How does Business Orientation of Manufacturing Enterprises Define the Utilisation of Lean Production?

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Abstract: The main purpose of the research presented in this paper is the investigation of how lean production is applied and whether business orientation of manufacturing enterprises has any effect on lean production's utilisation. In order to determine the situation of lean production, the paper presents a multidisciplinary research framework consisting of manufacturing, management tools, and business orientation theories and analyses 224 responses of employees in the sampling areas of Western Europe, Central Europe, and Arabian Peninsula. The study indicates intensive utilisation of lean production in the responding enterprises, with its highest use in Central Europe, followed by Western Europe and on the last place the Arabian Peninsula. The analysis of business orientation revealed that: (1) internal orientation is strongest in Western Europe and weakest in Central Europe with small differences in strength of orientation and (2) external orientation is strongest in Western Europe and weakest on the Arabian Peninsula with significant differences between orientations of enterprises. Correlations of business orientation and lean productions' utilisation showed significant and positive impacts of: (1) internal enterprise orientation on lean production' utilisation among enterprises from Arabian Peninsula, and (2) external enterprise orientation among enterprises from Western Europe and from the Arabian Peninsula, while other relations were found to be neutral.

Keywords: lean; lean production; business orientation; internal orientation; external orientation; manufacturing enterprises

1 Introduction

Since 1970s, the creation of the ideology of lean production, [1, 2] numerous approaches have emerged to improve enterprises' production to match the conditions of the globalised market. Promising improvement of the operations of enterprises has derived from the lean production concept, established through academic studies of Japanese manufacturing practices in the1970s [1, 3].

Early research of the lean concept was initiated in manufacturing, business, and logistic theories [4, 5]. These theories established the basic foundations and models of utilisation of individual production solutions and lean philosophy in enterprises [6, 7]. Business and management theories revealed how lean production contributes to costs reduction, quality improvement, utilisation of value chains, and flexibility of organisations [8, 9]. Logistics theory established foundations for optimising flows in organisations, structural changes of the production's structure and inter-organisational cooperation in production [3, 9].

Despite the comprehensive theoretical foundations of lean production [1, 7] literature remains fragmented in content and methodological conceptualisations of its: general definition [6, 10], measurement, and evaluation [1, 3], and suitability for the achievement of contradictory business goals [4, 5]. In addition, the studies about relationships between situational factors and lean production utilisation uncover issues of applicability of lean production for the production of enterprises, which operate in specific economic conditions and under various circumstances [11, 12].

The present paper introduces a study on Lean production with the help of the answers of 224 employees from manufacturing enterprises in Central Europe, Western Europe, and the Arabian Peninsula. According to Holweg [3] recommendations on how to properly apply theories from different disciplines, authors modified the research tools of business, manufacturing, and management theories to fit the specific objectives of the present contribution and used them for the analysis of lean production.

To underline the significance and novelty of the research below, the present paper highlights and addresses four gaps of lean production's research that have been exposed in prior studies [1, 5]. First, the authors study utilisation of lean production through multi-dimensional research, which includes heterogeneous production tools of enterprises and creates the bridge between the quite divided studies of manufacturing among scientific disciplines. Second, with consideration of business orientations, authors analyse the present orientation of enterprises and differences in enterprises' orientations among enterprises from several international areas. Third, following the studies about advantages and disadvantages of business orientations for enterprise, authors consider the direct causal effects of internal and external business orientation on utilisation of lean production among the researched enterprises. Finally, this study uncovers critical

knowledge about specifics in lean production's utilisation among enterprises which operate under specific conditions and circumstances, as well as suggestions for future utilisation of lean production in the constantly changing global business environment.

2 Theoretical Background and Hypotheses

2.1 Lean Production

Lean production - also named Lean manufacturing, originated from the "Toyota production systems" and practices of Japanese manufacturing enterprises developed in the 1970s [13, 14]. The term "Lean production" was first used by Krafcik [10], and established through academics' and practitioners' studies in the 1990s [1, 9, 15].

Leading 'Lean' theorists - like Womack, et al. [14] and Shah and Ward [1], provide guidance for conceptual frameworks addressing the lean production's challenges in organisational practice. Initial lean studies investigated the foundations and essential models of Lean production through research of: its individual components [16], interrelationships of its components [3], the impact of organisational variables on lean [8], and lean implementation among manufacturing enterprises [2]. In addition, lean production theorists extended the lean philosophy and created the guiding principles underlying lean to an enterprise-level [2, 14, 15].

Reviewing the current lean literature indicates many understandings and definitions of "Lean production", which are mainly descriptive and have become very expansive over time [4, 9]. The first conceptualizations of Lean production exposed its "practical perspective related to a set of management practices or techniques related to manufacturing" [1], while the newer ones expose its "philosophical perspective related to guiding principles and overarching goals of manufacturing" [3].

To avoid confusion concerning the available conceptualizations [9, 17] and traditions of lean theorists [3, 14], authors considered Lean production as an "integrated system that accomplishes production of goods/services with minimal buffering costs" [6].

2.2 Utilisation of Tools and Lean Production

During the last two decades' academics and practitioners expanded their study of lean production on several research areas and issues like: methodologies for measurement and validation [1], correlations between internal and external

organisational factors and lean [2], lean's implementation in networked organisations [18], and relations between specific operating conditions and lean utilisation [5].

Several 'lean' theorists, such as Holweg [3] and Shah and Ward [1], share the idea that the selected methodological approach determines the possibility of measuring of lean production. Literature review reported that the lean idea – similarly to other enterprise frameworks, - can be conceptualized and studied as " a concept, a methodology, a method, a technique or a tool" [19]. Each of these appearance forms of lean production supports realisation of specific needs and demands of production on particular levels of business operations - i.e., from strategic to operational level [3, 20].

Following the implementation of tools analysing manufacturing [8, 9], authors study lean production as a tool and defined it as "an entity of processes, exercises, and analytical frameworks that supports utilisation and management of lean idea on the operational level of enterprises" [19]. This methodological approach enables comparison of the lean with other individual manufacturing tools – like Just in Time, and Total Quality Management [16], and various other frequently arising manufacturing tools [5, 19].

2.3 Business Orientation and Lean Production

In addition, analysis of correlations between specific conditions – caused by the environment and situational characteristics, in which enterprises operate, - and lean utilisation revealed diverse results [5, 19]. Thus, Lamming [8] reported about strong impact of globalised automotive productions on lean utilisation among enterprises from well developed countries; research of Buckley and Ghauri [18] indicate weak correlations between different designs of "agile supply chain" and lean utilisation; and Naylor, et al. [4] revealed that analysis of the isolated impact of lean in modern enterprises is not appropriate (and neither relevant) anymore, and suggest its inclusion in the analysis of integrated impact in series of production paradigms.

The present paper collaborates to the stream of these studies with the analysis of lean utilisation among enterprises from Western Europe, Central Europe, and the Arabian Peninsula. The interest for comparative research of lean among selected international areas is stemming from their fast-growing goods exchange, reciprocal co-operations, and a common participation in global supply chains [18, 21]. In more details, interest for lean in enterprises from Western Europe accelerate their participation in the newest development initiatives – like Industry 4.0, application of new technologies and manufacturing solutions – like smart production, and needs for cost rationalization of operating [2, 17]. Reasons for the growing use of lean among enterprises in Central Europe originate from their supply orientation, limited availability of natural resources, and their position as

non-focal providers in international supply chains and companies [2, 22]. Specific conditions for applying lean for enterprises from the Arabian Peninsula are the availability of oil and natural gas and lack of other resources (natural, economic, technological), logistical potentials of their location, and plan for fast development of the countries [23]. Hence, all three target groups of countries are increasingly interested in and intent on utilisation of lean production.

In spite of the common lean orientation among sampled enterprises, specifics of their operations – like business orientations, ways of inclusion in international cooperation, and conditions in which they operate – like availability of natural resources, level of development, ways for international cooperation of individual enterprises, caused the development of specific characteristics and different levels of utilisation of lean among them [2, 23]. The following hypotheses are formulated on the basis of these differences:

Hypothesis 1: Utilisation of lean production significantly differs across Western Europe, Central Europe, and Arabian Peninsula areas.

In last decades, studies about globalization [18], supply chains - as the dominant type of enterprises' cooperation in 2000 s [5], and multinational corporations (MNC) [17, 24], provoke interest for the analysis of relations between enterprises' business orientations and lean utilisation in enterprises [11, 12].

Scholars quoted several classifications of business orientations – from basic internal and external orientations to more sophisticated orientations, each of which expressed applied contentual and methodological starting points for enterprises' operations [5, 25]. Irrespective of their variety, literature review of the known conceptualizations of orientations [26] revealed common presumptions about the importance of business orientation, existence of one prevailing orientation, and implementation of different streams of solutions for each orientation, among enterprises.

A detailed overview of the business orientation concept – together with its corresponding models, exceed the limitations of this research. Following the generally accepted basic presumptions about business orientation [25, 26] present paper focuses on the dichotomy of internal and external business orientations as variables of interests for the development of research hypotheses.

Following the traditions of business [25], management [9], and manufacturing [6, 15, 22] theories authors defined internal business orientation of enterprises as "an approach to business that prioritizes the achievement of selected internal goals – primarily profit, with high control of the overall costs and standards of quality in production and provision of services for customers". The meaning and content of internal orientation were developed over time [25, 26] from the maximisation of the profit with a product-centered view of the firm in the period before the 1970s [25], to the realisation of organisational profit with respect to customers' needs and demands through manufacturing and services in a globalised environment [5].

The review of literature about the operation of enterprises in globalised market environment [18, 21, 24] leads to the definition of external business orientation as "an approach to business that prioritises identifying market changes and meeting the needs of customers, while maintaining high standards of quality and controlling the overall costs involved in the production of products and provision of services". Such orientation enables organisations to balance their internal focus of execution with their higher exposure and their engagement with the external environment of their operations [2, 5, 15].

Since enterprises can apply internal or external business orientation in accordance with their goals and market conditions, academics and practitioners reported about the different selection of business orientation among individual manufacturing organisations [7, 25]. Thus, present paper also focuses on the exploration of the below-listed hypothesis:

Hypothesis 2: Significant differences exist in business orientations among enterprises across Western Europe, Central Europe, and Arabian Peninsula areas.

Hypothesis 2a: Significant differences exist in internal business orientations of enterprises across Western Europe, Central Europe, and Arabian Peninsula areas.

Hypothesis 2b: Significant differences exist in external business orientations of enterprises across Western Europe, Central Europe, and Arabian Peninsula areas.

Regardless of the popularity of internal and external business orientations in enterprises [15, 25], literature shows no consensus about the advantages and disadvantages of these orientations regarding the enterprises' utilisation of lean productions [15, 24].

Academics and practitioners formulate large congruency about positive correlations between internal business orientation and lean utilisation of enterprises [6, 17, 27]. Internal business orientation accelerates the stream of lean activities, like minimization of costs and time of production, optimization of the performance of operations, and improvement of relations with customers [12]. The adaptability of lean production in various cultural [2, 23], economic [2, 8], and technological [9, 15] environments in which enterprises operated is less studied and explained.

Following the previous business and manufacturing studies [2, 3], we hypothesize that:

Hypothesis 3: Differences exist in the impact of internal orientation on lean production utilisation among manufacturing enterprises from Western Europe, Central Europe and Arabian Peninsula.

Concept of external business orientation has been widely used among researchers for explaining of lean production utilisation in global environment through studies of: impact of environment and situational factors on its utilisation [5, 25], relations of lean with individual business solutions [2, 27], and impacts of lean utilisation on results of organisations and society [9, 18], among others. Another promising stream of studies revealed a series of contextual and situational' specifics which can affect the utilisation of lean in particular situations, like studies of lean utilisation in supply upstream in supply chains [7], the connection between lean and smart production [15], and lean utilisation in Industry 4.0 [12].

In line with the tradition of business and manufacturing theories [7, 16, 17], we hypothesize that:

Hypothesis 4: Differences exist in the impact of external orientation on lean production utilisation among manufacturing enterprises from Western Europe, Central Europe and the Arabian Peninsula.

3 Methodology

3.1 Instrument

For this survey, extensive research about knowledge, use, and satisfaction with management tools in organisations has been developed. International surveys for researching management tools in organisations [19, 20, 28, 29] have been utilized, while also new questions regarding 33 commonly used management tools in organisations have been added. The final version of the questionnaire consisted of three parts; Part 1 – which measures the basic demographic data of respondents and their organisations; Part 2 – which gathers general information about the use and knowledge about management tools in organisations; and Part 3 – which assesses knowledge about management tools, utilisation of management tools, and the satisfaction with the utilisation of management tools.

3.2 Sample and Procedure

The questionnaires were distributed in 2017 to the employees in manufacturing enterprises in Western Europe, Central Europe and the Arabian Peninsula via email. Based on a random sampling of enterprises, which had been determined for previous surveys of management tools [20, 28]. During the research up to 3 direct email addresses of employees of the selected enterprises have been identified with the help of the enterprises' websites, to which the link of the survey has been sent. In each investigated geographical area 500 emails have been sent to employees, containing link a to the survey. The response rate for Western Europe was 14.2

percent, for Central Europe was 17.8 percent and for Arabian Peninsula 15.8 percent.

The sample for this paper included 71 respondents from Western Europe, 74 from Central Europe, and 79 from the Arabian Peninsula. All respondents were involved in manufacturing organizations. The characteristics of the sample (n=224) are outlined in Table 1.

Table 1
Demographic characteristics of respondents

Variables	**Aggregated sample (*n=224*)**
Age	39.25
Work experience	17.14
Gender: *Male*	70 %
Female	30%
Education: *Finished high school*	25.4%
Bachelor's degree	64.3%
Master's degree	9.8%
PhD	0.4%
Position: *Professionals*	22.8%
First-line managers	15.2%
Middle managers	38.4%
Top managers	23.6%
Organizational size: *Below 250 employees*	16.1%
Between 250-1 000 employees	64.3%
More than 1 000 employees	19.6%

In present paper data from the first part of the survey, and data regarding utilisation of management tools from the third part of the questionnaire is introduced.

3.3 Measures

Demographic information such as education level was measured using scale items where respondents had options from "primary school" to "Ph.D.", for position from "professionals" to "top managers". For age, work experience, and organisational size respondents entered integer numbers regarding their age, work experiences and approximate number of employees in organisation. They also indicate their gender.

Management tools utilisation: respondents rated each of 33 management tools in the survey using a Likert-type scale ranging from "I always use" (1) to "I never use" management tool (7). Participants choose one answer for assessing each tool. Based on the exploratory factorial analysis, using varimax rotation and principal

component extraction of 32 management tools, (since lean production is considered as a measurable variable), two latent variables have been created (KMO = .802 indicate sampling is adequate and significant Bartlett's test of sphericity ($p < .001$) justify utilisation of factor analysis [30]).

- Internal organisational orientation is represented accurately and in a reliable manner by the utilisation of eight management tools, namely benchmarking, core competencies, business process reengineering, knowledge management, balanced scorecard, total quality management, six sigma, and change management programs. The Cronbach's alpha coefficient for this scale is 0.769.
- External enterprise orientation is represented accurately and in a reliable manner also by utilisation of eight management tools, namely customer relationship management, customer segmentation, outsourcing, supply chain management, satisfaction and loyalty management, mergers and acquisitions, and offshoring. The Cronbach's alpha coefficient for this scale is 0.718.

3.4 Research Approach

As a first step elements of descriptive statistics and zero-ordered correlations between variables in the study for the aggregated sample have been outlined. In the second step, we used aone-way analysis of variance (ANOVA) in order to determine the current state of enterprise orientation and current level of lean production utilisation in Western Europe, Central Europe and Arabian Peninsula. As a third step hierarchical regression analysis has been used to determine the impact of internal and external enterprise orientation on lean production utilisation, while also controlling the impact of selected control variables, namely age, gender, education, position, and organisational size. We examined the impact of enterprise orientations on lean production utilisation, with two repetitions of hierarchical regression analysis, for both dependent variables to be entered in regression analysis.

For assessing normality, the Kolmogorov Smirnov test has been utilized, which revealed that the most variables of interest in the study do not markedly violate the assumptions of the normal distribution [31]. Additionally, the values for asymmetry and kurtosis for considered variables are ranged between (-2;2), which are acceptable in order to prove normal distribution [31, 32].

