	7 (46.7 %)
	0.5 %	7 (58.3 %)	13 (52 %)	15 (45.7 %)
	0.25 %	19 (70.37 %)	26 (56.52 %)	30 (50 %)
Intel		**Min. confidence level**		
		0.85	**0.75**	**0.65**
Support	**1 %**	2 (33.3 %)	2 (28.6 %)	2 (22.2 %)
	0.5 %	4 (21 %)	5 (21.7 %)	5 (17.9 %)
	0.25 %	10 (26.3 %)	11 (20 %)	12 (17.9 %)
AMD		**Min. confidence level**		
		0.85	**0.75**	**0.65**
Support	**1 %**	4 (30.7 %)	5 (31.3 %)	5 (29.4 %)
	0.5 %	5 (25 %)	6 (20 %)	6 (18.2 %)
	0.25 %	15 (31.91 %)	16 (23.1 %)	18 (23.7 %)

Table 2 Result of the experiments

Note: Cells contain the total number of correct relevant hashtags and the ratio of correct relevant hashtags.

that are too general, e.g. $\#cloud$ or $\#security$. Second metric of interest was the total number of correct relevant hashtags.

The results shown in the table 2 indicate that lower levels of support mean higher amount of correct relevant hashtags in the resulting sets. To provide an example, in case of Google, hashtags such as $\#android$ or $\#gmail$ were considered as correct, and hashtags such $\#ryzen$, $\#threadripper$ or $\#radeon$ were accounted for AMD.

As already mentioned, hashtags that are too general, such as $\#cloud$ or $\#pcgaming$ were marked as *incorrect* under the assumption that the purpose of hashtag discovery is to detect tweets allowing the user to better analyze the sentiment expressed specifically towards a given company. Although these general hashtags are in many cases related to the business of that company, our opinion is that they are more useful for the analysis of sentiment expressed towards the whole industry instead of the company itself. This direction is further discussed in the next section.

Given the described use case, the ratio of correct relevant hashtags implies that post-processing performed by a human analyst is required. The decreasing level of confidence increases the relative amount of incorrect hashtags making this post-processing phase more time consuming. At the same time the absolute amount of correct hashtags is improved only slightly, with the only exception of Microsoft.

The recommendation is, therefore, to use low level of minimal support in combination with high level of minimal confidence.

	$t = 2$	$t = 3$	$t = 5$
Correct hashtags preserved	12	9	6
Incorrect hashtags preserved	16	9	5
Correct preserved ratio	0.43	0.5	0.54
Correct hashtags removed	0	3	6
Incorrect hashtags removed	13	20	24

Table 3 Effects of the specificity ratio rule $S_{r,i}$ on the related hashtag set

3.1 Mitigation of the General-Tags Issue

In order to remove general tags from a set of tags related to a given company, we computed a *specificity ratio* S_r as a ratio between the number of occurrences F_r of a given association rule r and the number of occurrences of the corresponding related hashtag i without the initial hashtag (rule f_i):

$$S_{r,i} = \frac{F_{r,i}}{f_i} \tag{1}$$

All hashtags with specificity ratio under a certain threshold t can be then removed from the set of related hashtags. This rule is based on the assumption that hashtags with low specificity ratio are often used on Twitter in general and hence are not specific to a given company.

The rule was tested on a set of related hashtags generated using hashtag $google$ as the initial hashtag, with minimal support of 0.25% and minimal confidence of 0.75. 3 threshold values were examined: $t = 2$, $t = 3$ and $t = 5$. Both the number of incorrectly removed hashtags and the number of correct hashtags in the resulting set were observed.

All correct hashtags were preserved, while 13 incorrect (i.e., too general) hashtags were removed from the result set for the lowest tested threshold value ($t = 2$), as shown in table 3.1. The number of removed hashtags predictably grows as the threshold increases and so does the ratio of the correct hashtags in the final set. More aggressive removal policy, however, lead to removal of some hashtags that are subjectively labeled as correct.

The specificity rule approach seems promising. Yet, we restrict ourselves from providing any recommendations for an exact threshold value, as more tests have to be performed in order to verify that the effect observed for the hashtag $\#google$ is the same for other hashtags.

4 Discussion

Two main issues were identified by the experiments. Inclusion of general hashtags is arguably the more important one. Manual filtering of the association rules might be needed, depending on the use case. Specificity ratio-based filtering of the hashtag pairs mitigates the issue, but does not completely solve it. The second issue is related to the assumption that a significant number of tweets contains both the initial and the other relevant hashtag. Otherwise, the other relevant hashtag can not be discovered. We assume that hashtags might be related through a third element: either other hashtag or even through word, or a user.

We assume that both issues can be further addressed by transforming the model of the discovery problem into a graph. In such a graph, nodes would represent hashtags and edges would represent their co-occurrence. Relevant hashtags could then be discovered by exploring the nodes in the proximity of the initial hashtag. This would mitigate the second issue. The problem of general hashtags could be solved by measuring centrality and then simply removing hashtags above a certain threshold from the result set. Graph theory was already applied for the analysis of Twitter hashtags in a different contexts, e.g. in Ferragina et al. (2015), hence we consider this research direction might be relevant and promising.

Reformulation of the problem could potentially lead to alternative applications. The unwanted general hashtags could be, for example, used to group companies into industries which could be then examined as a whole. The use of fuzzy-set theory could further improve the quality of such analyses, as companies could belong to multiple industries with different degrees of membership. Another promising application could be pattern discovery in location-based data, for example in the context of smart cities.

One issue with no clear explanation is the fact that after the experiments were later repeated with full texts of tweets, the result set contained significantly more general hashtags. We assume that this is due to the fact that more general hashtags are included in the following part of the tweet. No evidence for this hypothesis was, however, found even when we tried multiple text splitting strategies.

5 Conclusion

In the paper, we presented proposal of an association-rule based approach for automatic discovery of company-related hashtags. Experiments shown that the suggested solution provides useful results, although it requires some manual post-processing. The most significant downside of the method is the inclusion of hashtags that are too general. We attempted to mitigate this issue by defining *specificity ratio* for each hashtag identified as related by the association mining process. The problem of hashtag generality as well as other limitations and proposals for future research were discussed as well.

We are aware that the proposed method has to be further tested in a real situation setting. It is unknown whether the augmented dataset obtained by identifying more Tweets as relevant has a positive impact on the quality of the final analysis results. How exactly define a *relevant* hashtag is an additional issue related the real-world usage. One could argue that the concept of relevancy is fuzzy and depends on the context. The merge of the proposed approach with fuzzy-set theory principles will be considered in the future research as a promising answer to many of the issues mentioned above.

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On uncertainty in optimal behavior towards suppliers in automotive industry

Rijad Trumić[1], František Zapletal[1]

Abstract. Suppliers and the relationship with them are a crucial factor for every manufacturing company. And companies doing their business in the automotive industry are not different. The difficulty of substitution, number of suppliers necessary to complete a car, or the dependence on various natural resources and political decisions are one of the factors which make the negotiation of car producers with their suppliers more difficult. The aim of this manuscript is to find the best negotiation strategy which should be primarily adopted by an automotive company before and after the nomination of a supplier is done. Unlike the previous study of the authors, the proposed model enables decision makers to express their hesitance in answers. Using a thorough survey, the subjective opinions are gathered and aggregated to provide the recommendation for companies. The fuzzy-AHP method is used to find the best strategies. The results showed that the level of uncertainty in the provided answers is not neglectable but it does not influence the optimal strategy which should be adopted before the nomination is done (the company should primarily change the catalogue) and after this nomination (then, a decrease of the overhead should be applied).

Keywords: fuzzy AHP, negotiation, suppliers, nomination.

JEL Classification: C44, D81

1 Introduction

The automotive industry is one of the key industries in the world. The network of supplier-customer relationship is quite special here. The number of potential suppliers is usually not so high (it is not easy to substitute a supplier at any level of the car production), the network is heavily globalized, and many troubles with supplies occurred recently (the impacts of green policy like the Green deal in the EU, the lack of semi-conductors and many others). Moreover, the co-operation in the automotive industry between a supplier and customer should be ideally long-term, and the cash value of supplies is usually very high.

The aim of the manuscript is to find an optimal strategy of an automotive company how to behave towards the suppliers at two time periods – before a supplier is nominated, and after that. Due to evident subjectivity of the evaluation (given by many factors discussed later), the robustness and preciseness of the results are supported by the fact that the factor of uncertainty is included in the proposed model. The model is verified using the data gathered from 113 managers of various levels at a large car manufacturing company in 2022.

This research builds on Trumić (2021) where the first draft of the model has been introduced. In this manuscript, we use the same structure of the model, i.e., the same set of criteria and alternatives. However, the input data and the included factor of uncertainty is novel. Trumić

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(2021) has presented the results based on the crisp opinion of a single expert. Here, more than 100 practitioners provide their expertise.

In this paper, we use the fuzzy-AHP method to derive both, the weights of evaluation criteria and resulting suitability of possible strategies. Then, the comparison metrics between the fuzzy sets are used to provide the interpretation of the results.

Chen and Huang (2007) use the AHP method to find the best supplier, considering selection criteria such as costs (price, logistic costs) , delivery (supply chain response time, lead time, fill rate), business criteria (performance history, production flexibility, quality performance, reputation, organization structure) and assets (visitation to supplier facilities, inventory days of supply, cash-to-cash cycle times). These key figures were used as the basis for the supplier selection. The problem here is that this view is completely backward-looking. The quality indicators, performance, reputation, etc. come from the past and we have no indications for the future. The quality, performance and also the reputation can go in the undesired direction a day later after a supplier selection. In particular, the subject of costs has been given insufficient attention. The costs are based on an offer at the time of supplier nomination. We start here and continue with the question of how we react to the increasing costs after the supplier nomination.

Chiarini (2018) also uses the AHP to select a right strategy in a company with the criteria action plan a, b and c and the alternatives such as overall budget, payback period, economic return and control over the action plan. An action plan is selected with these aspects. Here it is also a static consideration of the facts and the current situation. A possible cost change over time is not considered. The dynamic part does not exist. The main challenge in our work is to avoid the costs caused by the change and the advancing time.

Astanti et al. (2020) use alternatives such as economy, capability and service with the criteria price, transport costs, payment terms, supplier capacity, delivery time, quality, supplier commitment and supplier policy. With an evaluation by the experts, these aspects are considered with an application of AHP and F-AHP and a decision is made. Here, the procedure is static and fully geared towards the past.

A number of papers have already been written on the criteria and sub-criteria for supplier selection. Service (Bhutta and Huq, 2002;), Delivery (Wilson, 1994; Kumar Kar and Pani, 2014), Quality (Kumar Kar and Pani 2014), Price (Kumar Kar and Pani, 2014), transportation costs (Azizi and Modarres, 2010; Paksoy et al., 2013), capacity (Gnanasekaran et al 2006 Paksoy et al. 2013), Supplier lead time (Çebi and Bayraktar, 2003).