Due to the single source of both the independent (i.e. lean production) and dependent variables (i.e. internal and external enterprise orientation) in one instrument, the possibility of bias exists [33]. We estimated the common method variance utilizing an exploratory factor analysis in SPSS. We loaded all 33 management tools onto a single factor and constrained so that there was no rotation [33]. The newly introduced common latent factor explains 22.667 percent

of the variance, indicating that the possible presence of common method bias is below the threshold value of 50% [34].

Regarding multi-collinearity, collinearity statistics for conducted hierarchical regression analyses were calculated [31]. Tolerance values are greater than 0.10 and VIF values are way below 10, which are acceptable [30] and indicate that multicollinearity is not an issue in this survey.

4 Results

Table 2 presents the mean values, standard deviations, and zero-ordered correlations among variables in the research for the aggregated sample.

Table 2

Means, standard deviations and zero-ordered correlations among variables in the research for aggregated sample

Variable[a]	M	SD	1	2	3	4	5	6	7	8
1.Age	39.25	8.19	1							
2.Gender	1.30	.46	-.07	1						
3.Education	2.85	.60	-.16*	-.11	1					
4.Position	2.67	1.17	.54***	-.08	.08	1				
5.Organisational size	4.01	.68	-.04	-.00	.28***	-.12	1			
6.Region	2.04	.94	-.09	-.28***	-.07	-.12	.13	1		
7.Lean production	4.54	2.09	-.29***	-.12	.02	-.29***	-.12	.27***	1	
8.Internal enterprise orientation	5.70	.94	-.28***	.10	-.26***	-.35***	-.18**	.03	.34***	1
9.External enterprise orientation	4.38	.94	-.31***	.00	-.15**	-.39***	-.21**	.23**	.51***	.48***

[a] *N = 224; * p < .05, ** p < .01, *** p < .001*

According to the above table several associations are noteworthy. First, there are associations between lean production and internal enterprises' orientation and (r = .34, $p < .001$) and between lean production and external enterprises' orientation (r = .51, $p < .001$), which provides fertile ground for discussion about the impact of lean production on enterprises' orientation. Second, region is correlated with usage of lean production (r = .27, $p < .001$) and external enterprises' orientation (r = .23, $p < .05$), indicating that differences exists regarding lean production utilisation and external enterprises' orientation between organisations from different observed regions. In Table 3 we present utilisation of lean production

and enterprises' orientation in Western Europe, Central Europe, and the Arabian Peninsula.

Table 3
Lean production utilisation and enterprises' orientation in Western Europe, Central Europe and Arabian Peninsula

Variables [a]	Western Europe		Central Europe		Arabian Peninsula		F
	Mean	SD	Mean	SD	Mean	SD	
Lean production	4.17	2.13	3.85	1.70	5.52	2.04	15.62***
Internal enterprises' orientation	5.63	.97	5.79	.61	5.69	1.15	.55
External enterprises' orientation	4.13	.92	4.33	.81	4.66	1.01	6.31**

[a] *N = 224; * p < .05, ** p < .01, *** p < .001*

The above results reveal significant differences in utilisation of lean production across Western Europe, Central Europe, and the Arabian Peninsula, where lean production has the highest use in Central Europe, followed by Western Europe, while it is at least used in the Arabian Peninsula. This confirms Hypothesis 1.

Turning to the state of enterprise orientation it is evident that internal enterprise orientation is the strongest in Western Europe, tightly followed by the Arabian Peninsula and Central Europe, revealing no significant differences among compared areas. This suggests rejection of Hypothesis 2a. Oppositely, regarding external orientation, there are significant differences, where external enterprise orientation is strongest in Western Europe and the weakest at the Arabian Peninsula. This supports Hypothesis 2b.

Next, we outline the results of hierarchical regression analysis, where the impact of internal enterprise orientation (see Table 4) and external enterprise orientation (see Table 5) on lean production utilisation across Western Europe, Central Europe, and the Arabian Peninsula is explored.

Table 4
Hierarchical regression analysis of internal enterprises' orientation on lean production utilisation in Western Europe, Central Europe and the Arabian Peninsula

Variables	Western Europe		Central Europe		Arabian Peninsula	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Block 1: Controls						
Age	-.51**	-.49*	.08	.10	-.06	.04
Gender	-.10	-.09	.02	.01	-.13	-.14
Education	.19	.20	-.02	-.02	-.09	-.01

Position	.01	.02	-.29*	-.27*	-.14	.00
Organisational size	-.09	-.08	-.16	-.19	-.42***	-.24*
Block 2						
Internal enterprise orientation		.03		.11		.54***
n	71	71	74	74	79	79
R^2	.18	.18	.11	.12	.26	.44
Model F	2.83*	2.33*	1.66	1.51	4.95**	9.41***

[a] *N = 224; * p < .05, ** p < .01, *** p < .001*

The above table reveals that internal enterprise orientation is significantly and positively correlated with utilisation of lean production in the Arabian Peninsula, while there is no significant association for Western Europe and Central Europe. This supports hypothesis 3.

Parallel to this the below table reveals that external enterprises' orientation is significantly and positively correlated with utilisation of lean production in Western Europe and the Arabian Peninsula, while there is no significant association for Central Europe. This supports hypothesis 4.

Table 5

Hierarchical regression analysis of external enterprises' orientation on lean production utilisation in Western Europe, Central Europe and Arabian Peninsula

Variables	**Western Europe**		**Central Europe**		**Arabian Peninsula**	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Block 1: Controls						
Age	-.51**	-.14	.08	.06	-.06	.06
Gender	-.10	-.13	.02	.02	-.13	-.10
Education	.19	.07	-.02	-.02	-.09	-.01
Position	.01	.07	-.29*	-.23	-.14	-.08
Organisational size	-.09	.11	-.16	.14	-.42***	-.31**
Block 2						
External enterprise orientation		.66***		.19		.36**
n	71	71	74	74	79	79
R^2	.18	.44	.11	.14	.26	.33
Model F	2.83*	8.33***	1.66	1.80	4.95**	5.87***

[a] *N = 224; * p < .05, ** p < .01, *** p < .001*

5 Discussion

The main purpose of the present paper was to examine the impact of enterprise orientation on lean production utilisation in Western Europe, Central Europe, and the Arabian Peninsula. Results outlined many possible focal points for discussion. Here, we are highlighting several most notable.

Turning first to the utilisation of lean production in enterprises, there is a significantly higher level of lean production utilisation in enterprises in Central Europe, than in other two observed regions, stemming from the fact that enterprises in Central Europe are mainly acting as suppliers, where there is a strong emphasis on the improvement of their processes in order to be competitive and comply with the requirements of focal organisations [28]. Focal organisations often also provide standard operating procedures in order to ensure quality and to strive toward cost minimization, which is reflected also in the relatively high importance of lean production in Western Europe. Turning to the Arabian Peninsula it is typical that the main source of income is generated from the oil & gas industry, the enterprises in this region are not strongly committed to the utilisation of lean production, such as in Central Europe for example. The constant strong demand for oil & gas does not push the enterprises in this area to put lean production in the focus. The nature of competition in oil & gas is different than in other industries – such as the automotive - which requires the mandatory implementation of lean principles [23, 35]. This implies low interest in lean production implementation in organisations in this area.

Regarding enterprise orientation, enterprises in all three considered areas put external over internal enterprise orientation in the forefront. This reflects the current trend in the world economy, which is emphasizing the prevalence of tight collaboration between organisations in the frame of supply chains, going beyond focusing solely on the enterprises' goals [15]. As outlined, the high external enterprise orientation of Western Europe is expected since organisations put the concern for their customers in the forefront [36], as well as they are having a plethora of relations with their suppliers, due to organisational focus on core activities [28]. Due to tight collaboration with suppliers, our results also confirm high external enterprise orientation in Central European organisations, where a plethora of enterprises are acting as first/second-tier suppliers to the large supply chains, often controlled by Western economics. The high external orientation of organisations from Central Europe is in accordance with their high level of outsourcing in former post-transition economies from Central Europe, as well as linkages with Western supply chains (e.g. automotive industry) [28, 36]. Turning to the Arabian Peninsula area, external enterprise orientation is more prevalent over internal; and it is reflecting the need for collaboration with organisations around the Globe. In this area, organisations mainly depend on sourcing the raw materials worldwide, while the percentage of the local components is minor. The main exception is the petroleum and petrochemicals industry, where the majority

of the raw materials exist locally. This trend of international sourcing made it necessary to enhance the collaboration with the supply chain partners worldwide which is also reflected in the external orientation of the organisations and the usage of outsourcing as a management tool [29].

Following the results regarding the impact of enterprise orientation on lean production utilisation across examined regions, we can outline following: In Western Europe enterprises usually focus on their core activities, while other activities are outsourced to the areas where labour costs are lower, ranging from Central and East Europe to Asia. This implies, that Western organisations provide very detailed standardized operating procedures, requirements for quality, efficiency of processes, etc. in order to ensure adequate quality, as well as to keep their costs low. These actions reflect key elements of lean production like standardized processes, total quality management programs, just in time, and the efficiency of processes [27]. This implies that in Western European enterprises less focus is needed on lean production, which is a primary concern of the supplier. Thus, Western European enterprises put in the forefront the focus on customers [28, 36]. These cognitions reflect significant impact of external enterprise orientation on lean production utilisation and non-significant impact of internal enterprise orientation on lean production utilisation of Western Europe enterprises.

For Central Europe, it is evident that there is no significant impact of both enterprise orientations on lean production utilisation. This may be a consequence of several factors. First, enterprises are the members of the supply chain(s), where they are following standardized operating procedures and rules provided by focal enterprises, which is confirmed by the findings that outsourcing is most commonly used and recognized management tools in Slovenia and in Croatia, as examples of Central Europe economies [28, 36]. Second, the role and the importance of lean production is not well recognized in organisations in this area, although our results emphasize relatively high utilisation of lean production, compared to the Western European and Arabian Peninsula sample. In international studies exploring management tools in that part of Europe, lean production is not among the top ten used tools [28]. Thus, high utilisation is often the consequence of following guidelines from Western economies, acting as a focal enterprise in the supply chain, which focuses on ensuring high quality and low costs. Third, enterprises in Central Europe are often criticized for their lack of long-term orientation and clear future strategy, which will put strategic management at the forefront of the enterprises interest [28]. Finally, there are also several post-transition problems, like dispersed ownership, unfinished privatization, which can have an influence on the current state. Consequently, lean production utilisation is currently used as a necessary tool when collaborating with supply chain partners and is used especially for improving enterprise operations, while the association with enterprises orientation is neither recognized nor established in this part of Europe yet.

Turning to the Arabian Peninsula it is evident that both, internal and external enterprise orientations support lean production. Higher-level external enterprise orientation is associated with high level of lean production utilisation, which reveals that the enterprises in this area recognize their position in the extended supply chain clearly. The reasons for this are mainly the following: First, the utilisation of lean production requires basically an active search for the best raw materials within the best cost [13, 14]. This needs strong connections externally with a group of suppliers upstream of the supply chain. Second, downstream the supply chain with the customers, the organisations also need strong connections to have high visibility of the demand. This certainty and predictability of demand is one of the main elements for lean production utilisation. Third, the internal enterprise goals are connected and contributing to the supply chain goals, so the internal orientation is utilized to support the orientation of the entire supply chain. This orientation – internally or across the supply chain – is very obvious in the Arabian Peninsula area due to the special characteristics of the enterprises in this area, like (1) the major portion of the business is related to oil & gas and petrochemicals industries, where not many alternative sources are available since due to the very technical nature of these industries, the number of reliable suppliers is always restricted; (2) with a limited number of reliable suppliers, and specific group of customers, the supply chain orientation must be high to support the portfolio; and (3) the internal orientation is used with a clear goal of contributing to the supply chain orientation.

Another obvious direction for the discussion, when lean production utilisation is in the centre of attention, is also its relatedness to the Industry 4.0 implementation. Lean production is considered an important building block of digitalization of organisations [12, 15]. Comparing obtained mean values of lean production utilisation with results of surveys using same scale and instrument for examining management tools utilisation [28, 29, 36], reveals that lean production is not among top ten used management tools in Central Europe, when considering several tools, implying relative low readiness for industry 4.0 implementation.

Conclusions

Based on our findings we can state that enterprises showed strong external as well as strong internal orientation, which is contrary to the traditional trade-off between optimization of internal enterprise processes vs. optimization of the entire supply chain [37]. This implies that enterprises have overcome the need for this trade-off [26]. What is even more striking, external enterprise orientation surpasses internal enterprise orientation, which had been on the pedestal for decades. We can further argue that enterprises from Western Europe are exposed the strongest to external enterprise orientation, which is reflected in their status as a focal company [26], around which the supply chain is built. Central European enterprises also emphasize the importance of external orientation, but their emphasis is lower than that in Western European enterprises. One can conclude that in both regions, enterprises put their external– i.e. supply chain orientation - in the forefront. This

may reflect that enterprises from Central Europe; (1) are not solely bonded to one but several supply chains; (2) act also as focal enterprises in other supply chains; or (3) have not yet developed and reached such levels of supply chain orientation as enterprises in Western Europe.

In terms of theoretical contributions, the paper first introduced two facets of enterprise orientations, building upon theoretical framework about relations of organisations in supply chains [37]. The study determined internal and external enterprise orientation based on the utilisation of commonly used management tools in enterprises [28, 29, 36]. Further, the paper provided empirical verification and further theoretical development of the model of linkages between enterprises in supply chains [37]. Second, the linkages between enterprises' orientation and utilisation of lean production were established and empirically verified across three regions, which will be helpful for further examination and discussion of lean production utilisation as well as about readiness of enterprises for digitalization.

Among practical implications, the most significant are the following: First, knowing the actual state of lean production utilisation is beneficial for the management of the enterprises since the implementation of lean manufacturing is a strategic decision [35]. With our survey's results, the managers get an insight into the current state of lean production utilisation, which provides a fertile ground for designing actions to increase the level of lean production utilisation. This will be helpful to improve the enterprise's performance, follow developmental trends, and adhere to the requirements of business partners. Multinationals may also benefit from the results since the actual state of lean production utilisation is revealed. Second, based on the presumption that lean production is a "cornerstone" for implementation of industry 4.0 principles [15, 22] and that wide adoption of Industry 4.0 practices will be easier if lean production practices are highly used in organisations [12], we can state to be able to influence the success and pace of industry 4.0 implementation in enterprises through utilisation of lean production. Third, from the supply chain management perspective, enterprises need to balance their strategy between focusing on internal optimization and focus on the entire supply chain [26, 37]. Thus, knowing the actual state of the enterprise orientation is helpful for enterprises to adopt further steps toward desired orientation, according to the needs of the enterprise.

The authors are aware of the present study's limitations. First, and foremost bias is prevalent since the actual level of management tools utilisation might be different from the assessed, while some of the respondents may not be completely familiar with the usage of every single tool in other departments in their enterprise. Second, the focus on three regions may limit broader generalization of the findings, due to the possible differences in management tools utilisation within the regions [28], as well as utilisation of management tools among countries [29]. For instance, specifics in post-transitional economies in Central Europe, like Slovenia, Hungary, Slovakia, etc. [36, 37] may hinder broader generalization. Third, with utilisation of regression analysis we examined the impact of enterprise' orientation

on lean production utilisation, separately for internal and external orientation. This may have some implications on the results since the impact of both orientations is not simultaneously considered. In addition, we do not distinguish between focal organisation and other participants in the supply chain, rather we are interested in orientation of each of the enterprises in supply chain [38].

Results and findings of present study outline future research directions. Our aim is first to follow the definition of business orientation [38], which in frame of external business orientation distinguishes between supplier and customer orientation. This study can be upgraded in a way, where external orientation will be considered as supplier and customer orientation [39]. This will more precisely explain external organisation orientation, due to the differences across regions regarding focusing on customers, suppliers and internal processes [29, 36]. Due to the significant effect of several control variables, (namely age in Western Europe, position in Central Europe and organisational size in Arabian Peninsula) on lean production utilisation, it would be beneficial to further examine the role of these variables. Linkages between lean production utilisation and industry 4.0 practices utilisation should also be further investigated, in order to support theoretical assumptions [15, 22]. IN addition to this, it would be beneficial to know, how definite management tools are used in enterprises, and are related to the enterprise's internal and external orientation [40]. This will reveal which management tools support, and which hinder each orientation.

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Radio Frequency (RF)-based, Real-Time, Indoor Localization System for Unmanned Aerial Vehicles and Mobile Robot Applications

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Abstract: The goal of this paper is to describe the indoor localization of a moving object, such as, an UAV or mobile robot, in real time. For localization, the triangulation method is used, based on a multiple fixed points anchors. The distance measurement between the moving object and the anchors is realized with DWM1000 UWB compliant, wireless transceiver modules. For distance measurement, the double-sided, two-way ranging method is used. The position is revealed after the triangulation is corrected, based on the Kalman filter. This computationally intensive task is running on FPGA and provides a real-time operation. One of the anchors is connected to FPGA with a serial communication interface. For the triangulation and Kalman filter, hardware module generation high level synthesis, is used. In the paper, in addition to the implementation, measurement results are also presented for real-time localization.

Keywords: Indoor localization; FPGA; High level synthesis; Kalman filter

1 Introduction

Indoor localization is a timely, active research area, with more challenges to be solved. More and more indoor applications require precise localization: mobile vehicle applications in factories and mines, healthcare applications [1], [2], fitness monitoring, assisted living [3], technical lab applications, games and entertainment, building automation [4] [5].

The reliability, required accuracy and response time, determine the selection of a solution/technology for the indoor localization implementation. The indoor positioning technologies can be grouped in several categories: wave propagation, image based and inertial navigation-based localization [5].

Other researchers categorize the indoor positioning technologies based on the kind of the signal used for object position determination: Radio Frequency Signals

(RF), light, sound, audible and ultrasonic respective magnetic field-based solutions [6]. A wide variety of RF signal localization systems are known like Wi-Fi, Bluetooth, ZigBee, RFID Ultra-Wideband. UWB technology presents some advantages in indoor positioning such as precision of time-of-flight measurement, multipath immunity and low power requirements [7] [8] [9].

Based on multiple reference devices, of which location is known, the position of the device attached to the moving object can be calculated. For distance estimation a variety of measurements can be used such as Received Signal Strength (RSS) [10] [11], Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA) [12].

Localization of moving objects in real time is a challenge, complex calculations are required. The emphasis and novelty of the paper is the acceleration of calculations of localization algorithm on the FPGA circuit. Critical parts of the real time localization process, for which calculations must be performed in a short period of time, such as triangulation, pre-filtering and the Kalman Filter, are modeled and implemented in hardware. For the future, the aim is to integrate into a single system the indoor localization methods, UAV systems [13] [14] and mobile robots [15] [16] [17], enabling mobile robots and UAV systems to be used for special indoors or even outdoors applications.

In this paper the chosen methods, algorithms, and their implementation are discussed. The paper is divided into six subsections followed by the conclusions, which summarize the results obtained. The indoor localization background is presented in section two. Theoretical background of the triangulation method and Kalman filter is detailed in the third and fourth sections. The fifth part describes the triangulation and Kalman filtering algorithms implemented on FPGA as well as the stand used to carry out measurements. The sixth section summarizes the results of the localization obtained with simulations and real measurements under laboratory conditions.

2 Indoor Localization Background

The project's aim is the development of a positioning system, used to locate the robot's position in real time.

There are many different localization systems and technologies which can be used for measuring an objects position. Each of these systems have their own advantages and disadvantages. Recent articles point out different aspects and applications of these, like, accuracy, energy efficiency, scalability, cost and such [18]. The goal was to use a system which is accurate and energy efficient, as well as it doesn't require any special or additional equipment. Recently UWB (ultra-wideband modules) have become popular in localization, because of low energy

consumption and accuracy. Using such modules, there were different attempts to develop better indoor localization systems, for either better accuracy or multiple tags, since these algorithms mostly rely on message transmission [19] [20]. The goal is to achieve an accurate position measurement using few moving objects, so an adequate hardware and algorithm are used and implemented.

The system using the triangulation technique measures the distance to different anchored points. For the distance measurement, DWM 1000 ultra-wide-band modules based on radio frequency were used. To improve the resulting position, after triangulation, a filtering algorithm is applied, to achieve a better estimation of the objects position. Both the triangulation and the filter algorithms are running in parallel on the FPGA.

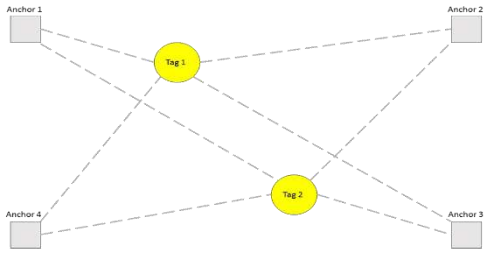


Figure 1
Essential connections

The RF modules used here, for the distance measurement, are a dedicated hardware, DWM1000, developed by DecaWave. The devices implied in position determination, are separated in two categories (Figure 1). In the first group there are the those with known and fixed positions and in the second group are the ones, in which the position has to be computed. These modules are deployed in the field, at least three in fixed positions and at least one is attached to the moving object, of which, the position has to be calculated.

The device controlling the RF modules, is an ESP8266 microcontroller. There is a written and working program library, for the measurements, which was rewritten according to the project's goals.

In the case of the moving target, of which, the position has to be measured, the ESP module is attached to the FPGA on SPI protocol (Figure 2). After measuring the distances, for noise reduction, a filter algorithm is used and then the location is computed using the triangulation method. The newly acquired location is optimized with a Kalman-filter. The filtering algorithms are also implemented in the FPGA circuit.

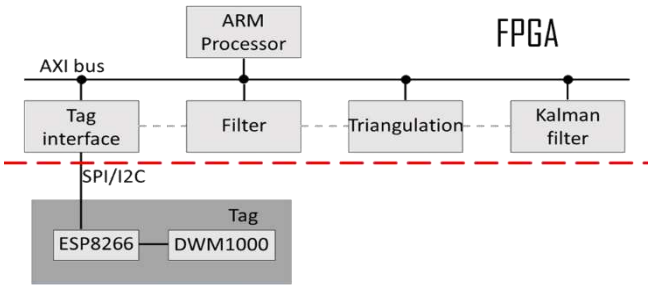


Figure 2
Block diagram of system architecture

2.1 Distance Measuring Methods with RF Modules

Choosing the right distance measuring method is crucial, in order to achieve accurate measurements. The primary target was to achieve an accuracy of 10 cm, or less, with a data acquisition rate of 10 Hz or higher.

Using the radio frequency based modules, the following methods can be used to measure the distance: signal's strength, signal's angle of arrival, signal's time of arrival, and signal's differential time of arrival, and the alternatives of the above mentioned, like single-sided two-way ranging or double-sided two-way ranging.

Since the signal's strength significantly varies, while the movable target is stationary, this option was not viable. The signal's angle of arrival was not viable either, since in an environment, where there are many obstacles, the reflection of the signal from these objects makes it difficult to calculate the distance of the target. In addition, this method requires more anchors, in order to measure the distance with a high accuracy. The calculation of the time of arrival consists in the following: a device that wants to know its distance sends out a message at time T1. Another device receives this message at time T2, and by this, the flight time can be calculated, if their time is synchronized.

2.1.1 Double-sided Two-Way Ranging

The above-mentioned method requires an almost perfect synchronization, because even a very slight difference can cause serious measurement errors, 30 cm/1 ns. [21] This concept was modified to reduce the needs of the synchronization. The new concept was based on the difference of the arrival times. The first one was the one-sided, two-way ranging. In this scenario, the tag sends a message at time T1. The anchor receives it at time T2. The anchor sends back another message at time T3, which is received by the tag at time T4. In this way, there are four timestamps in total, two pointing to the time when the messages were sent, and two to the messages received. With these timestamps, the distance can be calculated, assuming that the distance between the two devices remains unchanged.

$$tof = \frac{(t4-t3)-(t2-t1)}{2} \quad (1)$$

This was much better than the previous method, but still wasn't enough, so it was further developed. This method is called double-sided two-way ranging. This one is improved compared to the previous one by inserting an additional message, with this there are 6 timestamps in total, with which the distance can be measured [22].

$$tof = \frac{(t4-t1)*(t6-t3)-(t3-t2)*(t5-t4)}{(t4-t1)+(t6-t3)+(t3-t2)+(t5-t4)} \quad (2)$$

There is a drawback, when more messages are exchanged, the accuracy improvement is less and less and when using multiple messages for range calculation, the accuracy can be even worse, if the target is moving [21].

2.2 Measuring Distance with an Anchor and a Tag

In the program library an example application of double-sided two-way ranging between two modules was written already. The tag is initiating the distance measurement by sending a poll message, the anchor receives the message, acknowledges it, after which the tag sends all the necessary timestamps for the calculation of the distance. After that the anchor sends back a message with the calculated distance and both sides know the result. This example had a small problem, which appeared in the interruption of the communication after random amounts of time, so it was corrected accordingly.

2.2.1 Results Achieved by Others

The DecaWave manufacturer states that the used DWM1000 modules, can achieve an accuracy of 10 cm indoors [23]. Most of the users of this module achieved an accuracy of 5 cm; in some cases, they even achieved 2 cm. Examining the measured and the real distances, it is clear that every module has an offset which is usually between 20 to 30 cm. One of the best measurements others have achieved was with a 23.6 cm offset and a 2 cm standard deviation. There were cases, where the measurements were quite diverse.

This time they realized that the configuration used for the distance measurement was affecting it greatly, since these modules have different options for different use-cases. From measurement results presented in other works can be seen that at close range, and/or having different objects in the environment between the two modules, different distance values will be measured (Table 1).

Table 1
Test results provided by Steven (https://github.com/thotro/24ocaliz-dw1000/issues/205)

Real distance [cm]	Measured distance [cm]	Average error [cm]	Standard deviation [cm]
25	18.2	-6.8	2.030
50	42.1	-7.9	1.901
100	101.4	1.4	2.063
150	161.2	11.2	1.454

2.2.2 Results

There were varied results acquired during the measurements. The settings of the modules and the environment in which the measurements were made, affected the results. These modules can be configured for a certain goal. The performance of the module was set to the maximum, which means that the data rate and pulse frequency is set to the highest level. The maximum range was also reduced, at which the measured distance was reduced. Different measurement results showed that the modules needed calibration.

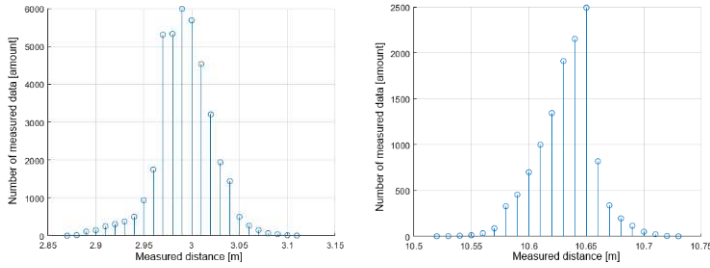


Figure 3
Test results: real distance 2.5 m, offset 50 cm, deviation 5 cm, Test results: real distance 10 m, offset 60 cm, deviation 5 cm

When only one anchor and one tag was used, the offset was usually around 40 cm. The deviations of our measurements were not greater than 10 cm (Figure 3). It has to be mentioned, that in case of measurement with multiple anchors, the accuracy decreases and problems occur in the communication between the modules presenting in the random shutdown of communications.

3 Triangulation Method

The triangulation method is used to find the position of a target, typically in a two- or three-dimensional space. The method is based on at least three points (positions are known) and with the distance of the target to these points, the device's exact

position can be calculated. For example, if the chosen space, where the positioning is used is two-dimensional, with one fixed point, a circle around the anchor, on which the target might be, can be determined. By using another fixed point, the section of the two circles give two points, where the target can be. If the exact position is needed, and both options are acceptable, then another anchor is needed. By this, another one of the points is eliminated, and the position of the device is exact. In three-dimensional space, it is slightly different. The only difference between the triangulation in two- or three-dimensional space is that the distance calculated results in a sphere. If two spheres are intersected, then they will provide a circle, which is similar to the previous one. By this, it can be said that increasing by one the number of dimensions results in an increase by one of the necessary fixed points to calculate the exact position. With this method, generally, in an N dimensional space, N+1 reference points are needed. If the triangulation method is used in a three-dimensional space, and all the reference points are on the lowest possible position, then the only position, where the unknown device's location can theoretically be, is somewhere above the plane created by the anchors. In this case, the second point is automatically discarded. If the device can be on both sides of the plane, N amount of reference points will not be enough. If four anchors are used in space, then another question must be taken into consideration. If all four anchors are on the same plane, then the exact position cannot be calculated, because the exact position is still unknown, since there are two possible positions. If the four anchors are not on the same plane, then one option of the two possible positions is going to be removed, since the distance of the fourth anchor is not the same for the two, it will match only one.

It is considered that there are k amounts of anchors in which the position is known. These coordinates are (x, y, z). *s* is the tag's position, which is unknown, and its coordinates are (*x*, *y*, *z*). The distance to the anchors can be calculated with the following formula:

$$t_{\mathrm{i}} = \sqrt{(\mathrm{x_i} - x)^2 + (\mathrm{y_i} - y)^2 + (\mathrm{z_i} - z)^2} \tag{3}$$

In this formula there are three unknown values, where result cannot be calculated so easily, using analytic methods. Every measurement has an error, which has to be taken into account. Because of this, it is divided into two parts: the real value, and the error.

$$t_{\mathrm{i}} = s_{\mathrm{i}}(x, y, z) + \varepsilon(x, y, z) \tag{4}$$

The error is calculated so the evaluation can be corrected. In order to reduce the error, an iterative method is used.

$$s_{\mathrm{i}}(x, y, z) = s_{\mathrm{i}}(\tilde{x} + \Delta x, \tilde{y} + \Delta y, \tilde{z} + \Delta z) \tag{5}$$

In order to reach the lowest possible error, linear evaluation is used, which consists in the following steps: in the first stage, each error value is defined.

$$s_{\mathrm{i}}(\tilde{x}+\Delta x,\tilde{y}+\Delta y,\tilde{z}+\Delta z)=s_{\mathrm{i}}(\tilde{x},\tilde{y},\tilde{z})+\frac{\partial s_{\mathrm{i}}}{\partial x}\Delta x+\frac{\partial s_{\mathrm{i}}}{\partial y}\Delta y+\frac{\partial s_{\mathrm{i}}}{\partial z}\Delta z \tag{6}$$

After this, the partial derivatives are calculated.

$$\frac{\partial s_{\mathrm{i}}}{\partial \tilde{x}}=\frac{-\mathrm{x_i}+\tilde{x}}{\sqrt{(\mathrm{x_i}-x)^2+(\mathrm{y_i}-y)^2+(\mathrm{z_i}-z)^2}}=a_{\mathrm{i}} \tag{7}$$

$$\frac{\partial s_{\mathrm{i}}}{\partial \tilde{y}}=\frac{-\mathrm{y_i}+\tilde{y}}{\sqrt{(\mathrm{x_i}-x)^2+(\mathrm{y_i}-y)^2+(\mathrm{z_i}-z)^2}}=b_{\mathrm{i}} \tag{8}$$

$$\frac{\partial s_{\mathrm{i}}}{\partial \tilde{z}}=\frac{-\mathrm{z_i}+\tilde{z}}{\sqrt{(\mathrm{x_i}-x)^2+(\mathrm{y_i}-y)^2+(\mathrm{z_i}-z)^2}}=c_{\mathrm{i}} \tag{9}$$

Having them renamed is easier to use in the future.

$$s_{\mathrm{i}}(\tilde{x}+\Delta x,\tilde{y}+\Delta y,\tilde{z}+\Delta z)=\mathrm{s_i}(\tilde{x},\tilde{y},\tilde{z})+a_{\mathrm{i}}\Delta x+b_{\mathrm{i}}\Delta y+c_{\mathrm{i}}\Delta z \tag{10}$$

From the equation the evaluated part was removed and vector remains for each anchor, holding the errors.

$$\Delta s_{\mathrm{i}}=a_{\mathrm{i}}\Delta x+b_{\mathrm{i}}\Delta y+c_{\mathrm{i}}\Delta z \tag{11}$$

The error is calculated using the measured and the evaluated distances difference. The evaluated distance can be measured using the formula (1).

$$\Delta s_{\mathrm{i}}=s_{\mathrm{i}}-\tilde{s}_{\mathrm{i}} \tag{12}$$

After this, the formula (11) is rewritten into a matrix form, where the error vector $\Delta\ldots$ is $\boldsymbol{b}$, the partial derivatives' values $a_{\mathrm{i}}, b_{\mathrm{i}}, c_{\mathrm{i}}$ go into matrix $\boldsymbol{A}$, and the $\Delta x, \Delta y, \Delta z$ vector to $\boldsymbol{g}$. Vector $\boldsymbol{g}$ results are used to correct the evaluated position.

$$\boldsymbol{b}=\boldsymbol{A}\boldsymbol{g} \tag{13}$$

Calculating $\boldsymbol{g}$ from the formula above results in the following equation:

$$\boldsymbol{g}=\boldsymbol{A}^{-1}\boldsymbol{b} \tag{14}$$

In many cases, the system is overdetermined, and because of this, the least square algorithm is used. First, the residual vector is calculated.

$$\boldsymbol{r}=\boldsymbol{b}-\boldsymbol{A}\boldsymbol{g} \tag{15}$$

Its Euclidean square is used in order to be able to calculate vector $\boldsymbol{g}$.

$$\|\boldsymbol{r}\|^2=\boldsymbol{r}^{\mathrm{T}}\boldsymbol{r}=(\boldsymbol{b}-\boldsymbol{A}\boldsymbol{g})^{\mathrm{T}}(\boldsymbol{b}-\boldsymbol{A}\boldsymbol{g}) \tag{16}$$

$$\|\boldsymbol{r}\|^2=\boldsymbol{b}^{\mathrm{T}}\boldsymbol{b}-2\boldsymbol{g}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{b}+\boldsymbol{g}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\boldsymbol{g} \tag{17}$$

The result is equal to zero, and after that, $\boldsymbol{g}$ is placed on one side and the rest to the other.

$$-2\boldsymbol{g}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{b}+\boldsymbol{g}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\boldsymbol{g}=0 \tag{18}$$

From the resulted equation, the $\boldsymbol{b}^{\mathrm{T}}\boldsymbol{b}$ is removed, because the equation's derivative was used.

$$\boldsymbol{g} = (\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A})^{-1}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{b} \tag{19}$$

Finally, at this point, the vector $\boldsymbol{g}$ is calculated, and the evaluated coordinates can be improved.

$$\boldsymbol{s} = \boldsymbol{s} + \boldsymbol{g} \tag{20}$$

This is an iterative method, so it is necessary to do this multiple times, until an error limit is reached, which is given by the user.