The rest of the paper is organized as follows. After this introduction part, the section with description of the used methodology follows. Namely, the necessary basics of fuzzy algebra and fuzzy are provided. Then, the model based on the study by Trumić (2021) is introduced in Sec. 3. Sec. 4 described the input data gathered from the survey are described carefully. The core part of the manuscript is Sec. 5 where the results and the discussion on these results can be found.

2 Methodological background

In the literature, many methods how to find the solution of a ranking problem can be found, see Triantaphyllou (2000). The choice of the method depends on many factors like complexity of a problem or input data type. Because the problem solved in this study works only with qualitative evaluations, some method suitable for this data type makes sense to use. Namely, the method should not require to transform the qualitative subjective evaluations using some quantitative artificial scale. In general, the methods based on pair-wise comparing satisfy this requirement like Analytical Hierarchy Process (AHP; Saaty (2004)), Analytic Network Process (ANP; Saaty (2004)), Best-Worst method (BWM; Rezaei (2016)) or Even-swap method (ESM; Hammond et al. (2000)). In this paper, the AHP method is used for the following reasons:

- The pair-wise comparisons are made using a qualitative Saaty's 9-point scale (Saaty, 2004) which is easy to understand for practitioners.
- There are only linear relationships in the problem (ANP is not necessary).
- The size of the problem is not so big, thus there is no need to use the BWM method where the number of required evaluations is reduced.
- The AHP has been one of the most popular multi-criteria decision-making methods for at least two decades.
- At the beginning of this research, the AHP method has been used to get the ranking based on the precise evaluation of a single expert, see Trumić (2021). Therefore, the choice of the same method will allow a better comparability of the results.

As it was written in Introduction, this study extends the study presented by Trumić (2021) with group decision-making and uncertainty in evaluation. For this reason, an extension of the original Saaty's AHP with uncertainty is applied here. Namely, the fuzzy AHP using the LGPPM algorithm introduced by Wang and Chin (2008) is applied here. This algorithm has been chosen because it is well-established and it provides the fuzzy results (therefore the complete information is preserved unlike, e.g., the method established by Csutora and Buckley (2001)). As well as in Staňková and Zapletal (2016), the fuzzy sets describing the uncertain evaluations of decision-makers are given by triangular fuzzy numbers (TFNs), see Ramík and Vlach (2012). A TFN $\tilde{a}$ is described using the piece-wise linear membership function, or in short by a triplet (a_l, a_m, a_r), see Fig. 1. The fundamentals of the original deterministic AHP are not recalled here for the sake of reasonable length but interested readers can look at Ramík and Vlach (2012), for instance.

For further calculation with TFNs, the fuzzy extension of addition, subtraction, multiplication, divination and geometrical mean for TFNs are necessary:

$$\tilde{a} \oplus \tilde{b} = (a_l + b_r, a_m + b_m, a_r + b_l), \tag{1}$$

$$\tilde{a} \ominus \tilde{b} = (a_l + b_r, a_m + b_m, a_r + b_l), \tag{2}$$

$$\tilde{a} \odot \tilde{b} \approx (a_l b_l, a_m b_m, a_r b_r), \tag{3}$$

$$\tilde{a} \oslash \tilde{b} \approx (a_l / b_r, a_m / b_m, a_r / b_l), \tag{4}$$

$$\widetilde{\mathrm{GM}}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) \approx \left(\sqrt[n]{\prod_{i=1}^{n} a_l^i}, \sqrt[n]{\prod_{i=1}^{n} a_m^i}, \sqrt[n]{\prod_{i=1}^{n} a_r^i}\right), \tag{5}$$

where $\oplus, \ominus, \odot, \oslash$ stand for fuzzy extension of crisp addition, subtraction, multiplication, and divination ($b_l, b_m, b_r \neq 0$), respectively. $\widetilde{\mathrm{GM}}$ is a geometrical mean of TFNs.

In the LGPPM algorithm, the fuzzy weights (TFNs) are derived first, see the description below.

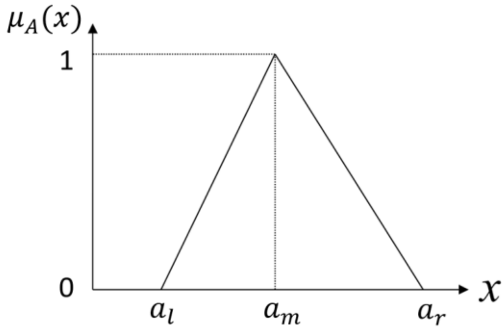

Figure 1 Example of triangular fuzzy number

The basic assumption that each pair-wise comparison is ideally equal to the ratio of the corresponding weights is preserved in the F-AHP too, see (6).

$$\tilde{s}_{ij} = \frac{(w_l^i, w_m^i, w_r^i)}{(w_l^j, w_m^j, w_r^j)}, \text{for } \forall\, i, j. \tag{6}$$

$$\mathbf{S}_L = \begin{pmatrix} 1 & \cdots & \frac{w_l^1}{w_r^n} \\ \vdots & \ddots & \vdots \\ \frac{w_l^n}{w_r^1} & \cdots & 1 \end{pmatrix}, \mathbf{S}_M = \begin{pmatrix} 1 & \cdots & \frac{w_m^1}{w_m^n} \\ \vdots & \ddots & \vdots \\ \frac{w_m^n}{w_m^1} & \cdots & 1 \end{pmatrix}, \mathbf{S}_U = \begin{pmatrix} 1 & \cdots & \frac{w_r^1}{w_l^n} \\ \vdots & \ddots & \vdots \\ \frac{w_r^n}{w_l^1} & \cdots & 1 \end{pmatrix} \tag{7}$$

In line with Wang and Chin (2008), (6) is decomposed to (7) that is further rewritten as (8), (9), and (10).

$$\mathbf{S}_L \boldsymbol{w}_R = \boldsymbol{w}_R + (n-1)\boldsymbol{w}_L, \tag{8}$$

$$\mathbf{S}_R \boldsymbol{w}_L = \boldsymbol{w}_L + (n-1)\boldsymbol{w}_R, \tag{9}$$

$$\mathbf{S}_M \boldsymbol{w}_M = n\boldsymbol{w}_M, \tag{10}$$

where $\boldsymbol{w}_L = (w_l^1, w_l^2, \ldots, w_l^n)^{\mathrm{T}}, \boldsymbol{w}_M = (w_m^1, w_m^2, \ldots, w_m^n)^{\mathrm{T}}$ and $\boldsymbol{w}_U = (w_r^1, w_r^2, \ldots, w_r^n)^{\mathrm{T}}$.

The weights are derived using the linear programming model (11)-(19), see Wang and Chin (2008). The goal of the LGPPM-FAHP method is to find the priority vector with minimum deviations from consistency given by equations (8), (9) and (10).

$$\min_{\boldsymbol{W}_L, \boldsymbol{E}^+, \boldsymbol{E}^-, \boldsymbol{\Gamma}^+, \boldsymbol{\Gamma}^-, \boldsymbol{\Delta} \geq \mathbf{0}} \quad J = \boldsymbol{e}^{\mathrm{T}}(\boldsymbol{E}^+ + \boldsymbol{E}^- + \boldsymbol{\Gamma}^+ + \boldsymbol{\Gamma}^- + \boldsymbol{\Delta}) \tag{11}$$

$$\text{Subject to} \quad (\mathbf{S}_L - \mathbf{I})\boldsymbol{w}_R - (n-1)\boldsymbol{w}_L - \boldsymbol{E}^+ + \boldsymbol{E}^- = 0, \tag{12}$$

$$(\mathbf{S}_R - \mathbf{I})\boldsymbol{w}_L - (n-1)\boldsymbol{w}_R - \boldsymbol{\Gamma}^+ + \boldsymbol{\Gamma}^- = 0, \quad (13)$$

$$(\mathbf{S}_M - n\mathbf{I})\boldsymbol{w}_M - \boldsymbol{\Delta} = 0, \quad (14)$$

$$w_l^i + \sum_{j=1, j\neq i}^{n} w_r^j \geq 1, \qquad i = 1, \dots, n, \quad (15)$$

$$w_r^i + \sum_{j=1, j\neq i}^{n} w_l^j \leq 1, \qquad i = 1, \dots, n, \quad (16)$$

$$\sum_{i=1}^{n} w_m^i = 1 \quad (17)$$

$$\boldsymbol{w}_R - \boldsymbol{w}_M \geq 0, \quad (18)$$

$$\boldsymbol{w}_M - \boldsymbol{w}_L \geq 0, \quad (19)$$

where $\boldsymbol{e} \in \mathbb{R}^{1\times n}$ is a vector of ones, $\mathbf{I} \in \mathbb{R}^{n\times n}$ is an identity matrix, $\boldsymbol{E}^+, \boldsymbol{E}^-, \boldsymbol{\Gamma}^+, \boldsymbol{\Gamma}^-, \boldsymbol{\Delta} \in \mathbb{R}^{1\times n}$ are the vectors of positive and negative deviations from (8), (9), and (10), respectively, caused by inconsistency, $n \in \mathbb{R}^{1\times 1}$ is number of rows (or columns) in the Saaty's matrix, $\boldsymbol{w}_L, \boldsymbol{w}_M, \boldsymbol{w}_R \in \mathbb{R}^{1\times n}, (\boldsymbol{w}_L = w_l^1, w_l^2, \dots, w_l^n),\ \boldsymbol{w}_M = (w_m^1, w_m^2, \dots, w_m^n), \boldsymbol{w}_R = (w_r^1, w_r^2, \dots, w_r^n)$ denote the fuzzy weights ($\boldsymbol{w}_L$, $\boldsymbol{w}_R$ and $\boldsymbol{w}_M$ represents left and right bounds of the TFN's support, $\boldsymbol{w}_M$ stands for the core of the fuzzy priorities.

The constraints (12), (13) and (14) come from (8), (9), (10), respectively. The constraints (15), (16) and (17) serves for fuzzy weight normalization. In line with Wang and Chin (2008), the fuzzy weight vector is normalized if and only if those constraints hold. (18) and (19) guarantee that $w_l \leq w_m \leq w_r$. The objective function (11) minimizes the deviation from matrix consistency.

If the evaluations in $\boldsymbol{S}$ is absolutely consistent there are no deviations from (8), (9) and (10) and $J = 0$. However, some level of inconsistency is accepted. To check the quality of the evaluations, a consistency ratio with 10\% threshold (like in the deterministic AHP method, see Saaty (2004)) is calculated from the cores of the fuzzy weights. For instance, the authors of the LGPPM algorithm Wang and Chin (2008) do not deal with inconsistency at all.