It is important to determine the application itself, the possibilities of placing the modules, and by this choosing the number of the reference points [24], [25]. The triangulation method was implemented in the FPGA, because the ESP8266 microcontroller couldn't calculate the position in time.

4 Kalman Filter

The Kalman filter is a linear quadratic estimator which can provide an accurate estimation of states. Kalman filters are typically used for linear systems having Gaussian noise. This filter can estimate states from the data provided by multiple sensors, which measurements are noisy. The Kalman filter doesn't have to store older data values. Kalman filters have relatively simple form and require relatively small computational power. There are two matrices, the covariance matrix of measurement noise (**Q**) and the covariance of the observation noise (**R**), which are responsible for the estimation. The **Q** with dimension 9x9 and **R** 3x3 was initialized with identity matrix multiplied by constant values initialized form the Simulink. In choosing these **Q** and **R** parameter values, their ratio matters. With a Q/R ratio of 1 for example, the estimated values change slowly, neglecting most of the noise, in case of slower systems. When the ratio is 10, the estimated values change fast but with less noise suppression [26].

Position prediction based on the transition model:

$$\hat{\boldsymbol{x}}_{\mathrm{k/k\text{-}1}} = \boldsymbol{\Phi}_{\mathrm{k/k\text{-}1}}\,\hat{\boldsymbol{x}}_{\mathrm{k\text{-}1}} \tag{21}$$

$$\boldsymbol{P}_{\mathrm{k/k\text{-}1}} = \boldsymbol{\Phi}_{\mathrm{k/k\text{-}1}}\,\boldsymbol{P}_{\mathrm{k\text{-}1}}\boldsymbol{\Phi}^{\mathrm{T}}_{\mathrm{k/k\text{-}1}} + \mathbf{Q}_{\mathrm{k\text{-}1}} \tag{22}$$

$$\hat{\boldsymbol{z}}_{\mathrm{k/k\text{-}1}} = \mathbf{H}_{\mathrm{k}}\,\hat{\boldsymbol{x}}_{\mathrm{k\text{-}1}} \tag{23}$$

Update steps

$$\boldsymbol{z}_{\mathrm{k}} = [x_{\mathrm{k}}, y_{\mathrm{k}}, z_{\mathrm{k}}]^{\mathrm{T}} \tag{24}$$

$$\boldsymbol{\varepsilon}_{\mathrm{k}} = \boldsymbol{z}_{\mathrm{k}} \text{-} \hat{\boldsymbol{z}}_{\mathrm{k/k\text{-}1}} \tag{25}$$

$$\hat{\boldsymbol{x}}_{\mathrm{k}} = \hat{\boldsymbol{x}}_{\mathrm{k\text{-}1}} + \boldsymbol{K}_{\mathrm{k}-1}\boldsymbol{\varepsilon}_{\mathrm{k}-1} \tag{26}$$

$$\boldsymbol{R}_{\mathrm{k}} = \boldsymbol{R}_{\mathrm{k\text{-}1}} + \boldsymbol{\varepsilon}_{\mathrm{k}}\boldsymbol{\varepsilon}_{\mathrm{k}}^{\mathrm{T}} - \mathbf{H}_{\mathrm{k}}\boldsymbol{P}_{\mathrm{k}}\mathbf{H}_{\mathrm{k}}^{\mathrm{T}} \tag{27}$$

$$\boldsymbol{K}_{\mathrm{k}} = \boldsymbol{P}_{\mathrm{k/k\text{-}1}}\mathbf{H}_{\mathrm{k}}^{\mathrm{T}}\left[\mathbf{H}_{\mathrm{k}}\boldsymbol{P}_{\mathrm{k}}\mathbf{H}_{\mathrm{k}}^{\mathrm{T}} + \boldsymbol{R}_{\mathrm{k}}\right]^{-1} \tag{28}$$

$$\boldsymbol{P}_{\mathrm{k}} = \left(\mathbf{I}\text{-}\boldsymbol{K}_{\mathrm{k}}\mathbf{H}_{\mathrm{k}}\right)\boldsymbol{P}_{\mathrm{k/k\text{-}1}}\left(\mathbf{I}\text{-}\boldsymbol{K}_{\mathrm{k}}\mathbf{H}_{\mathrm{k}}\right)^{\mathrm{T}} + \boldsymbol{K}_{\mathrm{k}}\boldsymbol{R}_{\mathrm{k}}\boldsymbol{K}_{\mathrm{k}}^{\mathrm{T}} \tag{29}$$

$$\boldsymbol{\Phi} = \begin{bmatrix} 1 & \mathrm{T} & \mathrm{T}^2/2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & \mathrm{T} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \mathrm{T} & \mathrm{T}^2/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \mathrm{T} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \mathrm{T} & \mathrm{T}^2/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \mathrm{T} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{29}$$

Where $\boldsymbol{x}_{\mathrm{k}}$ is the state variables, $\boldsymbol{\Phi}_{\mathrm{k}}$ system matrix, $\mathbf{H}_{\mathrm{k}}$ the observation model, z_{k} the measured positions, $\boldsymbol{K}_{\mathrm{k}}$ Kalman gain, $\mathbf{Q}_{\mathrm{k}}$ the covariance of the measurement noise, $\boldsymbol{R}_{\mathrm{k}}$ the covariance of the observation noise, $\boldsymbol{P}_{\mathrm{k}}$ estimate covariance matrix, ε_{k}-error between the measured and estimated positions. Finally, the estimated positions are obtained from $[\boldsymbol{x}(1)\ \boldsymbol{x}(4)\ \boldsymbol{x}(7)]$.

Transition model is defined based on the motion equation along the coordinates eq. (29).

5 Implementation

5.1 Distance Measurements between Tags and Anchors

For distance measurement between tag and anchors the double sided two-way ranging measurement was used (Figure 4).

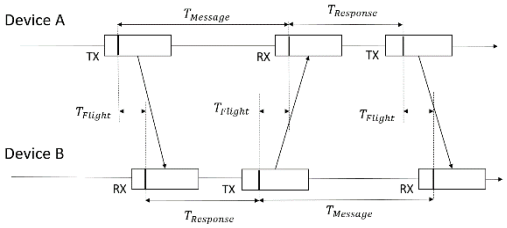


Figure 4

Double sided two-way ranging signal exchange between a tag and anchor

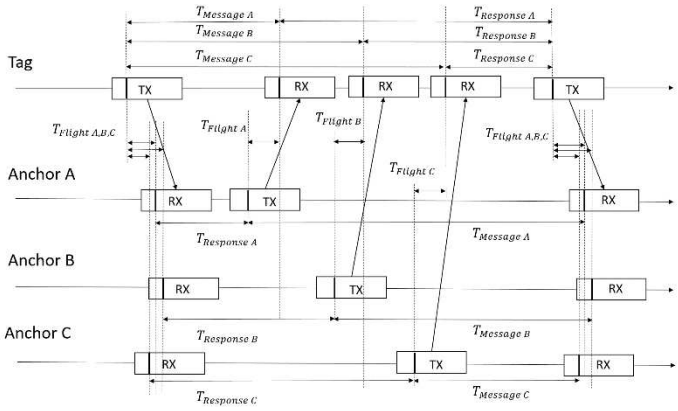


Figure 5

Double sided two-way ranging signal exchange between a tag and multiple anchors

By using multiple anchors, the communication between the tag and the anchors was modified, in order to achieve a faster distance measurement. In this case, the tag has sent one message to all of the anchors. After this, the anchors sent an answer for the polling message. These anchors sent the message one after another after a certain amount of time. After the tag received the messages from all the anchors, it sent another message containing the timestamps necessary to calculate the distance. After all the anchors received the message, each one calculates the distance, and sends back the results to the tag (Figure 5).

5.2 Triangulation Method Implementation

The triangulation hardware module was designed with high level synthesis in Vivado HLS environment. The function, from which the hardware module is generated, receives the position of the anchor devices as well as the distances to the fixed devices as inputs and provides the position of the device to be localized as output argument.

The positions of the fixed devices are stored in an array from which the triangulation module reads the values of the positions at the beginning of the calculation cycle. In the current configuration, the devices are spaced 2 m, 2 m and 2 m along the X, Y and Z axes relative to the origin, and in the first phase of development were hardware coded, which meant many limitations during the tests. During the research we have modified many important parameters that can be given as inputs to the module.

The input and output arrays are partitioned to elementary signals. In addition to the output positions, the ap_valid protocol signals help synchronize the data transfer between the triangulation module and Kalman filter. The module's hardware resource requirements are summarized in Table 2.

Table 2
Triangulation module hardware resource requirements

Name	BRAM_18K	DSP48E	FF	LUT
DSP	-	-	-	-
Expression	-	-	0	1822
FIFO	-	-	-	-
Instance	2	22	5450	8853
Memory	4	-	192	24
Multiplexer	-	-	-	1082
Register	-	-	1718	-
Total	6	22	7360	11781
Available	120	80	35200	17600
Utilization (%)	5	27	20	66

5.3 Kalman Filter Implementation

The hardware for the Kalman filter algorithm was also generated by HLS synthesis. The function receives as input an array of X, Y, Z positions after the triangulation and also provides the estimated position coordinates in an array.

As for initial estimated values, a position of [0 0 0] is chosen for the tag, which is equivalent the Origin of the triangulation system. At the beginning, some time is necessary for the Kalman filter to reach the position of the real system. In this transitional state, the mobile system should be stationary.

Table 3
Kalman filter module hardware resource requirements

Name	BRAM_18K	DSP48E	FF	LUT
DSP	-	-	-	-
Expression	-	-	0	180
FIFO	-	-	-	-
Instance	2	14	3043	4748
Memory	16	-	0	0
Multiplexer	-	-	-	1474
Register	-	-	98	-
Total	18	14	3141	6402
Available	120	80	35200	17600
Utilization (%)	15	17	8	36

HLS_ARRAY_PARTITION forces the input and output arrays to be partitioned in hardware modules into individual inputs and outputs. In addition to the output filtered positions, the ap_valid protocol signal helps synchronize signal

transmission between modules. The Kalman filter hardware resource requirements are summarized in Table 3.

Summing the hardware resources of triangulation and Kalman filter modules exceed the available hardware resources of Zynq XC7Z010, hardware resources are optimized during synthesis (Figure 6).

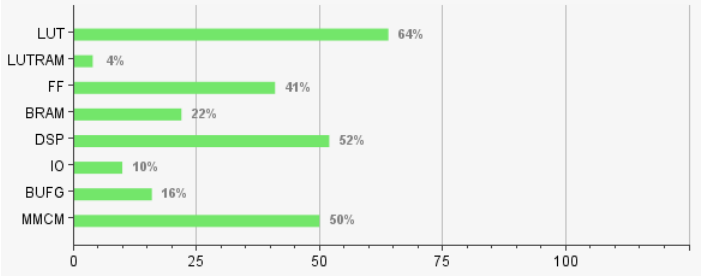


Figure 6
Full localization module hardware resource requirements

5.4 One Degree of Freedom Arm for Tag Movement

In order to test the localization system, measurements were made by mounting the moving device on a single-degree arm. The synchronization of the signals of the two measuring systems is easy to implement because both systems are integrated in the same FPGA circuit. Based on the position of the robotic arm and the estimated positions returned from the FPGA to the computer, the two measurements can be easily fitted.

The single-degree servo control loop consists of a cascade P and PID controller, a PWM signal generator, an H-bridge control circuit, and an encoder for decoding the servo angular position. The PWM signal generator, encoder and PID control are also implemented in FPGA circuits and are not described in detail since they are not present as the basis of the present research.

5.5 Complementary Modules used for Tag Movement

For measurements, the triangulation, Kalman Filter and single-degree positioning control modules are connected in the Xilinx System Generator (SG). Hardware co-simulation helped greatly in setting the correct parameters for the subunits and in developing a functional localization system. In the SG a multiple clock type system has been developed.

The data exchange over JTAG between the PC and the FPGA is synchronized to the clock signal of the JTAG interface, while the clock of the modules implemented in the FPGA is derived from the FPGA master clock.

During the implementation of the hardware co-simulation-based design for the development board used, to derive the clock from the board master clock special attention must be paid.

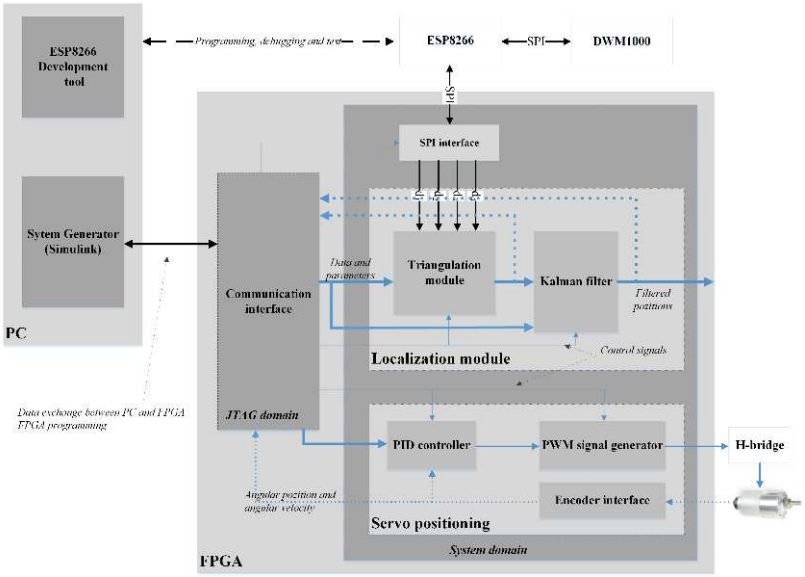


Figure 7

Hardware co-simulation system modules

set_property -dict { PACKAGE_PIN K17 IOSTANDARD LVCMOS33 } [get_ports { sys_clock }];

create_clock -add -name sys_clk_pin -period 10.00 -waveform {0 5} [get_ports { sys_clock }];

For the communication between the ESP and the FPGA a hardware implemented SPI protocol is used. The slave SPI, running in the FPGA, saves the distances in its own registers, which serve as inputs to the triangulation module.