Once the fuzzy weights are calculated, the utility of alternatives are calculated to get the ranking of the alternatives:

$$\tilde{u}_j = \bigoplus_{i=1}^{n} \tilde{w}_i \odot \tilde{u}_{ij}, \forall j, \quad (6)$$

where $\tilde{u}_{ij}$ represents the utility brought by the j-th alternative in terms of the i-th criterion. $\tilde{u}_{ij}$ is calculated in the exactly same manner as $\tilde{w}_i$ (the only difference is that the Saaty's matrix pairwisely compares the performance of the alternatives instead of the importance of the criteria.

When the (fuzzy) utilities of the alternatives are calculated, a meaningful interpretation is necessary. In this paper, we use the possibility and necessity measure allowing for comparisons between the fuzzy sets without necessary defuzzification of the fuzzy utilities. The possibility measure expresses a level of probability that one fuzzy set/number is greater than another one, meanwhile the necessity measure describes a level of certainty that one fuzzy set/number is greater than another one, see (20) and (21).

$$\mathrm{Pos}(\tilde{a} \leq \tilde{b}) = \sup_{x \leq y}(\mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)) \tag{20}$$

$$\mathrm{Nec}(\tilde{a} \leq \tilde{b}) = 1 - \sup_{x > y}(\mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)) \tag{21}$$

3 Decision model

The aim is to find the alternatives which will help the most to reduce the cost of change caused by a supplier, see Fig. 1. The decision-making criteria change over time or depending on the situation/phase the car manufacturer is in at the time. Based on the expert panel's opinion at the modelled company, the following decision-making criteria were defined:

- Speed of implementation,
- complexity,
- capacity effort,
- setting of premises,
- internal know-how,
- output.

The speed of implementation is an important factor in the selection of the tools. It is especially important how fast each topic can be implemented in practice; how complex the topics are in the preparation phase and how much manpower and time it would require.

Furthermore, it is also quite important whether specific requirements can be set for the respective topic. For example, if requirements are kept too rough and general in a change catalogue, the costs cannot be precisely defined. A precise and detailed definition of the requirements also enables a detailed statement of costs for a specific change action.

It is also important whether the know-how is available within the company itself because, the experience of the employees is also an essential aspect. Employees from the development and purchasing department can take all the topics from lessons learned bring them into the toolset and give them to the supplier for a cost evaluation.

Finally, output is the last, but not least important criteria. It may be that everything can be implemented extremely fast, with low-capacity requirements and high know-how, but if the output is small or it brings little savings, the focus is usually redirected to another topic.

As already mentioned, these decision criteria have a significant influence on the alternative options, that were defined by the expert group during the brainstorming process. These alternative options are:

- Change catalogue or pre-negotiation of possible changes in the future,
- Improvement of the technical requirements and specifications,

- A decrease of the overhead and profit surcharge or a question whether the used „Surcharge calculation" by many OEMs, is future-oriented.

The use of a cost catalogue after a nomination can be useful in many cases, amongst others to negotiate changes better and more effectively. Increasing product requirements are an important part of a nomination. A good change catalogue is developed in close coordination between the purchasing and development teams. In the second step, the contribution of a cost calculator is of course important in order to calculate the measures or changes requested in the change catalogue. This leads to better negotiation results.

By improving the detail and quality of the specifications, we can avoid many changes through the development of the series, so that the change catalogue can be made redundant or at least greatly reduced in complexity; however, this improvement is most often not possible in the early phase or at the time of nomination because the requirements for the component and the development goals are mostly still unknown, and because of that the requirements and conditions are often kept very general at the time of nomination.

The third main aspect in avoiding costs in series development, but even more importantly in series delivery, is a decrease of overhead and profit surcharges. Many OEMs use a surcharge calculation as a calculation base. The calculation uses the botton-up approach to calculate the cost components and then add the overhead and profit surcharges as a percentage of the material and production costs. This is primarily determined during the nomination and agreed with the supplier.

Figure 2 depicts a summary of the problems with the AHP decision tree. The second level lists the criteria that are most important for this problem. The third level shows the individual alternatives or tools that can be taken into consideration. The AHP method is also well suited to solve the problem because the assessment is quantitative in nature.

4 Input data

Within the survey done at one big automotive company, 113 sets of evaluations for the given decision problem have been gathered. The reviewees had to provide the evaluations for the pair-wise comparisons between criteria and performance evaluations between the alternatives. All the evaluations were done, moreover, for two time periods – before and after the negotiation is done. All the evaluations were done in Saaty's matrices using the Saaty's scale. To capture the uncertainty in optinions, the respondents had an option to choose only a single value from the Saaty's scale (if they did not feel any hesitance), or they could choose a range which was used to establish the support for the TFN (i.e., the values s_{ij}^l and s_{ij}^r), the core s_{ij}^c of such TFN was calculated as the mean value of s_{ij}^l and s_{ij}^r). In total, 30 fuzzy evaluations of preferences on criteria (pair-wise comparisons of 6 criteria for 2 time periods) and 36 fuzzy performance evaluations for alternatives (3 pair-wise comparisons of 3 alternatives in terms of 6 criteria for 2 time periods) were provided by each respondent.

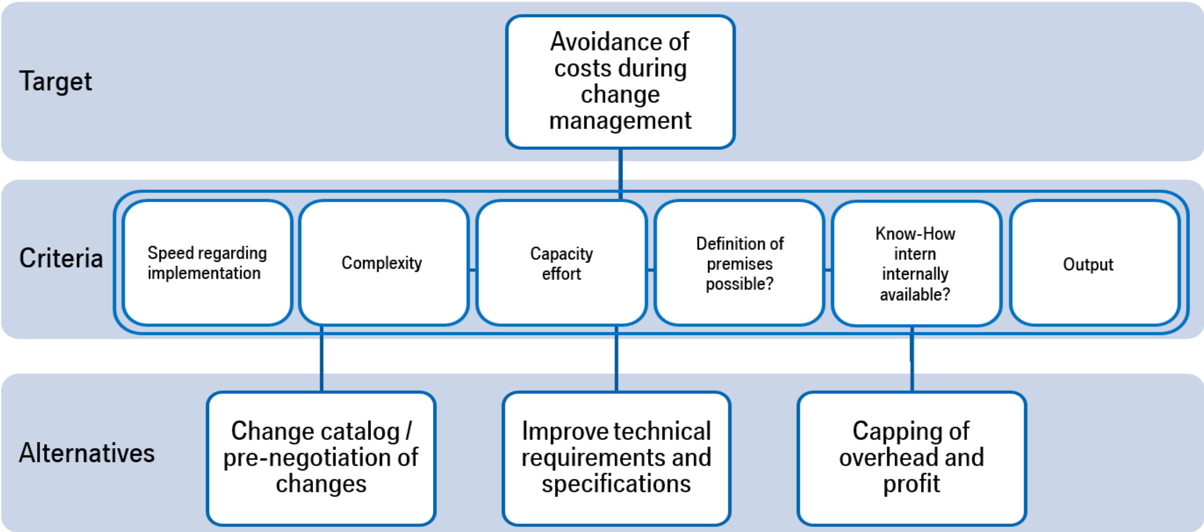

Figure 1 Presentation of the problem

4.1 Model quantification of criteria before supplier nomination

The resulting fuzzy weights for considered 6 criteria can be seen in Fig. 2. The final fuzzy ranking of the alternatives derived using F-AHP can be found in Tab. 1. Since there is no overlap between the resulting fuzzy numbers, the order of criteria in terms of their importance, as well as the ranking of the alternatives, is straightforward (with the value of Necessity (Nec) equal to 1 between all pairs). In other words, the uncertainty does not impact the order at all.

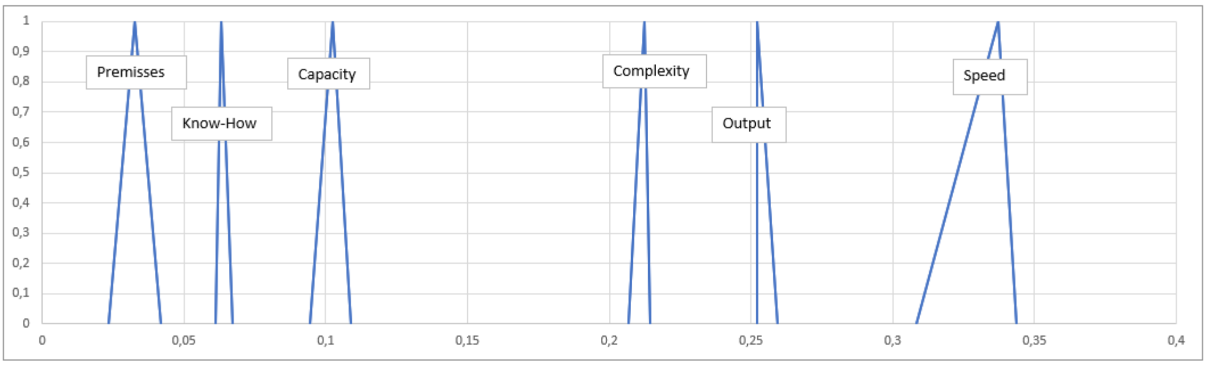

Figure 2 Final weights of criterion before the nomination

	Fuzzy utilities *l/m/r*			Ranking	Ranking by Trumić (2021)
Change cataloge	0.369	0.4094	0.435	**1**	2
Technical Requirements	0.237	0.259	0.272	**3**	3
Overhead	0.314	0.332	0.356	**2**	1

Table 1 Ranking of final results before the nomination

The top priority is overhead, followed by the change catalogue. In contrast, the subject of specifications is at the last place, which is also reflected in reality. As well as for the weights, the uncertainty does not impact the order of the considered strategies.

Tab. 1 provides also the ranking by Trumić (2021) for comparison. It came out here that the overhead and change catalog had swapped places. The technical requirements were ranked the third originally. In the big survey, it turns out that the catalog of changes appears to be more important than a reduction in overhead. These results are more reliable since they work with opinions of the expert panel and the hesitance/uncertainty is also included.

4.2 Model quantification of criteria after supplier nomination

Now, let us assume that the supplier has already been chosen, and that our position of power is much weaker. We have used the same rating criteria for all alternative methods, the only differences are the changed "points of interest" within the base conditions. After the nomination process, the most important tool is overhead followed by technical requirements and the change catalogue. The resulting weights for the time after supplier nomination can be seen in Fig. 3.