The following diagram shows the connection of the modules.

Modules are parameterized from the Simulink model via the JTAG interface and partial results from the modules are also displayed or saved from the Simulink model.

The triangulation and Kalman Filter modules are exported from the Vivado HLS environment. The reference model, applied to the Kalman filter, based on which position estimation is realized, describes the motion equations along the three axes.

Based on the developed and tested model, an IP core is generated, which is fitted to the bus system of the FPGA based control unit of mobile robot and UAV.

6 Measurement Results

6.1 Test Results: Simulated –Inputs - Simulated Processing

Depending on how many anchors are used, and which are the starting evaluated positions, different results were achieved. The calculations were made, while the device was stationary. First, four anchors were used (Figure 8), which were not located on a single plane. Different starting values were used, and the results were all the same. The data used for calculating the position was real.

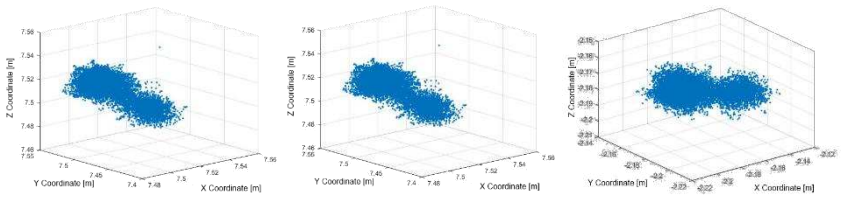


Figure 8

The result of the positioning using: four anchors, varying starting evaluated values; three anchors, starting evaluated values initialized with positive values; three anchors, starting evaluated values initialized with negative values

When three anchors were used (Figure 8) different starting evaluated values gave different results, using the same measurements as previously with four anchors. When positive values were used, then the evaluation was similar when measuring with four anchors.

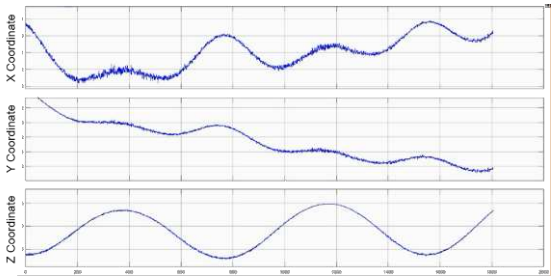


Figure 9

Result for triangulation method, which is running on the hardware module simulated on Simulink SG

However, when the starting evaluated values were negative, the triangulation method localizes the device on the other side of the plane, which is formed by the three anchors.

On Figure 9 a simulation is presented with generated data from Simulink. Multiple sine waves were generated with different parameters as distances in order to achieve these coordinates. On the first figure are the calculated coordinates received from the simulated hardware (Figure 10).

For the Kalman filter testing, the same coordinates were used as in the triangulation methods testing. In the following two figures the Q and R ratio was changed in order to see their accuracy and speed of convergence (Figure 10).

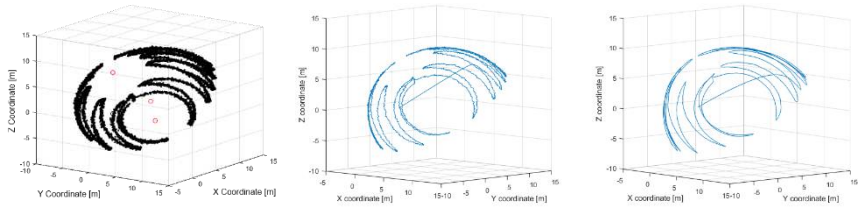


Figure 10

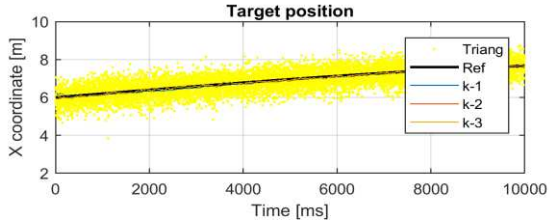
The results received from the hardware model simulated in Simulink SG. Results for triangulation, and Kalman estimation with two different parameter sets of R and Q.

6.2 Test Results: Simulated Inputs - Hardware Processing

The following measurements show the results obtained by testing the triangulation and Kalman filter modules. The calculations were running on the FPGA circuit. The inputs from the Simulink environment were generated, according to a real task. Using a cylindrical, two-degree of freedom robotic arm, the input points were generated, from which the distances to the anchors were calculated. The calculated distances, to illustrate the real circumstance, were perturbed with a normal distribution noise (variance 0.01 and different sample time 0.008, 0.007, 0.009). The simulation sampling time was 1 ms.

The robot arm was raised along the Z-axis and also was rotated along the Z-axis by + -360 degrees forth and back during lifting, as can be seen in Figure 12 d. The following Figure 11 shows the measured results.

Along axis X, Y, Z the coordinates calculated by coordinates obtained with the Kalman filter for different Q parameter sets (k-1, k-2, k3) is presented. During the simulations, the R matrix values along the main diagonal are set to 2 and the Q matrix values to [0.0005, 0.001, 0.002] with sampling time T used in the model for prediction of [0.01 0.01 0.01].



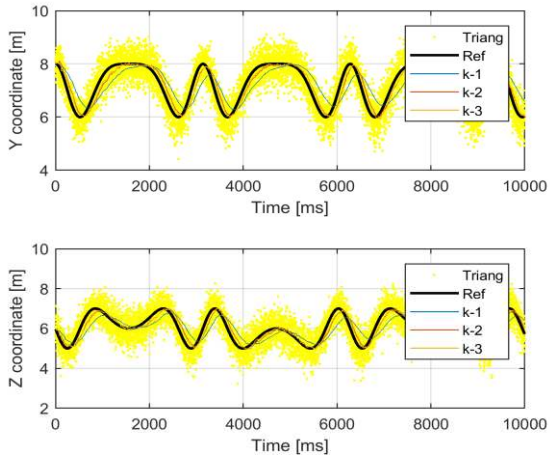


Figure 11

Simulated inputs, real processing of triangulation and Kalman filtering on FPGA for X, Y, Z axes. For each axis is presented the triangulation-based estimation (Triang), original reference signal (Ref), and results for Kalman filter for three parameter sets (k-1, k-2 and k-3)

The simulations support the correct operation of both the triangulation and Kalman filter modules. By tuning the Q parameter of the Kalman filter, can be found an appropriate mid-way solution that ensures the noise suppression with minimal error of approximation of original reference signal.

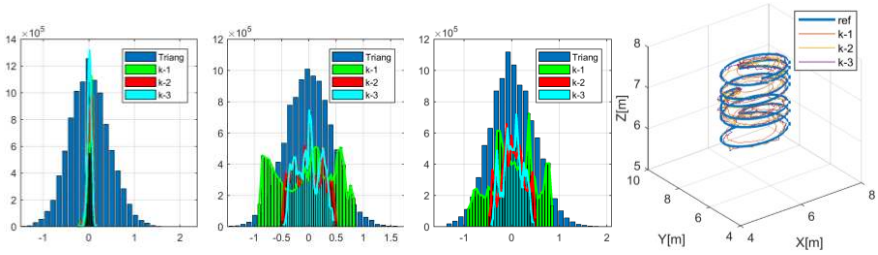


Figure 12

Error distribution along axes X, Y and Z (from left to right) for triangulation-based estimation (Triang), and for Kalman filter for three parameter sets (k-1, k-2 and k-3). Representation of the path evolution in XYZ coordinate system for original reference signal (ref) and for Kalman filter for three parameter sets (k-1, k-2 and k-3)

In Figure 12 the distribution of the difference between the original signal, the distribution of error between the original signal and the estimation with the triangulation and the three variants of the Kalman filter is presented.

Comparing the results obtained by triangulation with the original coordinates, the calculated variances on the X, Y and Z axes are 0.19, 0.18 and 0.21 respectively. The variance of the error between the original signal and the signals obtained for

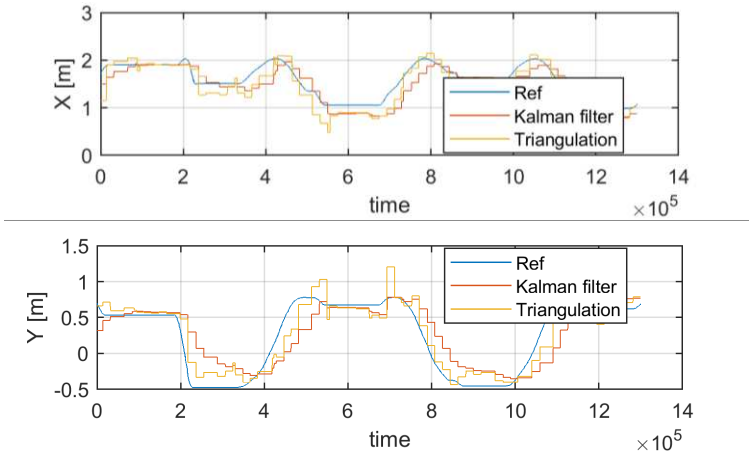
three different tuning sets of the Kalman filter is 0.0031, 0.0032 and 0.0021 respectively along the X axis, 0.2567, 0.0664, 0.0500 along the Y axis, as well as, 0.2056, 0.0579 and 0.0423, respectively along the Z axis.

Comparing the variation values for triangulation and Kalman filter, we can also deduce from this, but not only, the usefulness of the Kalman filter for noise reduction. The Figure 12 d illustrates the evolution in tridimensional space of the original path and for the three cases estimated by Kalman filter.

6.3. Test Results: Real Inputs - Hardware Processing

In real measurements three anchors were used. The tag was moved in space along a semi-circle using a dc servomotor. The servomotor's shaft was parallel to the XZ plane. The axis was tilted by 30 degrees relative to the XY plane, so changes can be seen on all three axis. The motor shaft position was 1.4 m, 2 m and -10 cm relative to the X, Y and Z axis respectively. The arm's length was 1 m, which was measured from the motor shaft to the tag's receiver.

The anchors were displaced at 2, 2 and 2 m along the axes X, Y, Z. First, the arm was moved into a starting position, which was considered to be 0 degrees. Then, the servo motor was rotating with a speed of 30 degrees / second. Results-wise, a delay can be observed between the triangulation-based estimation respectively the Kalman filter-based estimation (Figure 13). This delay explains the increase of variance of Kalman filter-based measurement compared with triangulation-based estimation.



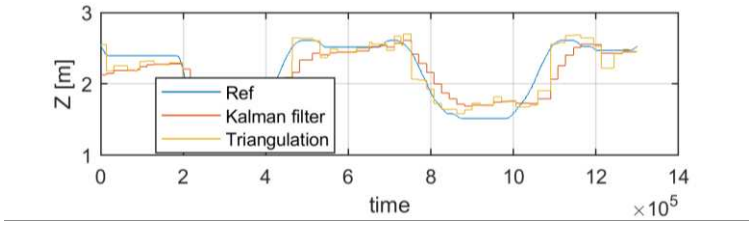


Figure 13

Real inputs, real processing of triangulation and Kalman filtering on FPGA for axes X, Y, Z. For each axis is presented the triangulation-based estimation (Triangulation), original reference signal (Ref), and results for Kalman filter

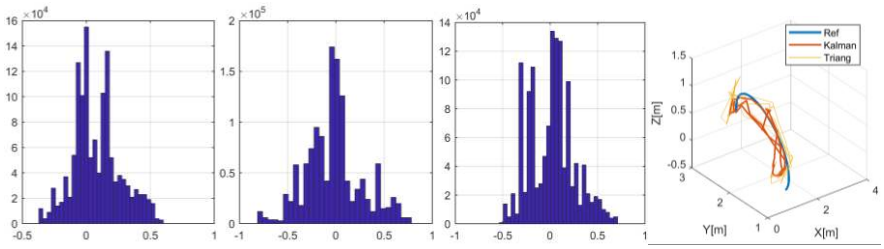


Figure 14

Error distribution along axes X, Y and Z (from left to right) for Kalman filter-based estimation. Real measurement-based representation in XYZ coordinate system of the path evolution for original reference signal (Ref) and for Kalman filter (Kalman) and triangulation-based estimation (Triang).

The variances for triangulation are 0.0365, 0.047 and 0.0313 respectively for Kalman filter-based estimation 0.0347, 0.0863 and 0.056.

For reduction of delay and respectively the variance, the increase of values used in the covariance matrix of measurement noise is proposed as resulted from simulations.

The error distribution for Kalman filter-based estimation along the three axes is presented in Figure 14 a) b) c). In tridimensional space the measurements with reference point coordinate, triangulation respectively Kalman filter-based coordinate estimation in Figure 14 d) are presented.

Conclusions

The triangulation module for localization and the Kalman filter for noise reduction, has been successfully implemented in the FPGA and tuned. In System Generator a hardware co-simulation model was used to perform the measurements.

The developed localization model makes it possible to use both virtual inputs generated from Simulink for testing scopes and to receive real distance measurements from ultra-wide band RF modules. HLS and hardware co-

simulation have greatly helped in the system's modules deployment, providing for different levels of test capabilities.

Instead of using frontend (RF modules), other solutions for distance measurement can also be used, the presented FPGA based localization solution is also applicable, the distances to the anchor can be introduced on the same serial interface.

There were some problems encountered during the FPGA based localization system implementation. One of the problems occurred during the export of the RTL model obtained (as a result of Vivado HLS synthesis) to the System Generator for hardware co-simulations.

Although both HLS simulation and synthesis were successfully completed, the module exported from Vivado HLS 2016.2 did not work in System Generator, the solution was an upgrade to Vivado HLS 2017.4. There were also compatibility concerns between the Vivado environment and the Matlab programs.

The simulations succeeded in verifying the correct operation of all the modules implemented in the FPGA. The IP cores generated from triangulation and Kalman filter modules can be integrated into mobile robot and UAV systems Zynq 7000 SoC family-based, control units, available in the University laboratory. Attention must be paid to the robustness of the RF ultra-wide band distance measurement unit, to increase the measurement sampling time and to minimize the loss of communication between RF modules.

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Earnings Management (EM), Initiatives and Company Size: An Empirical Study

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Abstract: This paper deals with the issues of Earnings Management. Earnings Management (hereafter "EM") can be stated as a modern phenomenon, in recent years. Under the influence of globalization, new ideas penetrate this theory. This topic remains one of the most controversial topics of current financial theories or accounting. The accounting procedures allow managers to exercise their judgment and to make subjective estimates, to a certain extent, when designing financial statements. When this freedom is used correctly, it can be helpful in the process of improving the relevance and reliability of financial statements and reducing information asymmetry. Conversely, the opportunistic use of this freedom can contribute to the exact opposite result - lower relevance and reliability of financial statements, as well as, higher asymmetry of information. The aim of this work is EM initiatives analysis, statistical verification of the existence of the relationship between EM and company size, defined by chosen criteria and provide conclusions with regard to results. The first theoretical part of the paper deals with the theoretical basis of EM. Within the practical part of the contribution, the authors try to detect the presence of earning management based on the calculation of accruals, structured as discretionary and non-discretionary accruals, in the sample of enterprises using a modified Jones model and to verify the existence of the relationship between EM and company size, using the one-way ANOVA test. The differences in the sample averages are too large to be random, it is shown that there is a statistically significant difference in the level of EM, regarding company size.

Keywords: earnings management; accrual-based EM; company size; modified Jones model; the one-way ANOVA test

1 Introduction

Academic community has started dealing with the issue of practice of earnings management (hereafter "EM") since at least the 1960s. The first works focused on the impact of accounting choices on capital markets. [1] There were stated the so-called, mechanistic hypothesis. These type of hypothesis predict that investors ignore differences in accounting policy choice and fixate on reported numbers. It shows that investors who do not take into account other financial reports, as a source of information, are sometimes misled by using EM initiatives, in the form of accounting directions. [2, 3, 4] If we assume that the mechanistic hypothesis was dominate, investors believed that their stock prices increased only as a result of higher reported earnings in the company. It is the chance to think that investors could be misled through manipulating accounting data, intentionally, by managers. On the other hand, the efficient market hypothesis predict that the share price is influenced by publicly available information, including the choice of accounting policy on profit. [5, 6, 7, 8] The efficient market hypothesis started to dominate in 1970s. It follows that stock prices are influenced by all available information in an efficient capital markets. Results of initial studies why EM exist were inconclusive. Based on the later polished study [9] research of earnings management were shifted from capital to non-capital markets. The name of the study is *Positive Accounting Theory* and was published by authors Watts and Zimmermann in 1978. The basis of the study was the assumption of rational manager's existence. Their rationality lies in the effort to influence financial outcomes for their interests by using appropriate accounting method. Since the 1990s, the research of the earnings management issue has moved back from non-capital to capital market. It highlights the importance of the economic consequences of EM initiatives on resource allocation on the capital market.

Many older, as well as, current studies show the importance of the implementation of the earnings management. Most of them are focused mainly on developed countries. [10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20] Authors Burgstahler and Dichev examined the relationship between EM and firm's losses in a sample of three hundred entities. They found out that large and small entities, manage earnings in cases to prevent small profits or losses. [21] Author Rangan verified the existence of a statistically significant relationship between performance of experienced equity offerings and EM. He examined that the largest companies that had long been operating in the market, he suggested that the older and the largest companies were adjusted current accruals in order to gain profits from the stock experience. [22] Authors Lee and Choi stated that larger firms faced more influence to get the analysts' demands to manage earnings more effectively. [23] Some authors tried to show that auditors sometimes consciously overlook EM initiatives of large companies. Their studies show a positive correlation between audit fees and company size and a negative correlation between adjustments in the financial statements by the auditors and company size. Kim, Udawatte and Yin verified the relationship between corporate EM and the company size. They claim

that company size has a positive impact on EM initiatives. [24] Fewer studies analyze the issue of EM in emerging or developing countries. The contribution consists of two parts. There is a theoretical background of earnings management, its history, definitions, forms, and motives. Further, the basic mathematical and statistical procedures used in the practical part in the verification of described hypotheses. The practical part of our work is focused on the impact of company size on EM under the condition of the emerging market. The aim of our work is EM initiatives analyzing, statistical verification of the existence of the relationship between EM and company size defined by chosen criteria and providing conclusion with regard to results.

2 Theoretical Background

The first ways to capture Earnings Management are based on graphical methods based on time-series data (Gordon, Dopuch, Drake or Archibald). Another group of authors dealt with the detection of EM by mathematical modeling of specific accruals (Copelamd, White, Barefield, Comiskey, Dascher, Malcom or Beidleman). The third group of authors detects earnings management through mathematical modeling of total discretionary accruals using time series data (Healy, Kaplan, DeAngelo, Wilson, Jones, Dechow, Kothari, Watts, Beneish or Young). Another group was authors who decided to use cross-sectional abnormal accruals instead of time series data, namely DeFond, Jiambalvo, Subramanyam, Pope or Young. Beneish constructed a model detecting earnings manipulation similar to Altman's bankruptcy model. Especially after 2000, the group of authors (Dechow, Skinner, Grahamet, Penman or Zhang) has dealt with the issue of so-called real earnings management. Cho, Choi and Kwon dealt with the role of employee on financial reporting. They investigated the relationship between real EM and employee length of employment. [25] Authors Hamza and Kortas dealt with the impact of weaker regulatory environment on EM. [26] Jeong and Choi showed the existence of the negative association that real EM prevents the market from assessing companies' future earnings reflected in the current stock prices. [27] The results of work by Kim, Udawatte and Yin [24] shows that the higher the CSR level is, the lower the EM initiatives level are in the company. In connection with the development of information and communication technologies, also modeling using neural networks penetrates into the issue of earnings management. [28, 29, 30]

2.1 Definitions of Earnings Management

Achieved economic result can be considered as a tool for measurement of the company performance during the year. It is set as the difference between revenues and costs of the fiscal year. There are many situations in which achieved

economic results are intentionally influenced by managers. These initiatives on the accounting earnings are also known as earnings management. [31] There are several definitions of the earnings management, in particular depending on the positive or negative understanding of the concept by the authors. The authors Ronen and Yaari offer a comprehensive view of the issue of different understanding of the term in their publications Earnings Management – Emerging Insights in Theory, Practice, and Research. [32] They summarized definitions of EM and divided them into the three groups, namely:

- White EM
- Gray EM
- Black EM

White EM takes into account the ability to use the flexibility in choosing an accounting policy to signal a manager's private information about future cash flow. Gray EM takes into account that the ability to use the flexibility in choosing an accounting policy can lead to maximizing economically efficient or the manager's utility. In these cases, EM is used as a tool for achieving the goals set by management [32] Black EM is defined as initiatives to misrepresent or reduce the relevance and reliability of financial reports. The intention to use earnings management techniques is still not clearly defined. Therefore, it is difficult to clearly identify only one of the three types of mentioned types of EM that the company uses. It is also possible that, at different stages, it uses EM techniques for a different purpose and thus the dedicated EM types can overlap. Definition created by Healy and Wahlen captures both approaches, the costly, Contracting (company uses EM to influence contractual outcomes) and the Informational (company uses EM to mislead investors). There is no specified boundary between EM initiatives and common activities influencing earnings. [32] Authors Ronen and Yaari define EM as a set of activities performed by managers in an effort to not reporting true, value-maximizing, short-term earnings in the form that are known to business management. [32]

2.2 Forms of Earnings Management

According to studies, there are two different ways that earnings in the company can be managed. [33, 34, 35, 36, 37, 38, 39] Reported earnings can be influenced through discretionary accruals activities allowed under GAAP. It is also known as Accrual-based Earnings Management (hereafter "AEM"). Accrual-based earnings management can be observed especially after most of the real operating activities are done toward the end of an accounting period. Two types of accruals can be distinguished, non-discretionary accruals, as well as, discretionary accruals. Non-discretionary accruals are determined by the normal economic situation of the company. On the other hand, discretionary accruals are the manager's choice policy not regulated in the contract. It can be state that discretionary accruals are

the result of manager's opportunism. The amount of accounting accruals is influenced by AEM, while AEM has direct impact on cash flows. On the other hand, reported earnings can be manipulated by structuring real activities. This practice is also known as Real Earnings Management (hereafter "REM"). During the accounting period, timing or scale of real activities (such as sales, financing, investment, production) can be managed with the intention to achieve a specific earnings goals. Achieved economic results are sometimes influenced by chosen activities such as accelerating the timing of production, cutting discretionary expenditures, deferring the timing of expenditures and so on. REM activities can be most often seen as the effort to reduce R&D expenditures to decrease reported expenses. Significant work dealing with REM is *Earnings management through real activities manipulation* by Sugata Roychowdhury. His research was focused on seeking evidence that managers use REM activities to avoid reporting annual loses. He also dealt with the idea that price discounts increase sales temporarily, lower costs of sold products or services are reported due to the overproduction and decreasing discretionary expenditures to improve reported margins can be seen. [40] Roychowdhury distinguishes three ways how REM can be done, namely sales manipulation, manipulation by reducing discretionary expenses, and manipulation through the production process by overproduction. [40] REM activities have a direct impact on current as well as future cash flow and it is also more complicated to recognize REM activities for average investors as well as the auditors or regulators – it can be seen as an advantage of this EM form. [40] The impact on company future cash flow can be perceived negatively as a disadvantages of REM activities. These activities must be really anticipated by stakeholders because it endangers the survival of the company. Kim, Udawatte and Yin state that while REM activities has impact on executive compensation, AEM does not influence it. [24] REM has not been as widely studied as AEM. Current researches deals with an idea that managers prefer REM activities, by such means as reducing discretionary expenditures, over AEM as a way to manage achieved economic results. [41, 42, 43, 44]

2.3 Motives for Earnings Management

The three main theories, namely Contracting Theory, Bounded Rationality Theory and Information Asymmetry Theory, which describe motives of EM activities in the company. The following Table 1 shows the main earnings management motives derived from mentioned theories.

Table 1
The main earnings management motives. Source: own research based on [45]

Theory	**Contracting Theory**	**Bounded Rationality Theory**	**Information Asymmetry Theory**
Motives – group	**Contracting Motives**	**Capital Market Motives**	**External Motives**

Factors	Management compensation	Stock market	Industry
	CEO turnover	Issuance of equity (in case of IPO/SEO)	Industrial diversification
	Managerial ability	New listing and cross-listing	Regulations
	Corporate governance	Mergers and acquisitions	Political environment and country-specific policies
	Loans	Insider trading	Accounting standards
	Firm characteristics	Management buyouts	Tax considerations
		Meeting or beating a benchmark	Competitors
		Analysts	Suppliers and customers

3 Hypothesis Development and Methodology

This part of our contribution describes the used techniques, methods and hypothesis development. Authors used the Amadeus database to obtain data for their research. Sampling criteria were adapted regarding to the aim of contribution. Data covers 2018. The financial statements of the Visegrad Four countries have been selected. Authors updated the sample several times, by excluding companies due to incomplete data necessary for the calculation of formulas, as well as, by excluding companies that were marked as canceled in the monitored year, in liquidation, restructuring, resp. were not found. Finally, authors also excluded from the database companies whose values were determined as an outliers by using Grubbs' test. The remaining number of enterprises was 1,548.

As was mentioned above, there are several techniques for measuring earnings management. One group consists of discretionary accrual estimation models. Based on this type of techniques EM initiatives are calculated by detecting discretionary accruals. Discretionary accruals are known as a part of total accruals therefore it is necessary to calculate them. There are two different ways how to do it. Based on current literature, the balance sheet approach and the statement of cash flows approach can be distinguished. [28] The balance sheet approach is widely used. The sum of total accruals is calculated by using following formula.

$$TA = \Delta CA - \Delta CL - \Delta Cash + \Delta STD - Dep \quad (1)$$

Where:

TA	the sum of total accruals
ΔCA	the year-on-year change in current assets
ΔCL	the year-on-year change in current liabilities
$\Delta Cash$	the year-on-year change in cash and cash equivalents
ΔSTD	the year-on-year change in the current maturities of long-term debt and other short-term debt included in current liabilities
Dep	depreciation and amortization expenses

The standard Jones model was denoted as the most used discretionary model. The essence of this model is the decomposition the sum of total accruals to non-discretionary accruals (hereafter "NDA") and discretionary accruals (hereafter "DA"). To estimate DA, it is necessary to run a regression with the dependent variable TA. The total accrual is estimated using the formula by Hoglund. This model can be applied to both cross-sectional data and time series. NDA are estimated by the model, residuals are DA. The use of the modified Jones model can be possibly recognized in current research. The difference is that changes in sales are adjusted for the change in receivables. [46] The standard Jones model has been modified to decrease the measurement error of DA when discretion is applied over sale. There are also some studies that prove that the modified Jones model is the most powerful technique to indicate EM initiatives compared to the others (e.g. industry model, Healy DeAngelo model or standard Jones model). Based on the modified Jones model, discretionary accruals estimation is calculated using the following formulas.

$$\frac{TA_{it}}{A_{\mathrm{it}-1}} = \alpha_0 \frac{1}{A_{\mathrm{it}-1}} + \alpha_1 \frac{\Delta REV_{it} - \Delta REC_{it}}{A_{it-1}} + \alpha_2 \frac{PPE_{it}}{A_{it-1}} + \varepsilon_{it} \tag{2}$$

$$TA = NDA + DA \tag{3}$$

Where:

TA_{it}	the sum of total accruals in year *t*
$A_{\mathrm{it}-1}$	the sum of assets in year *t-1*
ΔREV_{it}	the change in revenues between years *t* and *t-1*
ΔREC_{it}	the change in receivables between years *t* and *t-1*
PPE_{it}	the sum of the property, plant & equipment in year *t*
ε_{it}	statistical error
NDA	non-discretionary accruals
DA	discretionary accruals

DA calculated by the modified Jones model are also known as abnormal accruals. These accruals are used as an estimation of the EM initiatives. The higher the

value of DA is, the lower is the quality of reported achieved earnings. Based on the previous defining DA, the hypothesis was developed.

H_0 $\mu_{Discretionary\ Accruals} = \mu_{Total\ Assets}$

H_a The means are not all equal

Note: The amount of DA was used as an estimation for detecting EM initiatives in the companies. The amount of natural logarithm of total assets was used as an estimation for company size. Choice the amount of natural logarithm of total assets as a criterion for company size measurement is supported by many researchers and many works. Almost a half of papers use total assets, market capitalization, sales, number of employees and so on have been used in other articles. The amount of discretionary accruals were too small compared to the amount of total assets, so authors decided to use natural logarithm of total assets. Also other members (Qichun Wu, Abdul Qadeer) from the academic community recommend this indicator for firm size measurement.

The hypothesis was derived from the research question: *Is there a statistical difference in the level of EM regarding firm size?*

To verified hypothesis, the one-way ANOVA test was used.

$$SST = SSB + SSE \tag{4}$$

$$\sum_{i=1}^{n}(x_i - \bar{x})^2 = \sum_{j=1}^{k}\left(\overline{x_j} - \bar{x}\right)^2 n_j + \sum_{i=1}^{n_j}\sum_{j=1}^{k}\left(x_i - \overline{x_j}\right)^2 \tag{5}$$

Where:

x_i i-th value of interval variable

n sample size

$\bar{x}$ mean

n_j the frequency of the j-th group

k the number of nominal variable groups

$\overline{x_j}$ mean j-th group

The estimate of intergroup (MSB) and intragroup (MSE) variance can then be expressed as the ratio between the sum of squares and the corresponding number of degrees of freedom.

$$MSB = \frac{SSB}{k-1} \tag{6}$$

$$MSE = \frac{SSE}{n-k} \tag{7}$$

By using a test statistic that has Fisher's F-distribution with degrees of freedom $v_1 = k - 1$ and $v_2 = n - k$ which equals the share of intergroup and intragroup variance $F = \frac{MSB}{MSE}$, we decide about not reject or reject the null hypothesis. The second possible decision criterion is based on the achieved $p - value$, which we compare with the chosen level of significance. This was determined by using statistical analysis software in Excel XLSTAT. If the $p - value$ at the selected significance level $\alpha = 0.05$ is less than 0.05, this means that the differences in the sample averages are too large to be random, we reject H0and do not reject H1, which state of the existence of a statistically significant difference in the level of earnings management regarding to firm size.

4 Results and Discussion

As was mentioned above, authors used the Amadeus database to obtain data for their research. Sample consists of 1,950 companies operated on emerging market during the year 2018. In the first step, the variables needed for the next steps were calculated. The sum of total accruals was calculated according to the formula 1, then the variables needed for DA estimation based on the modified Jones model were calculated. Due to sample size, Table 2 shows only a preview of the calculated variable in the first five companies of the sample.

Table 2
A preview of the calculated variable. Source: own research

Company	Variables			
	$\frac{TA_{it}}{A_{it-1}}$	$\frac{1}{A_{it-1}}$	$\frac{\Delta REV_{it} - \Delta REC_{it}}{A_{it-1}}$	$\frac{PPE_{it}}{A_{it-1}}$
Company 1	0.0121744	0.0000085	0.2197624	0.5399518
Company 2	0.0703312	0.0000300	0.1238191	0.0204686
Company 3	0.0665522	0.0000186	0.1489563	0.0194390
Company 4	-0.0320197	0.0000065	0.0400184	0.8336340
Company 5	0.0855861	0.0000243	-0.0375922	0.2875401

The values of variables showed a striking deviation from the others. Such values are also known as outliers, and it is recommended to exclude them from the database because it can falsify the results of the other analyses. For this reason, authors decided to proceed to the exclusion of extreme values. Results from a survey conducted within database without extreme values –"outliers" can be considered more relevant. There are several known methods for outliersexclusion. To identify outliers the two-sided Grubbs' test was used. It is defined for the hypothesis:

H_0 There are no outliers in the data set

H_a There is at least one outlier in the data set

The significance level was set at α=0.05. Companies whose values in some of the variables were marked as outliers were excluded from the database.The remaining number of enterprises was 1,548.

As was mentioned above, the modified Jones model sets DA as residuals from a regression of total accruals. The following Tables (3-5), show the results of regression.