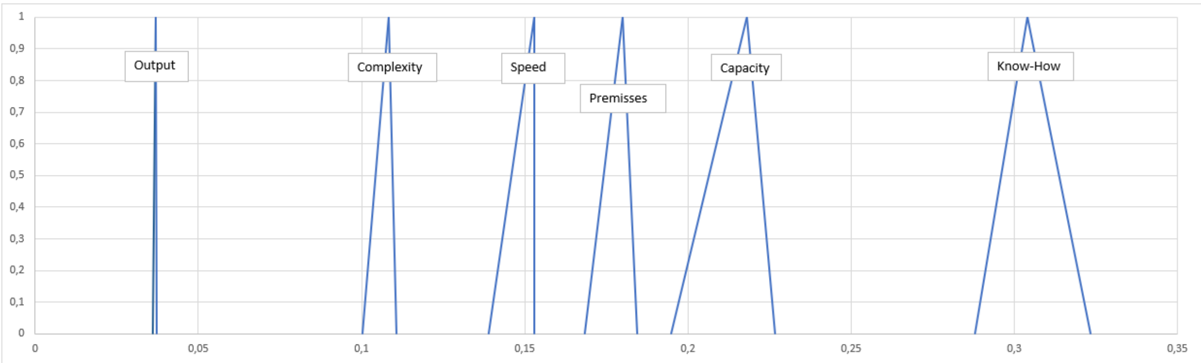

Figure 3 Final weights of criterion after the nomination

Taking into account the new weighting of the criteria, after the nomination process, the most preferred tool is the overhead, followed by the technical requirements and the catalog of changes. The evaluation of the alternatives after the supplier nomination can be seen in Tab. 2. As well as for the period before the nomination, the uncertainty does not impact either the weights, or the utilities (all pairs can be clearly compared without any hesitance and with Nec degree of 1).

	Fuzzy utilities *l/m/r*			**Ranking**	**Ranking by Trumić (2021)**
Change cataloge	0.133	0.152	0.160	**1**	2
Technical Requirements	0.272	0.300	0.316	**3**	1
Overhead	0.503	0.548	0.578	**2**	3

Table 2 Ranking of final results after the nomination

As a comparison with the results from the survey, the comparison with the results by Trumić (2021) is done again, see Tab. 2. It can be seen that a single-expert evaluation by Trumić (2021) is different, however, the results based on the survey in this paper are more robust and reliable.

When comparing the results before and after the nomination, the topics change their priority, which proves that a decision is time-dependent. In this example it is reasonable that, after selecting the part supplier, the technical requirements are not changed, to avoid "cost of change", independent of the fact if a Change catalogue exists or not. The fact that the overhead cost is the least important part is comprehensible, because a part supplier, after the selection process, would never agree to a limit of overhead cost, because it is one of their biggest sources of profit (Trumić, 2021) which was the premise at this time. During the survey, we changed the premise to “when is this tool best to use” and the time is of course after the nomination as the parts are going to be changed during the development process. The creation of a change catalogue is possible after the appointment, but the conditions are significantly worse compared to the conditions before the appointment of the supplier.

Another question was by what proportion the cost of change would decrease when using the alternatives. The survey found that without using the tools, costs would increase by 23.58%, while using the tools would only increase by 11.21%. If it is assumed that the purchased parts for a mid-range vehicle cost around EUR 13,000 the changes made between the nomination and the SOP would result in an additional EUR 3,065 for this vehicle. In total, the vehicle would cost EUR 16,065 with the purchased parts for the SOP. With the use of the tools, the costs would only increase by EUR 1,457 instead of EUR 3,065. The vehicle would then cost a total of EUR 14,457 instead of EUR 16,065.

This results in avoiding costs of EUR 1,608 per vehicle. This result must be processed further and serves as an orientation. If other assumptions are included, such as the fact that an OEM produces around 2.5 million vehicles a year, it would mean savings of around EUR 4 billion in total for purchased parts.

5 Conclusion

This paper presents a decision model for companies which want to optimize their behavior to keep the costs brought by suppliers as low as possible. The model with 6 criteria and 3 possible strategies towards the suppliers taken over from Trumić (2021) were considered. One of the biggest problems when applying multi-attribute decision making methods, based on subjective input, is the relevance of time and uncertainty in evaluation. In this context, the fuzzy analysis for two time periods was done. Therefore, the time when the contract with a supplier is signed and the hesitance and different opinions of evaluators were taken into account. The model has been verified using an automotive company.

The results showed that the priorities of criteria differ in time of decision-making, as well as the ranking of strategies do. The large panel of experts used for evaluation should guarantee the robustness of the results. Surprisingly, when the geometric mean of individual opinions is used to get the group evaluation, the revealed hesitance of the individuals do not play any role despite the most of individuals expressed that their opinion is not necessarily precise. This also supports the conclusion that the results are reliable and robust enough.

For the future, the model will be applied to different processes and parts of the company to explore if the recommended strategy is influenced by these factors or not.

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Game theory approach to public transport pricing

Martin Václavík [1], Ivana Olivková [2]

Abstract. Public transport is a very popular topic nowadays and widely promoted as sustainable means of transport. Choosing the right price might persuade people to switch to public transport and make it the best option for the people. Underpricing the service will lead to losses and overpricing will lead to a decreased ridership. In this paper a game theoretic approach is used to determine the optimal price regarding the generalized travel cost of all passengers.

Keywords: public transport-pricing-game theory-generalized travel cost.

JEL Classification: C44

1 Introduction

Public transport today is hugely promoted as sustainable means of transport and advised to the general public to be used. A public taken as a group of individuals take decision on their mode of transport based on their possibilities and preferences. A rational passenger will choose the best mode for them. The best mode is the one that brings the passenger the highest utility.

Every journey can be explained by a cost which can be generalized and quantified among all means of transport. Besides the monetary cost for the journey itself, there are other factors influencing our choices. Everybody has a different value of time or requirements for their comfort.

We are facing a decision on our choice of means of public transport. Game theory is a mathematical discipline providing us tools for decision making based on the total utility (payoff). Players can be understood as entities entering a game. A game is any process, where we have to make decisions and based on its properties, we can distinguish cooperative or non-cooperative games, games of players and games against nature, zero-sum and non-zero-sum games, repetitive and non-repetitive games… (Démuth, 2013). Games are played by a player who chooses strategies from their set of strategies, which are the options a player can take (e.g. in commuting, the strategies can be: choosing a car, choosing a public transport, biking…). Each strategy then leads to a payoff and every player wants to maximize their payoff.

John Nash defined the Nash equilibrium as a point "such that each player's mixed strategy maximizes their pay-off if the strategies of the others are held fixed. Thus, each player's strategy is optimal against those of the others." (Nash, 1950). This means, that no player can obtain a higher expected payoff by changing their strategy, if other players keep their strategy fixed.

In public transportation, we face the decision almost on daily basis, when choosing the mode of transportation, when choosing the route we will take, when choosing a single ticket or a

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prepaid ticket or choosing our time of travel. Price can be perceived as not only the money, we have to pay for the service, or car amortization, but also the price of our time, safety, risk of delay (due to congestion) or comfort.

2 Literature review

We can find several papers dealing with game theory-based pricing model in public transport. Linlin, Luo and Yang (2012) are using a game theory approach to compare the pricing strategies of rail and road public transport considering the generalized travel cost. The road and rail operator can adjust their prices to attract more passengers and therefore reach higher profit. Koryagin (2014) is also using the cost of travel as a criterion for his model, however he tackles the problem of passenger distribution between the modes of transport (public transport and car). Then he compares the different circumstances that affect the pricing, total travel cost and frequency depending on the management system of the public transportation differentiating the private transit companies and authority governed companies. His findings show that it is to a passengers' benefit for the public transport to be under an authority regulation, where public transportation reaches higher frequency and lower fare compared to a private public transport company. Pašagić Škrinjar, Abramović and Brnjac (2015) use game theory on public transport routing and planning using matrix game theory.

The maximized social surplus based on the surplus of the producer (transport operator) and surplus of the consumer (passenger) is the goal of optimal public transportation pricing. Jansson, Holmgren and Ljungberg (2015) are using a door-to-door approach to the public transportation pricing. Therefore, the travel cost does not include only the price of fare or fuel, but also the journey time and passengers' comfort. There are many approaches to public transportation pricing, but majority of them adapts the idea of generalized travel costs and general social welfare.

3 Game theory as decision-making tool

There are many reasons why people use public transport. It is a public service, people might use public transport to get to work, go to school, reach healthcare facilities, cultural facilities, shopping or visiting family or friends. This all adds up to the total social welfare of public transport.

Public transport pricing is an extensive topic. The service must be priced just right so that people are using public transport, yet loss of transport company (usually under a municipality authority operation) is minimal. It happens rarely that a public transport company makes a profit, only at very busy lines. Municipalities are willing to subsidy the loss to the public transport company because of the added value of this services mentioned above.

Too high price of public transport service might lead to the smaller demand among the passengers who might then consider switching their primary mode of transport to cars, which then can create congestions and traffic jams in the city. This event is not in interests of a city. If this happens, public transport services might fall into a vicious circle shown in the Figure 1.

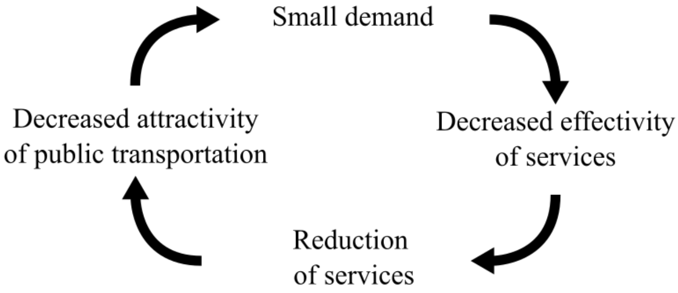

Figure 1 Vicious circle of public transport

On the other hand, we must consider the total cost of every journey. To calculate the total passengers' generalized travel cost (Linlin, Luo, Yang, 2012), we use the equation:

$$C_i = \alpha_i T_i + \beta_i N_i + P_i + \delta_i \tag{1}$$

Where:

- C_i – the generalized travel cost when the passenger chooses traffic mode i
- α_i – cost coefficients of passenger's time
- T_i – time the traffic mode i costs
- β_i – the cost of discomfort of traffic mode i caused by traffic jam
- N_i – the number of passengers who choose traffic mode i
- P_i – the economic cost of traffic mode i (ticket fare)
- δ_i – the general cost of traffic mode i including the cost of security and punctuality

As all passengers come from the same population, we can assume that their value of time is the same $\alpha_1 = \alpha_2 = \alpha_3 = \alpha$.

We can model this problem as a non-cooperative game between a transport company and passengers. The amount of passengers choosing public transport is based on more factors as discussed previously, however price plays a significant role in it. Let's assume that fare price is the main criterion.

Let us define the set of players $Q = \{q_1; q_2\}$, where q_1 represents the transport company and q_2 represents the passenger. Both players have a set of strategies to choose from. For transport company the set of strategies is defined as $S_1 = \{s_1; s_2; s_3\}$, where s_1 corresponds to the strategy to lower the fare price, s_2 corresponds to keeping the same fare price and s_3 corresponds to raising the fare price. The passenger has their set of strategies $P_1 = \{p_1; p_2; p_3\}$ where p_1 means that the passenger chooses public transport, p_2 is the strategy where passenger switches to car, which then contributes to the congestions and p_3 is choosing an alternative mode of transport (cycling or walking), which we will consider free, but takes a lot more time.