Table 3

Regression Statistics. Source: own research

Multiple R	0.320
R Square	0.103
Adjusted R Square	0.101
Standard Error	0.144
Observations	1,548

Table 4

Regression Results. Source: own research

	Coef.	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.035	0.009	4.069	0.000	0.018	0.052
$\frac{1}{A_{\mathrm{it}-1}}$	-273.736	57.613	-4.751	0.000	-386.745	-160.728
$\frac{\Delta REV_{it} - \Delta REC_{it}}{A_{it-1}}$	-0.037	0.009	-4.190	0.000	-0.055	-0.020
$\frac{PPE_{it}}{A_{it-1}}$	-0.168	0.014	-11.865	0.000	-0.196	-0.140

Table 5

A preview of residuals. Source: own research

Observation	Predicted Y	Residuals
Company 1	0.010	-0.158
Company 2	-0.024	-0.119
Company 3	0.018	0.062
Company 4	-0.004	-0.042
Company 5	0.008	-0.231
…	…	…

The aim of the contribution is EM initiatives analysis, statistical verification of the existence of the relationship between EM and company size defined by chosen criteria and providing conclusion with regard to results. After the calculation of DA according to the techniques described above, the hypothesis was verified. To verified hypothesis, the one-way ANOVA test was used. The results of ANOVA are shown in Tables 6-7.

Table 6
ANOVA. Source: own research

Groups	Count	Sum	Average	Variance
Residuals	1,548	-2.8E-14	-1.8E-17	0.021
Natural logarithm of total assets	1,548	-14741.5	-9.52294	0.681

Table 7
ANOVA. Source: own research

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7,0191.28	1	70191.28	200147.3	0.000	3.844466
Within Groups	1,085.06	3094	0.350698			
Total	71276.34	3095				

The results mean that the differences in the sample averages are too large to be random, we reject H_0 and do not reject H_a, which state of the existence of a statistically significant difference in the level of earnings management regarding to firm size. ($p - value\ (0.000) < \alpha(0.05)$)

Conclusions

Current studies highlight the importance of the role of EM initiatives, mainly in relation to reliability of the financial reports. The aim of this contribution is EM initiatives analysis and the statistical verification of the existence of the relationship between EM and company size, defined by chosen criteria and provide conclusions, with regard to the results. Within the practical part of the work herein, authors tried to detect the presence of EM, based on the calculation of accruals structured, as discretionary and non-discretionary accruals in the sample of enterprises using modified Jones model and to identify the relationship between EM and company size, using the one-way ANOVA test. Based on the results, it can be stated that the Authors confirmed the existence of EM in emerging markets. According to the one-way ANOVA test, it can be also confirmed that there is a statistically significant relationship between the level of EM initiatives and company size. The resulting sample of enterprises will become the basis for the relevance of models developed for earnings management in the V4, within futures research. So first, there is evidence of earnings management initiatives in the market of v4 countries and second, there is dependence between the EM iniciatives and firm size. The final findings, based on a comparison of the achieved results SMEs and large enterprises, are as follows:

- 58.35% of large companies managed profit by increasing it
- 36.98% SMEs managed the profit by increasing it

- By applying EM initiatives, large companies increased profits more significantly than SMEs
- By applying EM initiatives, SMEs reduced profits more significantly than large companies
- For large companies, the average value of positive DA reached the value 0.047
- For SMEs, the average value of positive DA reached the value 0.031
- For large companies, the average value of negative DA reached the value 0.038
- For SMEs, the average value of positive DA reached the value 0.051

These findings should be taken into account when creating a comprehensive model of EM that may vary, depending on the size of the entity.

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Reconsidering the Cybersecurity Framework in the Road Transportation Domain

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Abstract: The Automotive Industry has advanced significantly and this process is constantly continuing. Cars are controlled by hundreds of electrical units, which affects directly numberless safety and security related risk factors, especially considering incidents realized in the cyberspace. Due to the increasing number of connected cars, new testing facilities and methods need to be established, to support the solutions, for these novel challenges. For this reason, the Hungarian government has founded the Zalaegerszeg test track, and its special purpose is to provide space for the validation of future vehicles. The overview focused on the presently applied validation methods and processes has highlighted, that cybersecurity related testing methods – from a scientific point of view – are only slightly detailed in the sector of Automobile Industry. In a sector specific term, the lack of a holistic approach, may result a relevant barrier, in the future, for providing a socially tolerable level of cybersecurity. Accordingly, this paper aims to introduce a comprehensive cybersecurity reference model, to provide a solid basis for describing attack patterns and characterizing malicious intervention profiles.

Keywords: Security-and-Privacy; Physical-Layer; Autonomous-Driving-and-Communication; Vehicle-to-vehicle/roadside/Internet-communication; vehicular-security; cybersecurity-reference-space

1 Introduction & Related Work

Automobile technology has greatly developed in the last decades and is still relentlessly developing; consider the introduction of driverless cars. Vehicles are now controlled by hundreds of electrical units (ECUs) that form an internal network of devices within the vehicle. This development has raised questions about the vulnerability of the transport system, especially considering safety and security issues influenced by cyberattacks [1].

The growing proportion of automated and connected vehicles makes it necessary to establish new testing facilities and methods supporting the solutions of these

novel challenges. For this purpose, the Hungarian government has founded the Zalaegerszeg test track [2] called ZalaZone, which beyond the conventional test issues, especially focuses on the validation of future vehicles. ZalaZone ensures not only validation facilities for conventional vehicles, but it also makes it possible to implement different components of the approval process of autonomous and electric vehicles. To support this objective, ZalaZone has started various research projects in the field of cybersecurity of connected and autonomous vehicles (CAV). The working group, providing the foundational evaluation of the presently applied validation methods and processes, has recognized, that cybersecurity-related testing methods – from a scientific point of view – are slightly detailed in the automobile industry. In a sector-specific term, the lack of a holistic approach seems to be a relevant shortcoming, which may cause a serious barrier to achieve a plausible cybersecurity level, which could be cost-efficiently provided, in light of the available resources. On the other hand, the application of state-of-the-art testing methods is common in the field of informatics [3]. However, they do not necessarily suit the safety and security requirements of the automotive industry.

Following this – summarizing the result of the evaluation carried by the working group of ZalaZone – the paper aims to introduce the most important general cybersecurity approaches, based on the models applied in fundamental robotic systems. As a result of the analysis, new classification categories, and possible synergies between the related scientific fields are going to be introduced and explained. First, the most important research and literature references are presented regarding the investigated scientific field of automobile-related cybersecurity sector.

Eiza et al., give a well-constructed illustration of vehicle network architectures and how different hacking processes can threaten different architectures [4]. Monostori has further developed the concept of cyber-physical production systems and some related research challenges [5]. Khalid and others have given a general description of the cybersecurity characteristics of a collaborative robotic cyber-physical system (CRCPS), and the proposed a general security framework [6]. The study has also stated that there should be an option about CRCPS to change the operation to manual mode if the current industrial scenario makes it necessary. The study written by Khalid and his colleagues, is quite holistic and well-adaptable for the field of autonomous transport systems, since many autonomous transport systems related research studies just ignore important parts of the holistic approach. However, there are still other important system components that should be covered by an overall cybersecurity framework. The overall concept has to aim to cover the whole process network [7] related to the automobile industry and the transportation system. For example, during the formation of vehicle industry related cyber-security framework, the network [8] of the related processes should contain the processes of production, the processes of the operation phase, especially considering mobility, service and reparation processes and technical inspection related processes.

Gratian et al. emphasize that humans are often identified as the weak link in cyber-security, since any system containing human-robot collaboration can be dramatically influenced by human error [9]. For example, as a result of their research, certain social groups differentiated by age, gender, and other demographic property can be characterized by weaker cybersecurity properties. They proved to have less intention of password generation, updating, and proactive awareness. Accordingly, this kind of social groups can be identified as a demographic group needed additional cybersecurity training and guidance [9].

M. Alali et al. present an implementation of a fuzzy-based risk assessment model in cybersecurity, applying a probability approach [10]. However, it has to be emphasized that their study focuses on a very specific slice of the scientific field without aiming to have a holistic approach. In accordance with this, further analysis is required to provide a general interpretation of their research results. Guerrero-Higueras et al. presented in their study, that cyber-attacks on real-time location systems can be protected by a supervised learning detection [11]. Furthermore, they show that some type of cyber-attacks on real time location systems, specifically denial of service and spoofing, can be detected by special machine learning techniques. The paper articulates the importance of sensor proofing in robotics, which should also be adopted by the automobile industry.

Rizvi et al. analyze the denial of service attack and replay attacks within a car network. The study proposes a hybrid security system that consists of multiple security layers [12]. The structure of the study is acceptable, but the general framework of the article is not complete, especially focusing on the partly automated and autonomous vehicles, dispensing with the discussion of the production phase, malicious bug generation, or the importance of sensor disturbance. The paper of De La Torre et al. presents a categorized summary of security methodologies considering secure sensing, positioning, vision, and network technologies that can be equipped in driverless-vehicles [13]. The study is well-adaptable, and the discussed security fields are investigated in a quite detailed manner; however, the connections of the introduced security components are not clarified in a satisfying way. The journal of “Intelligence in Theory and in Practice” introduces a new organizational component in intelligence service which can be involved in the detection, prevention and treating process related to different type of cyberattacks as well. It also introduces the definition of the unknown-unknowns security elements, which can result in significant benefits in the security field. This approach can be efficiently adopted in cyberspace as well, especially in case of automated systems [14].

El Mrabet et al. analyze the basic pillars of cybersecurity, focusing on the classification of cyberattacks, demonstrating the practical applicability of their theory in the case of a smart grid system [15]. They propose a cybersecurity strategy composed of three phases: pre-attack, under attack, and post-attack. The paper includes a description of the relevant published solutions in terms of security protocols, security technology, cryptography, and other cyberattack

countermeasures. The study is well adaptable to autonomous transport systems; since many previously formed autonomous transport system related studies ignore the importance of operation management and process analyzing approach. Axon et al. study the application possibilities of blockchain theory in cybersecurity [16]. They provide a detailed and prudential analysis. However, the introduced models are presented through quite specific demonstrations, and therefore general representations of the methods in an overall autonomous vehicle cybersecurity framework would be expedient. This study can exemplify the importance of a common classification framework since without a general reference space, this solution does not seem to be easily applied in other fields of automotive cybersecurity.

Ding et al. give a good insight into the challenges and possibilities of security control and attack detection, which is well adaptable to autonomous transport systems [17]. Mascareñas Stull and Farrar study the conditions and requirements of the precision immobilization technique (PIT) with an autonomous car [18].

Hasrouny, Samhat, Bassil, and Laouiti, present a general overview of the most important security challenges [19] related to vehicular ad-hoc network (VANET) and their causes and current solutions in a general way.

Based on the revealed potential development scopes, the paper aims to unify, join, harmonize, and complement the currently applied cybersecurity framework structure.

Accordingly, the identification of the novel automotive cybersecurity reference space will contribute to the more accurate characterization of cyberattacks. The evaluation of the incidents based on the newly developed reference space makes it possible for security experts to develop more efficient prevention methods and defense mechanisms. In light of this, the scientific aim of the investigation is to test and validate the suggested evaluation factors, especially considering their independence.

In accordance with this, in the next section, the basic methodology of the framework developing process is presented, in the third section, the main result of the framework reconsideration process is summarized, while in the fourth section the components and the related processes are discussed in a more detailed form.

2 Proposed Methodology

To identify the relevant factors for the characterization of the automotive sector related cyberattacks, other relevant related researches are reasonable to be analyzed. Several research studies [20] have already focused on the characterization of different cyberattacks. However, most of these studies [21] have focused on general cyberattack patterns instead of automotive industry

related attacks, which reasonably narrow their applicability in case of a certain problem.

On the other hand, it has to be mentioned as well, that the reviewed literature has rather focused on a very specific research problem instead of drawing a more general conclusion regarding automotive industry related attack pattern composition. Researchers have already analyzed incidents according to harmonization, organization, extension, control, thoroughness, purposefulness, and resource demand of the specific cyberattack. [22] Conversely, this kind of study does not evaluate the basic time and space-related properties of event-based approaches [23]. However, time and space-related aspects should be the first step in characterizing malicious cyber-incidents targeting certain parts of the mobility processes. Some of the performed researches take into account spatiotemporal patterns [24] of cyberattacks; however, these researches rather focus on the geographical location and time-dependent predictability of cyberattacks [25]. Contrary to this, to have a more general result, it seems to be reasonable to investigate the relationship of the perpetrator and the target in time and space, since this approach could be applied to characterize the investigated sample on a more general level.

Additionally, it seems to be reasonable to test the strength of the relationship among the evaluation factors to validate their applicability, which final step has been left in most cases. The reason for the emphatic importance of the relationship among the evaluation factors is the possible risk of unfavorable effects, which can influence the conclusions drawn from the analyzed dataset if a strong dependence is identified among the factors.

In accordance with the achieved results, besides other basic evaluation factors like the targeted object or the involved OSI layer, the current research has to focus on the relationship of the perpetrator and the target in time and space and beside this; the selected variables have to be tested with regard to the strength of their relationship. Based on the findings of the research group and the evaluated references, it has been found to be expedient to introduce a new general framework for cybersecurity, which is applicable to distinguish cybersecurity-related issues based on temporal, spatial, and structural aspects. Temporal aspects are investigated in our study by characterizing attacks according to their relationship to past, present, and future. Spatial aspects are evaluated in our paper by defining the relationship of the attacker and the target in space. Structural aspects related to the transportation sector are considered through four main system components: vehicle, production, road infrastructure environment and the targeted OSI layer. In accordance with the considerations mentioned above, this section presents the main concepts behind the developed framework structure. In other words, the below-presented approach can assist the reader in understanding the endpoints of the possible cyber-attack paths and channels that can significantly influence the safety and the security of the road transport system.

2.1 Structural Aspects

In this section, we introduce a novel representation methodology for describing and classifying cybersecurity incidents. This concept makes it possible to analyze new aspects of cyberattacks and analysts should be able to identify new prevention techniques aimed at reducing the risk of specific attack paths that target influencing the operability and safety of transportation processes. Accordingly, the novel representation framework differentiates the vehicle component, the production process, the transportation infrastructure as possible objects of a malicious intervention focusing on the transport system and the importance of the ISO-OSI layers in the current framework. After presenting the most relevant target objects, in the next sections, we introduce the factors of the newly developed reference framework that can be applied to characterize, classify, and evaluate the analyzed attack types.

2.1.1 Vehicle Component

The security and safety level of the road transport system is seriously affected by the operation reliability of the vehicles. Since many vehicular control processes are electronically coordinated in vehicles nowadays, they are equipped with numerous electronic control units (ECU) supervising important vehicle functions [26]. The direct connection required for different services, diagnostic and driver activities is provided by the human-machine interface (HMI) control panel. Processes related to short-range information exchange can be ensured by local area wireless communication (e.g., Bluetooth, WiFi, NFC) units and several different types of sensors, for example, the radar sensor, the LIDAR sensor, the image sensor [12] providing information channels within and between the vehicles and its environment [27]. Wide area networks (e.g., cellular, satellite connection) can ensure the medium of long-range communication and online connection. To handle the cybersecurity system of a vehicle as a whole, - beside the communication, perception and detection components - human factor, the related private data and key database also have to be considered as critical factors in the overall security environment. In accordance with the recommendations of ENISA [28], the complex communication and electronic architecture of modern vehicles are illustrated in Figure 1. However, it has to be emphasized that the detailed description of high-level CAV architecture and external CAV interfaces is not in the focus of this analysis.