Among the passengers, let's define the population of passengers N which consists of group of passengers who choose public transportation (N_1), a group of passengers who switch to car

(N_2) and a group of passengers who choose alternative mode like walking or cycling (N_3). Therefore, the whole passenger flow will be defined as $N = N_1 + N_2 + N_3$.

If too many passengers switched their mode of transport to cars, then there is a higher risk of congestions in the city. A congestion can be viewed as a two-player or three-player game (Levinson, 2005). This view shows us that players can choose their strategy to arrive preferably on-time to their destination. Any other result (early arrival, late arrival) is penalized depending on individual preferences. The possible strategies for the players are to depart early, on-time or late. Nash equilibrium depends on the given penalties (e.g. whether late arrival is penalized more than early departure) however, most of the studied scenarios do not result in a congested outcome. Setting the fare price too high might encourage passengers to switch to cars, which would then lead to congestions and therefore the overall utility is lowered.

Van Vugt et al. (1995) have conducted a social experiment with subjects being questioned about their preferences on mode of transport for daily commute. Their options (strategies) were a car or a public transport. Then the subjects were presented with a negative impact when too many commuters choose a car from congestions and delays to environmental concerns. Hollander and Prashker (2006) formed the payoff matrix based on Van Vugt's experiment. This matrix is presented in Table 1.

	Player 2	**Public transport**	**Car**
Player 1	Public transport	(4, 4)	(-4, 8)
	Car	(8, -4)	(0, 0)

Table 1 Payoff matrix of Van Vugt's experiment [Hollander and Prashker, 2006]

The exact values are not significant, but their relation is. We can see that the player reaches the highest payoff when they choose a car, and the other player chooses public transport (then there is no congestion). The only Nash equilibrium is reached when both players choose car.

Based on the game theory, passenger chooses the strategy, which brings them the highest utility, thus the generalized travel cost is minimal. Transport company wants to make the biggest possible revenue from selling the tickets.

To calculate the revenue, we use formula

$$R = N_1 \cdot P_1 \tag{2}$$

Where:

- N_1 is the number of passengers choosing public transportation
- P_1 is fare price

We can now develop a bicriteria linear programming model with 2 objective functions. We want the generalized travel costs for all passengers to be minimal and the revenue of the transport company to be maximal.

$$\min \sum_{i=1}^{3} C_i\,(N_i) = \alpha T_i + \beta_i N_i + P_i + \delta_i \tag{4}$$

$$\max R\,(N_1) = N_1 \cdot P_1 \tag{5}$$

Subject to

$$N_i \in N^+ \quad for\ i = 1,2,3 \tag{6}$$

$$\alpha; T_i; \beta_i; P_i; \delta_i \in R^+ \quad for\ i = 1,2,3 \tag{7}$$

$$N_1 + N_2 + N_3 = N \tag{8}$$

The values of individual coefficients depend on individual cases; however we should remember that $T_3 > T_1 > T_2$ since we consider cycling or walking to be significantly slower than public transport and a car usually being faster than public transport (in a non-congested conditions). Also $\beta_2 > \beta_1 > \beta_3$ because the discomfort caused by a significant number of car passengers causes heavy traffic jams and big delays in the total travel time, also a packed public transport brings some discomfort to a passenger, but it is usually a subjective feeling and the arrival time does not delay, on the other hand, when walking or cycling, we are not that influenced by the other passengers. P_1 is the fare price of public transport, we can say that $P_3 = 0$, because there are usually no other costs to walking or cycling (disregarding the initial price of the bike) and the relations between P_1 and P_2 should be $P_1 < P_2$, since using public transportation is usually cheaper than travelling by car.

As a solution to this model, we get the optimal modal split of the passengers for individual means of transport. We can use an iterative approach and change the price P_1 to find the optimal price with the maximized revenue R for the transport company and at the same time with minimalized general travel costs of all passengers.

4 Numerical examples

Let's now have a look at a numerical example. We will consider a generalized cost of a journey according to (1). The authors have assumed the values of coefficients and other constraints based on their experience in the field and the relation of means of transport to each other (e.g. car travel is more likely to be delayed by congestions than public transport on a designated infrastructure, if there are many passengers choosing this mode). The obtained results are presented in Figure 2.

We can see from the Figure 2 that the generalized travel cost in relation to the distance of the journey. We conclude that the public transport is the best option for a journey longer than 7 km. Bike is the best option on the short distance journey. This makes sense since we pay a fixed price for the ticket, whereas car generalized cost is based on the length of journey (amortization and fuel consumption), the bike transfers our effort we need to give into biking to generalized travel cost also based on the journey length, but we do not pay any additional monetary costs to travel. The results were obtained based on the average speed of respective means of transport.

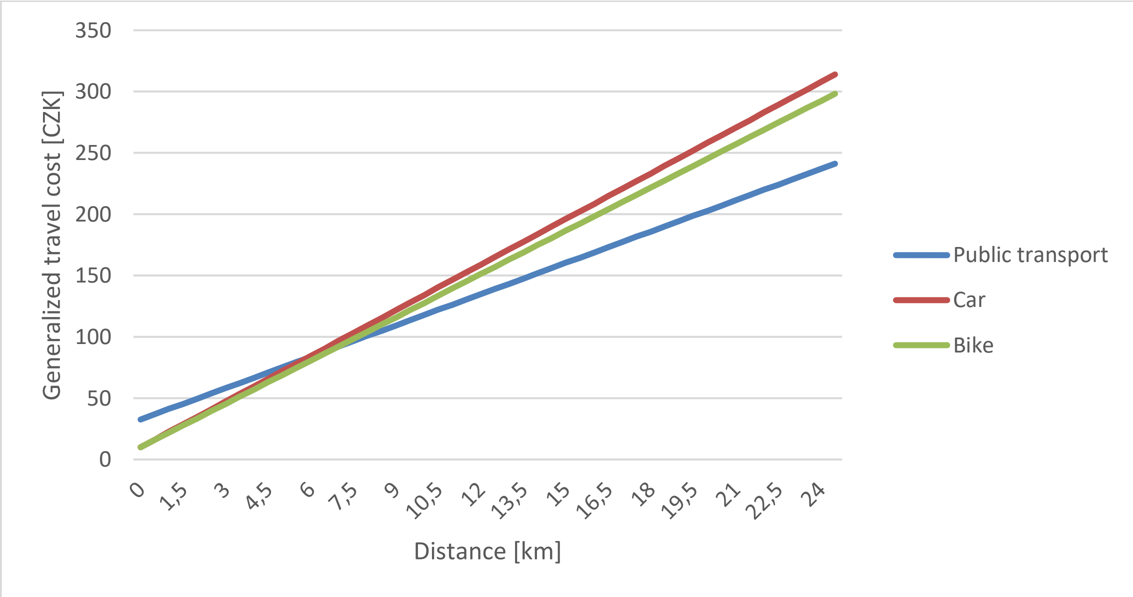

Figure 2 Cost of single journey in relation to distance

Let's now consider an average journey of passengers. If we take Ostrava as an example, we are considering a journey between Poruba district and city centre, which is the busiest line in the city. The generalized travel cost of all passengers' journeys is shown in Figure 3.

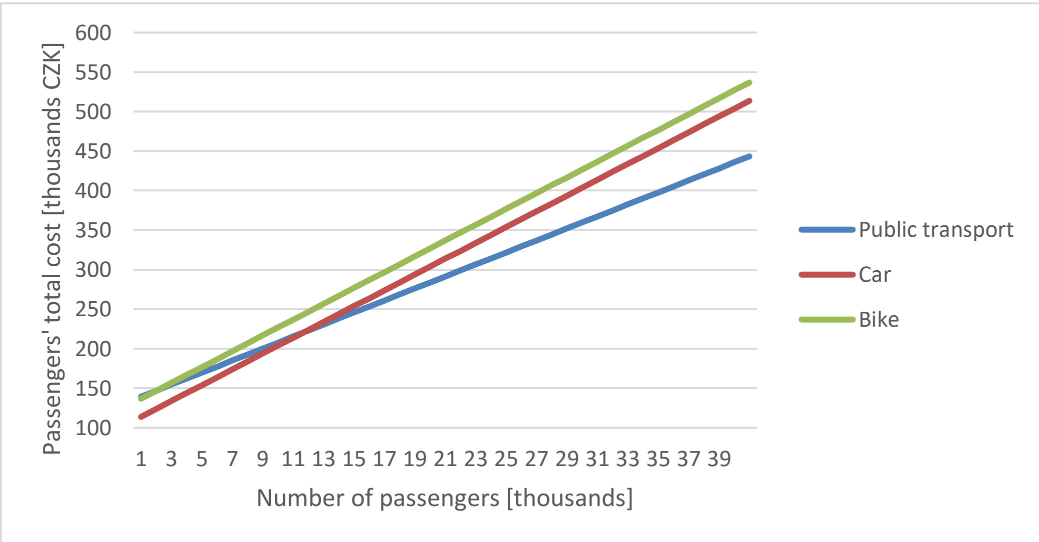

Figure 3 Generalized travel cost on a selected journey

We can see that if less than 12 thousand passengers travel on this route by car, the best strategy is to choose car, however if there are more passengers, public transport takes the lead because the roads will be congested, and the journey will take longer and have higher generalized cost. The price of a single ticket was assumed 25 CZK as it is the current price on this route.

If the public transport operator has the data about ridership and general mobility of people on this route, they can find their optimal price based on the presented model. If the ridership on the route is more than around 12 thousand passengers per day, even with the higher fare it would still be the best strategy for the passengers to use the public transport.

Since we can't affect how many people will choose car, public transport or bike, choosing public transportation is the best strategy for a passenger regardless of other passengers' choices, therefore choosing public transport is Nash equilibrium of the game.

5 Conclusion

This paper presents a game theory-based approach to public transportation pricing. Game theory is based on maximizing the player's payoff, which is based on their strategy. Choosing a mode of transport for our journey can be viewed as a non-cooperative game, because we cannot affect the decisions of other passengers. The generalized cost of journey is not determined only by the price we pay for it, but also by the time consumed, the punctuality, safety, discomfort, etc. Therefore, the cheapest option might not be the best option. A mathematical programming model is developed, but it is a complex non-linear multiobjective model. A numerical approach is then taken to demonstrate the properties of the model. This example is based on the busiest journey within the city of Ostrava. This approach is suitable on for pricing on one line, e.g. pricing of a single metro line system and would not be satisfactory for a big public transport system with many lines and relations within the city, but serves as an example.

Game theory provides powerful supporting tools for decision making and can show us that what seems as the best option, might not be the best option under all conditions.

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Firm's bankruptcy prediction with two-stage machine learning approach

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Abstract. We propose a new approach prediction of firm's bankruptcy in which the neural network is combined with linear discriminant analysis. The former materializes its predictive power and the latter can take advantage of its speed to identify the relevant inputs for the neural networks. We verify the applicability of this approach on a relatively large-scale dataset of Polish firms in manufacturing sector in period 2000-2013. The results of our analysis show that this approach can correctly classify all cases of non-bankrupted firms (in-sample and out-of-sample) and the rate of correct prediction of bankrupted firms is over eighty percent for the given dataset.

Keywords: Altman model, MLP Neural network, Linear discriminant analysis; Polish firm, Bankruptcy prediction.

JEL Classification: G33, G34

1 Introduction

An accurate prediction of bankruptcy of firms has great important both for internal and external decision-makers. A banker will provide resources to fund the development of a firm if it is a viable enterprise. Firm' management and its stakeholders need to know where the firm stands in order to make the right decision for its further development. Therefore, the development of the bankruptcy prediction technique has become a great focus of theorists as well as practitioners for decades. It has ranged from the z-score model of Altman using multiple discriminant analysis (Altman, 1968, 1983) to the logit model of Ohlson (Ohlson, 1980) to the similar probit model of Zmijewski (Zmijewski, 1984). Later, with the boom in machine learning, its techniques have permeated into bankruptcy prediction. Prediction models based on machine learning seem to outperform the traditional prediction models (Zhang (2017) and Devi and Radhika (2018)).

Despite this common wisdom, we believe that traditional classification models still have their own advantages. These models are simple, fast to be estimated and easily interpretable. To make use of the advantages of both streams, we propose an integrated approach which combines the predictive strength of a neural network with the benefits of the multiple linear discriminant analysis to predict the bankruptcy of firms using their financial indicators. At the first stage of this approach, we us linear discriminant analysis to identify the most information-bearing financial indicators which later serve as input signals of the neural network which will be used for classification at the second stage. In the second step of this approach, using only relevant features, the classification is performed with the neural network. As the number of input features is lower, it helps to save time to find the optimal solution and also makes the optimization task stable and its solution stable. We verify the ability of this two-stage approach

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on a dataset of Polish firms in manufacturing sector in period 2000-2013 to predict the bankruptcy of these firms. Based on the results we obtained form this approach, recommendation on its applicability will be made.

2 Financial ratios as inputs to bankruptcy models

Financial ratios are derived from numerical values extracted from financial statements like balance sheet, income statement and cashflow statement to obtain valuable information about a company performance. The financial ratios can be divided into five categories: liquidity ratios, leverage ratios, efficiency ratios, profitability ratios, and market values ratios. Here are some examples of them. An example of liquidity ratio is the working capital-total assets ratio

$$X_1 = \frac{Working\ Capital}{Total\ Assets}. \tag{1}$$

This ratio measures the liquidity of a firm with respect to its size. Profitability ratios can be the profit-to-total-assets ratio

$$X_2 = \frac{Profits}{Total\ Assets}. \tag{2}$$

This ratio provides information on the rate of return on total assets. Another one can be

$$X_3 = \frac{Profits\ on\ slaes}{Total\ Assets}. \tag{3}$$

This ratio can be interpreted as the profit margin on each unit of assets. Other ratios can be found in Ehrhardt and Brigham (2016).

Altman (1968) was the first one who used the financial ratios in a multiple discriminant analysis to derive the z-score model to predict corporate bankruptcy. This original model was later modified and refined (Altman, 1983) into the following form:

$$Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + 1.0X_5, \tag{4}$$

where X_1 is the ratio of working capital to total assets, X_2 is the ratio of retained earnings to total assets, X_3 is the ratio of earnings before interest and taxes to total assets, X_4 is the ratio of market value of equity to book value of total liabilities, and X_5 is the ratio of sales to total assets. Firms with z-score higher than 2.99 should be in a safe zone, firms with z-score lower than 1.81 would fall into the distress zone and firms with z-score in interval (1.81,2.99) should occur in the zone of uncertainty.

Ohlson (1980) proposed a probabilistic model of bankruptcy where the probability of financial failure is captured by the logistic probability distribution function. The argument of this function is a linear combination of nine factors as follows

$$Z = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_6 X_6 + \alpha_7 X_7 + \alpha_8 X_8 + \alpha_9 X_9 \tag{5}$$

where X_1 is the size of the firm (logarithm of the total assets), X_2 is the working capital to total assets ratio, X_3 is the liabilities to assets ratio, X_4 is current liabilities divided by current assets ratio, X_5 is. a dummy variable for negative difference of liabilities minus assets, X_6 is the net income to total assets ratio, X_7 is the ratio of funds provided by operations divided by total liabilities, X_8 is another dummy variable for negative net in the last two years, and X_9 is the relative change in net income in the last two years. Parameters $\alpha_i, i = 1, \ldots, 9$, in equation (5) in the logistic regression model are estimated from data. A firm with probability of bankruptcy $P > 0.5$ would be in a bad condition and vice versa. Zmijewski (1984) proposed a similar model using probit model for probability of bankruptcy of firms.

Since the last three decades, researchers have started using advanced machine learning techniques to predict bankruptcy of firms using financial ratios as predictors. For example, Leshno and Spector, (1996) used a neural network bankruptcy prediction analysis. Shin et al. (2005) applied support vector machines technique for bankruptcy prediction. Zięba et al. (2016) used ensemble boosted trees with synthetic features generation to predict bankruptcy of firms in Poland. Altman himself has also teamed up with other researchers (Barboza, Kimura, and Altman (2017)) to investigate the possibility of machine learning techniques for bankruptcy prediction. A survey of the use of machine learning models for bankruptcy prediction can be found in the work of Zhang (2017) and Devi and Radhika (2018). In all cases, the prediction power of advanced machine learning techniques tends to outperform the one of traditional models.

3 Methodology and data description

In this research we combine the traditional machine learning technique previously used for bankruptcy prediction called multiple discriminant analysis (MDA) with backward propagation neural network. Both techniques alone are classification tools and in combination, they can produce more precise prediction results.

(Multiple]) Linear discriminant analysis is a traditional robust supervised multiclass classifier in machine learning. It can used as a dimensionality reduction technique in order to solve a supervised classification problem in machine learning. LDA maps the features space with higher dimension into a lower dimension space which maximizes the between-class variance and minimizes the within-class variance. To do so, first, we calculate called the *between-class variance* classes which is the distance between the mean of different classes. This can be interpreted as the separability between classes.

$$S_B = \sum_{i=1}^{g} N_i \,(\bar{x}_i - \bar{x})(\bar{x}_i - \bar{x})^T \tag{6}$$

where $\bar{x}_i$ is the group mean, $\bar{x}$ is the whole sample mean, g is the number of groups and N_i is the number of members in each group. Then, we calculate the within-class variance which is the distance between the mean and sample of each class.

$$S_W = \sum_{i=1}^{g} \sum_{j=1}^{N_i} (N_i - 1)(x_{i,j} - \bar{x}_i)(x_{i,j} - \bar{x}_i)^T \tag{7}$$

Finally, the lower dimension space or the discriminant rules are computed as follows

$$z = W(x - \bar{x}) \tag{8}$$

where $W = (e_{(1)}, e_{(2)}, \dots, \boldsymbol{e}_{(g-1)})$ is the solution to the following equation:

$$(S_W^{-1} S_B - \lambda \boldsymbol{I})\boldsymbol{e} = 0 \tag{9}$$

where λ is the vector of eigenvalues of matrix $S_W^{-1} S_B$, $\boldsymbol{I}$ is the unity matrix and $\boldsymbol{e}$ is the matrix of its eigenvectors.

A neural network is a complex machine learning tool using computers to process data in a way similar to how the human brain works. A neural network can consist of an input layer, hidden layers, and an output layer. Each layer can contain a number of neurons. Input layer takes information from outside, pre-processes and passes it to a hidden layer. A net may have many hidden layers with various number of neurons. A hidden layer in a net receives inputs from a previous layer and hand them over to a next layer which creates the feedforward mechanism. The output layer takes inputs from the last hidden layer and after processing them, it gives the final result of the whole data processing task. An elementary unit of each network is a neuron. A neuron (also or a node), inspired by behavior of biological neurons, receives inputs from neurons in the previous layer, put them into the activation function and gives the corresponding value of this function as the output. A neuron from one layer is linked to all neurons in the next layer through a net of connections whose strength is determined by their weights. These weights are unknown and they are obtained as the optimal solution to the minimization objective function of the problem through a backward propagation of error algorithm.

A neural network can be used for classification. In this case, the inputs into the net are the features that distinguish one class from others and the outputs are the predicted classes using the inputs for a pre-defined net architecture. The objective function in this case is

$$\min_{w \in W} L = \frac{1}{2} \sum_{i=1}^{g} \sum_{j=1}^{N_i} (y_{i,j} - \hat{y}_{i,j})^2 \tag{10}$$

where *w* is the weight vector, *W* is the set of all permissible weights, $y_{i,j}$ is the true class of the sample and $\hat{y}_{i,j}$ is its predicted class. When training a net, we use a portion of data find the optimal weights and net structure and then cross-validate the net on the remaining part of dataset. In this research these two machine learning methods briefly described above are combined to obtain a more effective classification tool for bankruptcy predictions.

To evaluate the quality of the approach, we use the dataset provided by Zięba et al. (2016). The dataset is available for machine learning community at data repository of University of California Irwin (https://archive.ics.uci.edu/ml/datasets/Polish+companies+bankruptcy+data). Data on financial conditions of Polish firms in manufacturing sector from period 2000-2012 for still operating firms and 2007-2013 for bankrupted companies from database Emerging Markets Information Service (EMIS). From the original data in firms financial statements, the authors constructed 64 financial indicators of all categories. The dataset is rich and for our purpose we will use of a part of it, namely only the five year section. This section contains financial indicators of firms one year away from bankruptcy time. The data in this section contains 5910 firms, 410 firms will bankrupt in the next period, 5500 firms that would not bankrupt in the following period. However, the dataset has many observations with missing values. We exclude all of them. After that, the extent of dataset is reduced to 2133 non-bankrupted firms and 100 bankrupted firms.

In Tables 1 and 2 descriptive statistics of some main financial indicators are displayed. They are profits-to-total-assets ratio (X1), working-capital-to-total-assets ratio (X2), logarithm of total assets (X3), profits-on-sales-to-total-assets ratio (X4), and profits-on-sales-to-sales ratio (X5).

Characteristic	**X1**	**X2**	**X3**	**X4**	**X5**
Mean	0,086	0,222	4,595	0,119	0,086
Median	0,067	0,207	4,542	0,094	0,066
Maximum	0,708	0,936	7,662	0,803	0,728
Minimum	-0,623	-1,470	1,647	-0,109	-0,102
1st Quartile	0,027	0,084	4,180	0,049	0,035
3rd Quartile	0,120	0,352	4,992	0,156	0,116
St. Deviation	0,097	0,199	0,638	0,106	0,080
Skewness	1,213	-0,074	0,348	1,981	2,161
Kurtosis	10,470	5,422	3,811	9,055	10,486
Num. of Obs.	2133	2133	2133	2133	2133

Table 1 Descriptive statistics of non-bankrupted firms

Characteristic	**X1**	**X3**	**X29**	**X35**	**X39**
Mean	-0,098	-0,039	3,965	-0,084	-0,099
Median	-0,053	-0,007	3,954	-0,064	-0,042
Maximum	0,251	0,638	5,579	0,202	0,141
Minimum	-1,373	-1,407	2,185	-1,103	-1,723
1st Quartile	-0,178	-0,208	3,512	-0,148	-0,120
3rd Quartile	0,022	0,161	4,299	0,033	0,019
St. Deviation	0,223	0,311	0,724	0,202	0,239
Skewness	-3,117	-0,778	0,044	-2,493	-4,203
Kurtosis	17,089	5,604	2,836	12,291	25,890
Num. of Obs.	100	100	100	100	100

Table 2 Descriptive statistics of bankrupted firms

The numbers in these two tables show that on average non-bankrupted firms have better financial indicators than bankrupted firms. However, the minimum values of all fives selected ratios of non-bankrupted firms are always lowers than the maximum values of financial indicators of bankrupted firms. In fact, the 3rd quartile values of financial indicators of bankrupted firms are very close to the 1st quartile values of financial indicators of non-bankrupted firms (the value of working-capital-to-total-assets ratio and the logarithm of the size of the firm even slightly exceed those of the first group). This indicates that these two groups may not be absolutely separable by using financial indicators in general.

4 Bankruptcy prediction with two-stage machine learning approach

Though the Altman model and Ohlson model are already known, they are inapplicable for prediction of bankruptcy of Polish firms both in terms of the coefficients and the ratios present in the model. The reason simply is they are invented to predict the failure of American firms which operated under conditions of the American economy at the time they were proposed. Therefore, we use all financial indicators in the dataset to estimate our own Altman-like model with multiple discriminant analysis. All 64 indicators were used and the only restriction we impose on our model is that it should have five indicators as in the Altman model. The computation was carried out in Matlab. After having tried many combinations of five indicators, we have found this combination which best separates the two groups of firms:

$$Z = 3.91X_1 + 2.14X_2 + 0.88X_3 + 0.66X_4 + 4.47X_5, \tag{11}$$

where X_1 is the profits-to-total-assets ratio, X_2 is the working-capital-to-total-assets ratio, X_3 is the logarithm of total assets, X_4 is the profits-on-sales-to-total-assets ratio, and X_5 is the profits-on-sales-to-sales ratio. All coefficients in equation (11) have the right sign which is the positive sign. This means that the higher the ratios are (or the bigger the size of the firm is), the more stable financial conditions the firm are in. Also, the estimated coefficients are elements of the eigenvector corresponding to the biggest positive eigenvalue of matrix $S_W^{-1}S_B$. Equation (11) has four ratios similar to those present in the Altman model and the fifth one is the size of the firm which is present in the Ohlson model. This result differs from model estimated by Geise et al. (2021) and Zięba et al. (2016) (from the same dataset with a different method). Using equation (1), we compute the Altman z-score for firms in our dataset. The decision rule is as follows. If a firm has a z-score higher than 5.30, it is in the safe zone and there are totally 960 firms in the safe zone. If a firm has a z-score lower than 3.72, it would be in financial distress (there are 69 firms in our dataset in this zone) and if a firm has a z-score in interval (3.72,5.30), than it would fall into the grey zone and there are 1211 of them in the grey zone. The maximum value od z-score is 11.62 and the lowest value of z-score in our dataset is -5.61.

Next, we use the indicators identified in the previous part as inputs to a neural network. The architecture of the net is shown in Figure 1 below. It has one hidden layer and we use the whole dataset to find the optimal number of neurons in the hidden layer. We have found that we need only 10 neurons to get high-quality and stable results. We have also found that best optimization algorithm for the net is the Levenberg-Marquardt algorithm.

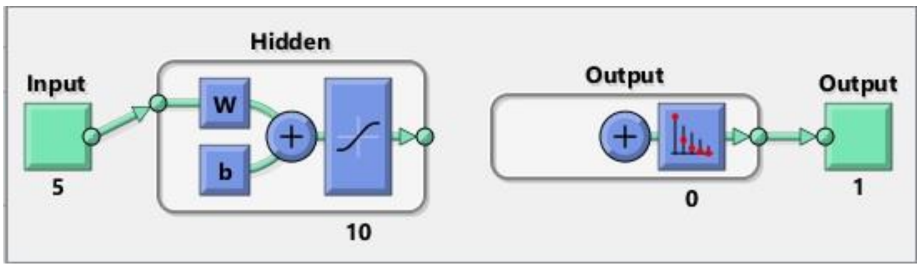

Figure 1 The architecture of the network for classification

The in-sample prediction results are as follows. The net predicts correctly all 2133 cases of non-bankrupted firms. Out of 100 bankrupted firms, the net predicts correctly their bankruptcy in 82 cases and misclassifies them as non-bankrupted firms in 18 cases, see Table 3. To cross-validate the results, we proceed as follows. For non-bankrupted firms, we randomly choose 300 of them from dataset and set them aside. Using the remainder of the dataset, we generate the optimal weights and use them to predict the bankruptcy status of 300 firms. The correctly classifies all of them as non-bankrupted firms. Regarding the bankrupted firms, we cross-validate them using the leave-one-out technique when one bankrupted firm is left aside and the remaining part of the dataset is used to find the optimal weights. Out of 100 bankrupted firms, the net correctly classifies them as bankrupted in 83 cases and misclassified them in 17 cases as non-bankrupted firms.

Characteristic	Training prediction	Cross-validation
True negative	2133	300
False positive	0	0
True positive	82	83
False negative	18	17

Table 3 The results of bankruptcy prediction with neural network

It is clear that a neural network is a powerful classification tool. In our case, it is absolutely successful in predicting the status of non-bankrupted firms using their financial indicators. In the case of bankrupted firms, the rare of correct prediction is also very high. Compared to the Altman-like model, it eliminates the existence of grey zone where one cannot say anything univocally about the status of a firm of interest. However, in our two-stage approach, linear discriminant analysis also plays an important role. As it is linear, it is fast to find solution of the problem. Hence, it can be used and we use it as selector of important inputs that then enter into a network as input signals. It speeds up the prediction process very much compared to the case of using only neural network.

5 Conclusion

We have combined two classification methods in a two-stage approach to utilize the strength of both methods in order to create a prediction model of firm’s bankruptcy. The strength of multiple linear discriminant analysis is capitalized at the first stage to select suitable financial indicators for the second stage when the neural network, which has stronger predictive power, is used to classify the survivability of firms. We verify this approach on a relatively large-scale dataset of Polish firms in manufacturing sector in period 2000-2013. The classification results we obtained show that this approach can correctly classify all cases of non-bankrupted firms and increase the rate of correct prediction of bankrupted firms. The results are so promising that further testing would be desirable to confirm its advantage over other approaches.

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Legal Information Sources and Legal Information Systems

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Abstract. Knowing the individual sources of law in detail, as distinguished by legal theory, is as important as knowing the means by which to become familiar with the individual sources of law and with law as such. Law, like other disciplines, is constantly evolving. What is true today may be different tomorrow. Each of us must react and adapt to these changes, but in order to do so, we need to know about these changes and be able to apply them in practice. The sources of information about the law and legal information systems discussed in this article serve to familiarize oneself with them. The authors aim to provide a comprehensive overview of the tools used by the subjects to get acquainted with the law and legally re-relevant information.

Keywords: legal information systems, legal literacy, public registers, sources of law.

JEL Classification: G53, K10

1 Introduction

Legal literacy encompasses knowledge and awareness of one's rights and obligations, but it also includes the important area of acting in accordance with the law, i.e. knowing how to exercise and enforce one's rights. Also, Zariski (2014) explains that legal literacy is not only knowledge of the law, but more importantly understanding the law and being able to use it also to make a difference for oneself and others, and to improve society. Because Zariski (2014) highlights legal literacy in conjunction with general literacy and relates legal literacy as an integral part of being a member of society, that is, a society that is regulated by law. The ordinary citizen should be able to find and understand basic information (Kořenský, Cvrček and Novák, 1999; Cvrček and Novák, 2017), describe the basic problem, find a legal institution (court or competent authority) that can respond to the citizen's objections (or when to contact the police, for example), plan the basic steps to solve the problem (whether it is a common life situation, such as This includes the conclusion of a contract, the making of a will, the purchase of a property or the filing of a lawsuit) and the search for (or preparation of) documentation. Legal regulations are the primary source of information about legal norms and facts, but to interpret and apply them to real situations we need to work with a variety of other documents (Šavelka *et al*., 2011). Thus, we cannot do without searching for legal information. Novotná (2021) states that the number of legal sources can no longer be searched and processed in terms of the volume of information without the use of information technology and digital formats. The aim of this

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article is to analyze sources of legal information, databases of court decisions, public registers or online sources that are publicly available.

2 Literature Review

Legal literacy is related to the search for legal information. It is just as important to know the resources we can use to find the legal information we need, to look up specific legal standards or just the information we need about a business partner or competitor. We can use several means to orient ourselves in legal regulations and to understand their meaning and content, e.g. legal information systems, databases of court decisions, public registers or online resources, or other more narrowly focused databases (Kühn, Bobek and Polčák, 2006; Šavelka *et al*, 2011; Korhoň, 2012; Kozieł, 2014; Myška *et al*., 2016; Cvrček *et al*., 2020; Harašta, 2020; Ha-rašta *et al*., 2021; Novotná, 2021) Access to the online version of legal regulations is absolutely essential for basic orientation (Cvrček *et al*., 2020; Novotná, 2021). Sources of information about law, including but not limited to legal information systems, which are a unique source of information about law and which are time-to be used and subscribed by universities for teaching students. However, there is still a lack of a unified nationwide information system (Cvrček *et al*., 2020) or even other databases, such as an information system of regional regulations, a central register of methodological guidelines issued by state authorities, which would constitute a comprehensive verified database and, above all, would be free of charge for citizens.

Studies regarding legal information systems are already relatively more frequent (Ptašnik, 2007; Ša-velka *et al*., 2011; Korhoň, 2012; Myška *et al*., 2016; Cvrček *et al*., 2020; Harašta, 2020; Haraš-ta *et al*, 2021), as well as studies in terms of the use of appropriate methods for legal information retrieval, e.g. Novotná (2021) describes the advantages of network analysis for working with legal information or Dvořák (2013) explains the mission of markup languages and their use in the field of electronic editing of legal documents. Searching legal texts is not facilitated by legal language or legislative drafting, as computer processing is not envisaged (Cvrček *et al.*, 2020).

3 Legal Information Sources

Sources of information on law can be divided into several categories according to different criteria. The basic criterion is whether we are looking for formal sources of law, information about law, or information relevant to the law. The first category will include all legal regulations, i.e. generally binding normative legal acts, then judicial and administrative precedents, normative contracts and finally legal customs (Kozieł, 2014). Not all formal sources of law can be encountered in the Czech Republic. Some of them, especially judicial and administrative precedents and legal customs as defined by legal theory, are defined in theoretical terms and we can encounter them more in international law. In view of the fact that in the Czech Republic the emphasis is on the so-called written law, the most significant are legal regulations and normative legal contracts.

The second category of information on law includes, on the contrary, professional books and journals, decisions of courts and other authorities, or the outputs of scientific conferences on the subject of law. Within this category, the individual legal norms contained in formal sources of law are clarified through their interpretation (professional literature) and application to specific situations (decisions of courts and other authorities). Thanks to this category, the seemingly complex and often very difficult to understand text of a legal norm for the general public is given concrete contours, is filled with content and thus becomes more comprehensible.

Finally, the third category, called legally relevant information, includes all sources of information approved by the legislature, the introduction and creation of which is envisaged by the legislation. It is therefore primarily information from publicly available registers.

Legal Information Systems

Legal information systems are comprehensively processed databases of legal regulations of the Czech Republic (some of them also include regulations of the Slovak Republic), international treaties and European law, supplemented by expert articles, commentaries on the most important laws and relevant judicatures. It thus provides a unique source of information on law and legal norms, which helps in orientation in legal regulations and their interrelations (Kozieł, 2014). Individual legal information systems are usually already accessible from the web interface and it is not necessary to install special software, they are also available in the basic version for free, there are discounted packages for university students, the full version is usually charged in the form of a so-called subscription, where the user can set up access to the full modules according to their needs (we can say that we can tailor the system). Of course, there are differences between the systems, e.g. in the user interface and user-friendliness, the way of structuring legal regulations, the way of searching and the algorithms set up (Harašta, 2020). The fundamental difference is in the full-text access to literature and journals, mostly from selected cooperating publishers.

Legal information systems include ASPI, CODEXIS, Beck-online or Laws for People PLUS (Zákony pro lidi PLUS).

Collection of Laws and Collection of International Treaties

The Ministry of the Interior of the Czech Republic publishes a copy of the Collection of Laws and the Collection of International Treaties (Act No. 309/1999 Coll., on the Collection of Laws and the Collection of International Treaties). This method of publishing applicable law is to be replaced by the eCollection and eLegislation project.

eCollections and eLegislation (eSbírka and eLegislativa)

The upcoming eCollection and eLegislation projects are part of the eGovernment system. The aim is to increase the accessibility of the applicable law and to make the whole system more transparent at all stages of the legislative process (Stupka, 2014). *"The eCollection system will be divided into two parts – a portal where binding electronic versions of legal acts published in the Collection of Laws and International Treaties, including legally binding full texts, will be published, and a database of information on legal acts."* (Ministry of the Interior of the Czech Republic, 2023) *"The eLegislation system represents modern tools for the creation and discussion of legislation. It brings significant changes to legislative work, in particular the preparation of amendments to legislation by entering changes directly into the full text. Amendments to legislation will now be accompanied by their legally binding full texts, making* *it easier to navigate the frequent changes to the legal order. The introduction of eLegislation will bring greater clarity to the drafting, especially the discussion of legislation, while reducing the number of errors in the legislative process and generally increasing the quality and transparency of the legislative process."*(Ministry of the Interior of the Czech Republic, 2023) The project was scheduled for October 2022 but has been postponed to 2024 (CTK, 2022). The aim of the project is to increase information and clarity for ordinary citizens so that they can find the current text of all applicable Czech laws free of charge via the internet. The list of new and repealed obligations that the proposed changes to the law would bring is also intended to increase clarity and information. At the same time, it should also contain a list of sanctions for non-compliance. The systems and their limits are discussed in more detail by Fronc (2022).

Database of Court Decisions

A court decision is an individual legal act, which is the result of a proceeding before a court, which is a conclusion about a specific pending case and specific rights and legal obligations of the subjects (parties). (Šavelka *et al*., 2011; Večeřa *et al*., 2015) Along with the terms court decision, there are also the terms case law or case law, which are often understood and used as synonyms (Králík, 2015; Gříbková, 2018).

Court decisions and case law can also be found online from the justice.cz portal - court decisions and case law (Ministry of Justice of the Czech Republic, 2017). On this portal, however, we must first choose which database we will search - the database of decisions of the Constitutional Court, the database of decisions and opinions of the Supreme Court of the Czech Republic, the database of decisions of administrative courts, the database of case law of supreme and regional courts, the database of case law of the ECLP, the database of decisions of district, regional and supreme courts. From the justice.cz portal, it is also possible to search for decisions of the Ministry and Minister of Justice of the Czech Republic (Ministry of Justice of the Czech Republic, 2020). The portal redirects us to the websites of the relevant courts or their databases. Each database has its own specific system for the search form and, presumably, its own algorithm for searching. There are also portals that allow searching across decisions and case law, for example *judikáty.info*, which searches court decisions in full-text in combination with other criteria. It is also possible to search the legal information systems mentioned above.

Public Registers

Among the most important registers in the Czech Republic are the Commercial Register, and with it the Register of Associations, the Register of Foundations, the Register of Institutions, the Register of Unit Owners' Associations, and the Register of Benefit Corporations. These registers record the statutory data on legal and natural persons, which are then publicly accessible to all. Documents which are part of the collection of documents, such as founding acts, annual reports, etc., are also publicly accessible. An equally important register is the Trade Register, which records data relating to the operation of trades. The insolvency register should also be mentioned which also contained the list of bankrupts. The insolvency register includes a list of insolvency administrators, a list of debtors and insolvency files. If an insolvency petition is filed, all documents are published in this register throughout the insolvency proceedings.

The above-mentioned registers are linked to the information system of the Ministry of Finance of the Czech Republic, Ares.cz, which searches for Czech and Slovak economic entities and uses public registers and registers for searching (see more in (Šavelka *et al*., 2011; Ministry of Finance of the Czech Republic, 2023).

Among other sources of information important from the point of view of law, we can mention for example the Cataster of Real Estate containing a set of data on real estate in the Czech Republic, the register of contracts, which serves to publish certain private contracts, the administrative register of economic entities enabling searches over economic entities registered in the Czech Republic or e.g. the land register (Land Parcel Identification System) containing records of land use according to user relationships. All publicly available registers are an important source of information for the subjects of law, which can and in many cases must be known in order for the subjects to exercise their rights in accordance with the law.

Other online resources

Online sources are innumerable in these turbulent times, both official and unofficial. Citizens have become accustomed to searching the Internet - search engines for any information and solutions to problems, which brings with it the spread of unverified information and instructions for not always correct solutions to legal or other problems.

A specific project is the Legal Electronic System (PES), which shows businesses the obligations they have under the applicable regulations. The system was created by the Economic Co-operation and NEWPS.CZ (Cvrček, 2015; *Právní elektronický systém* | PES, 2023).

Šavelka *et al*. (2011) also mention the Theses system as an interesting source of primary sources on a particular legal topic. This is a system used to detect plagiarism in theses and ab-sessional papers from 65 universities and colleges. Theses.cz is developed and operated by the Faculty of Informatics of Masaryk University. (*Theses.cz – Vysokoškolské kvalifikační práce, 2023*) A final thesis prepared on a specific topic, which a person is currently solving or researching, can be a comprehensive source of primary information.

Another source are legal information portals that publish news and articles in the legal and economic field. There are a number of such portals, in particular epravo.cz; pravniprostor.cz.

4 Discussion

The electronization of law can be seen as beneficial, especially in the case of searching case law, which is already a huge amount (Cvrček *et al*., 2020). Each system has its own search engines, its own search algorithms, and different user environments (Šavelka *et al*., 2011; Korhoň, 2012; Harašta, 2020), which must be learned to work with in order to use the potential of the above-mentioned tools. Online legal information increases the possibility of familiarising oneself with the applicable law, finding out the necessary information or verifying it. And from the above overview it is clear that there are plenty of possibilities. However, the essential fact remains that the correct interpretation of the information searched for, and the correct application of the information remains. And this can be a problem for persons (addressees) without legal education.

In terms of the possibility of free searches, the problem lies in the inconsistent system. For the time being, there is no unified nationwide information system, which would include full texts of regulations and explanatory notes, regional regulations, case law, methodological guidelines issued by state authorities (Cvrček *et al*., 2020). Such a system should then be available on the Internet free of charge for the use of all citizens. While these replace commercial legal systems, they are inadequate in their basic free form. These should be remedied by the forthcoming eCollection and eLegislation project, the aim of which is to make it easier to navigate through legislation and to find Czech legislation in force in one place. As with other information systems, the user interface and search options will be important.

5 Conclusions

Today, the addressees of legal norms can draw on a plethora of sources of information about the law. Whether it is access to formal sources of law or to other sources that help to understand or apply the sources of law, there are always several ways for recipients to access the information they need. We present the options and tools for subjects to learn about the law and legally relevant information in our article. On the other hand, at the same time, these addressees are also subject to increased demands in the form of a requirement to know certain information relevant to the exercise of their rights. These situations are encountered not only by persons whose profession is directly related to law - lawyers, notaries, bailiffs, judges - but also by ordinary people who often do not have a legal education. For example, an entrepreneur who is a creditor and has a claim on a debtor is required to keep an eye on the insolvency register in case his debtor becomes insolvent. In the case of a few debtors, we can imagine that this check is carried out once in a while by the creditor himself, but if there are a large number of debtors, the entrepreneur has no choice but to rely on automated paid services that perform this obligation for him. The situation is the same in the case of real estate purchases. Anyone wishing to buy a property should first of all visit the land registry website or the land registry office directly to check whether the property has any legal defects that would prevent or significantly hinder the future use of the property.

A separate chapter is the ambiguity of legal norms, where the addressees of legal norms are required to apply them, but these addressees, often without legal education, may not always apply the legal norm in the way its creator intended. In this situation, it is therefore advisable to use other sources containing information about the law, in particular legal information systems, and through these to become more familiar with the practice of the courts and the opinions of the professional public on the issue. However, not everyone has the desire, time or knowledge to look at the issues and legal standards in detail, so in many cases the addressees have no choice but to turn to legal professionals to resolve the issues for them for a fee.

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