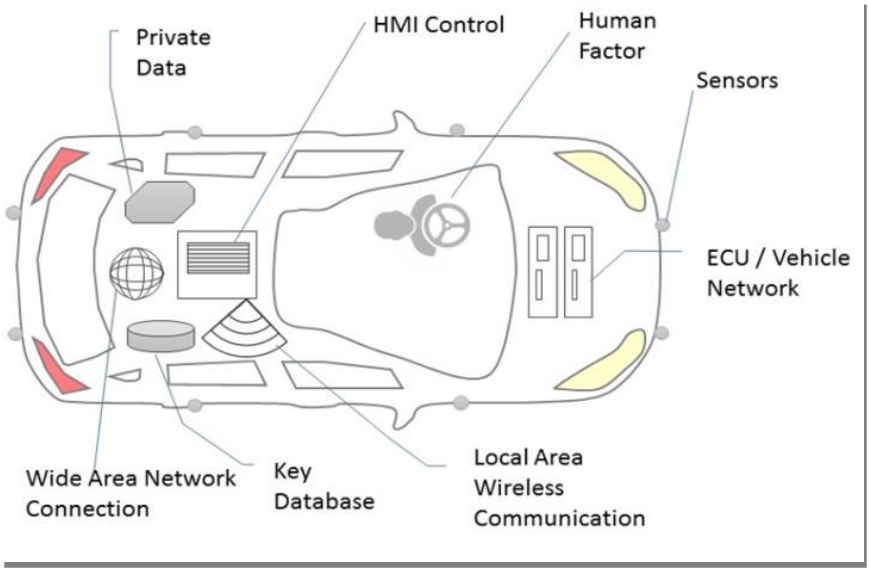

Figure 1
Vehicle components

2.1.2 Production Process Component

It is generally accepted that traditional operation factors and circumstances of connected transportation systems - such as protecting communication channels of connected vehicles, providing the integrity of basic transportation processes, or ensuring reliable authentication methods - influence the cybersecurity of road transport significantly. However, it seems reasonable, to extend the reference space of cybersecurity in the field of transportation, and so, fit the security system to product life-cycle theory. Therefore, cybersecurity-related issues should be investigated during the production phase. Besides this, in the production phase, the human components frequently cooperate with the physical machine components. Thus it is crucial to ensure a safe and secure environment for the production processes. During the production phase, malicious interventions can be implemented by either intruding from the cyberspace or by spoofing sensors at short range or by connecting directly on the internal network. [6].

In the case of a normal operation mode, the control unit receives information from the human and the physical components of the production process by sensing their locations and movements. Besides this, the operating production program can be modified from the cyberspace through a certified and authenticated communication channel. In the next step, information can be processed, and commands can be sent to the actuators and the physical components. Figure 2 illustrates the production process component.

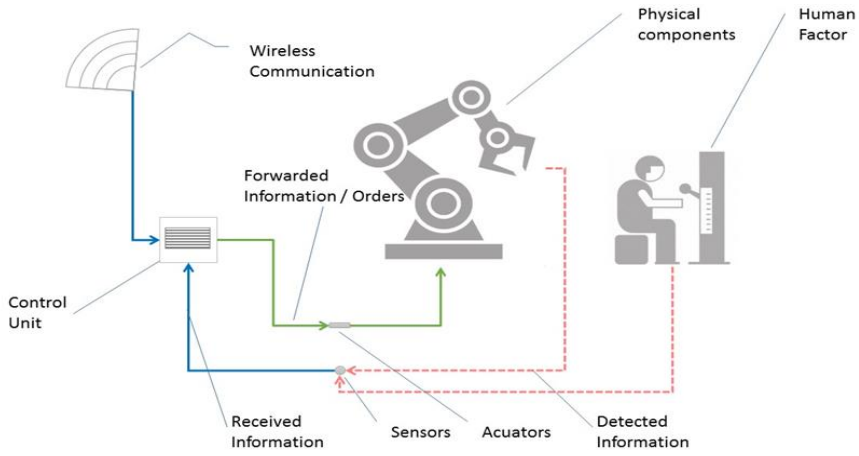

Figure 2
Production process component

2.1.3 Infrastructure Components

As mentioned earlier, ZalaZone has started different research in the field of cybersecurity of connected and autonomous vehicles (CAV). According to the findings of the research group, one of the most efficient components of the protection concept is the reduction of vulnerabilities. This purpose can be significantly supported by improving the ability of the system to protect itself. Beyond the continuous development of protection systems and the adaptation to the latest attack solutions, it is also an extraordinarily important task to inspect the possible and expected effects of relevant cyberattacks. In the automotive industry, in the first part of the inspection, it is more reasonable to perform the demonstrative cyberattacks separately from public traffic, preferably on a test track dedicated to these kinds of tasks, equipped by object-specific modules. ZalaZONE, the Hungarian proving ground, is planned, based on the introduced approach.

Accordingly, the proving ground has several test modules, which can provide a wide range of test circumstances. The concept of the new test track has been developed in accordance with the recommendations of the most important industrial actors and scientific institutions in Hungary. The test track has the technical modules: High-speed oval, Dynamic surface, Braking surfaces, Handling courses, Motorway section, Rural road, Smart City Zone. The proving ground is going to be built on a 260-hectare area from 130 million EUR.

From a cybersecurity point of view, it has to be mentioned, that the proving ground will also provide active test modules including intelligent traffic control [29], V2I communication and cellular 5G communication system, which provides

a unique possibility to test different attack channels related to the automated and connected vehicles. Beyond the automotive testing facilities, the test track will be equipped by a special telecom and IT test environment. Besides this, it will also include an automotive cybersecurity test and certification center.

In accordance with the results of the working group, the proving ground will be capable to evaluate the security level of the infrastructure and vehicle connections.

The transportation process's safety and security are strongly affected by cooperative intelligent transport systems (C-ITS) allowing connected and automated vehicles to communicate with each other, with traffic signals, with roadside infrastructure components, and also with other road users. In accordance with this, the road infrastructure is equipped with sensors, detectors, and communication devices, making it possible to collect data from the road environment, traffic and road users as well as to share information with the actors of the transportation process. These components are connected to the cyberspace; they exchange information between each other and send it to the involved parties (traffic organizations, vehicle). Figure 3 illustrates the infrastructure components.

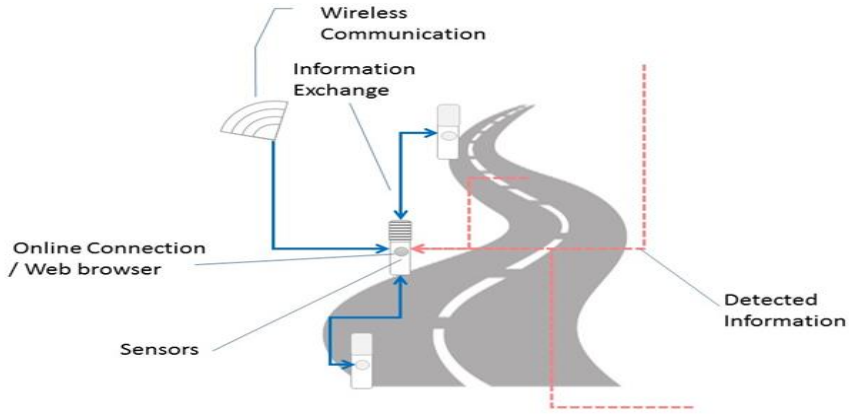

Figure 3
Infrastructure components

2.1.4 Cyberattacks classified based on ISO-OSI Layers related to the Automotive Industry

The definition of open systems interconnection (OSI) model is well known in the field of cyber-sciences. OSI model consists of seven layers. To make the basis and the context of the following conclusions related OSI layers clear, the applied definitions are summarized briefly. The first one is the physical layer, which is responsible for hosting and conveying information. It transforms the binary information codes into physical signals, which can be - among others - radio wave, electrical signals as well as optical signals [30]. The second level is the data link layer performing data transmission between the linked devices. It perceives

and, if necessary, repairs failures that is originated from the physical layer. The data link layer determines the protocol to set up and close a connection between two nodes connected physically. The data link layer defines the control between the two connected devices. The third one is the network layer, which is responsible for the process of transmitting different sized data packets. This level provides the capability of the system to be able to connect numerous nodes, ordering addresses to every connected device to be able to send messages to other devices. The transport layer is the fourth level, which makes it possible from a functional point of view to transmit different sized data packets. It is responsible for the reliability of an information channel applying flow control, partition, merging, and failure control. The next level is the session layer, which provides the capability for the system components to be able to establish and coordinate dialogues. The sixth level is the presentation layer, which turns network format into application format and vice versa. The seventh OSI layer is located closest to the human component of the system, and it provides the platform for the direct information exchange between the system and the user involving communicating software components, resource definition, and communication synchronization.

From a cybersecurity point of view, it is important to emphasize that some of the OSI layers do not play a crucial role in reference to the in-vehicle network communication in the conventional term. For example, transport, network, session, and presentation layers are mainly involved in the vehicle's external communication. Therefore, the vulnerability of these layers rather influences the v2x communication processes [31]. The physical layer can unequivocally be differentiated from the other layers of the in-vehicle network. The main vulnerability of this layer regarding the in-vehicle network is the possibility of distracting or preventing the communication with the modification or detachment of the internal network by manipulating the terminating resistors. In case of the data link layer the bitwise modification of the communication frame has to be defined as a serious sensitivity, even if, the protocol controller does not allow such interventions in normal circumstances. The most relevant attack type regarding the network layer can priory affect the v2x communication channels instead of the in-vehicle communication by allocating unexpected extra occupancy influencing the available network bandwidth. The sensitivity of the transport layer can similarly be described as in the previous case since the critical impact can be triggered by making the system reach its capacity constraint. The session layer's typical vulnerability can be exploited through distributed denial of service attacks, which can keep the system from providing switch management processes [32]. The presentation layer can be maliciously influenced by applying modified SSL requests, which can result e.g., in rejecting SSL connection. Regarding the application layer, serious vulnerabilities can be observed in both kinds of networks. Autonomous-transportation related communication processes are reasonably data-sensitive, which means that the malformed, spoofed, or maliciously generated data can cause significant hazards. Accordingly, the information gained from environment sensing (e.g., RADAR signal), dynamic

data utilization (e.g., GNSS signal), static data utilization (e.g., HD mapping) or V2X communication channels have to be handled by considering strict confidence rules and reliable risk estimation processes.

Table 1
Cyber-incident relevancy in light of the targeted OSI layer

	Relevant External Accessibility		Considerable External Accessibility		Limited External Accessibility		
OSI Layer	LAN Conn.	WAN Conn.	Sensors/ Actuators	HMI Ctrl	ECU	Private Data	Key Datab.
App.	High	High	Medium	High	High	Medium	High
Pres.	High	High	Low	Low	n/a	Low	Low
Sess.	Medium	Medium	Low	Low	n/a	Low	Low
Transp.t	Medium	Medium	Low	Low	n/a	Low	Low
Net.	Medium	Medium	Low	Low	n/a	Low	Low
Data	Medium	Medium	Low	Medium	Medium	Medium	Average
Phys.	Low	Low	High	High	Medium	Medium	Average

As presented in Table 1, it can be concluded that channels characterized by relevant external network accessibility are more sensitive to network processes occurring in the higher OSI layers, since these processes can directly affect their operational efficiency.

On the other hand, vehicle components responsible for in-vehicle communication or one-directional data surveying are less sensitive to incidents, which target OSI layers located in the middle part of the table. This structure of the table can be explained based on the in-vehicle communication network framework, where transport, network, session, and presentation layers do not play an emphatic role in the communication process.

2.2 Spatial Aspects of Cyber-Attacks

Incidents intending to influence vehicle operation processes can be classified in three different groups based on their spatial characteristics. Incidents carried out through a direct connection can be ordered to the class of direct local attacks. Malicious interventions implemented at short range, for example, through Bluetooth, CALM, or DSRC can be classified into the group of indirect local attacks. Cyberattacks performed and coordinated remotely is classified in the group of remote attacks. The spatial aspects of different cyberattack types are demonstrated in Figure 4.

According to the aforementioned distinctions, the following figure represents the three different attack methods. In the first part of Figure 4 (a), the attacker (blue) is situated in the immediate surrounding area of the target (yellow) and has a direct connection to the specific object. In the second part of Figure 4 (b), the perpetrator (blue) is located considerably close to the target (yellow), but the object and attacker are connected through an indirect, wireless channel with each other. In the third case (c), the attacker is located considerably further from the target. Accordingly, the perpetrator has to use an indirect, remote channel to reach the target.

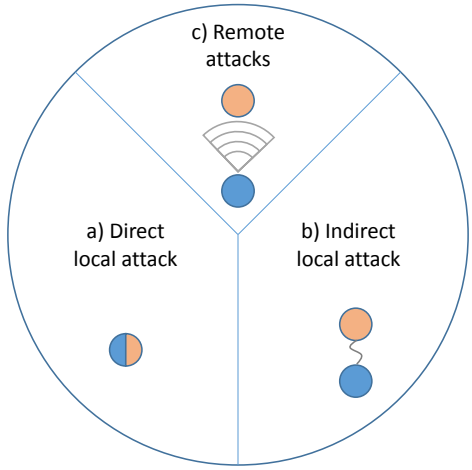

Figure 4
Spatial Aspects of Cyber-Attacks

2.3 Periodic and Time Related Aspects of Cyber Attacks

Preparation, implementation, and infection of malicious cyber-incidents may have different relations with the influenced transport process in time. A cyber incident can aim to affect stored, or archived data describing a process or activity carried out in the past. In this case, the object of the attack is a terminated occurrence; however even in this case, the target of the incident has significant effects on certain presently operating processes. Summing up, these kinds of attacks refer to a terminated occurrence. Hence, these malicious interventions are classified as cyberattacks targeting processes terminated in the past.

Of course, cyber-incidents can influence processes occurring presently. In this case, the prior objective of the malicious intervention is to modify the normal, safe operation of a system, mainly causing hazards affecting the integrity of safety, security, or data or, in some cases, public confidence negatively. The risks related to moving away from the safety state have been properly discussed in functional safety related research. Recently the scientific society completely accepted that

these risks have to be treated emphatically in the applied analytical system engineering methods as mentioned for example by Sebron et al. [33].

Cyber incidents focusing on the infection of a process being implemented in the future can be similarly described as cyberattacks targeting processes being implemented in the present. These kinds of cyber incidents also aim to divert the targeted process from a safe and secure state, violating the required conditions of safety, security, privacy or possibly public confidence. However, the objective of this kind of malicious intervention is going to be realized in the future.

Besides the introduced time-related aspects of a given cyber incident, periodicity should also be discussed as an important property of the attacks implemented in the cyberspace. In the case of periodicity, the study differentiates three main clusters. A malicious intervention may affect the target as a one-time incident. Thus this type of incident is classified as single cyberattacks. A cyber-incident can influence its objective several times; repeatedly, this type of intervention is classified as multiple cyberattacks. Finally, there are incidents that aim to generate infection focusing on the target object continuously in a given interval.

In light of the introduced time-based representation of cyberattacks, the next figure represents the different relationships of the time and the cyberattacks. In accordance with this, compared to the perceived result of the interventions, attacks can be implemented in the past, in the present, and in the future. Thus, the perpetrator in the present (indicated by a blue dot on the time axis) can implement malicious intervention targeting a process in the past (Figure 5 a) in the present (Figure 5 b) or in the future (Figure 5 c). considering the periodic aspects of the attack, the perpetrator can perform the attack through a single (Figure 5 I), a multiple (Figure 5 II), or a continuous (Figure 5 III) intervention.

Periodic and Time-Related Aspects of Cyber Attacks are presented by the following figure.

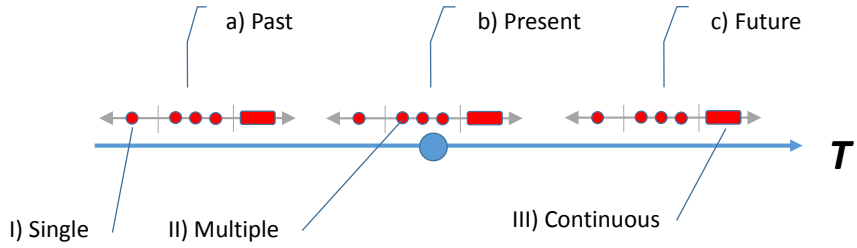

Figure 5
Periodic and Time Related Aspects of Cyber Attacks

3 Quantitative Validation of the Proposed Method

Cyberattacks mean a permanently intensifying threat to mobility processes, especially considering the spread of connected vehicles in road transportation [34]. The more accurate characterization of the discovered cyberattacks is essential for preparing an efficient prevention strategy against the different interventions. This rather risky competition has already stepped beyond the borders of the cyberspace. Hence prevention also needs to cover more and more phases of the activities related to cyberattacks. This concept is also in accordance with the approach of defense strategy identification [14]. Accordingly, it is reasonably important to gain as much information on the circumstances of the attacks as possible, including the targeted object, the spatial and time related aspects and the technical characteristics of the attack. Based on this consideration, the paper aims to build up a new cyberattack reference space framework constructed from the mentioned factors. In accordance with this, an important aim of this study is to analyze whether the new framework is applicable to properly characterize the cyberattacks in a comprehensive way or the suggested variables are not adequate to provide the required information without a significant amount of latent information overlapping.

To validate the new concept, based on practical experiments, a complex analytical framework has been developed to prove that the main elements of the reference space theorem (component, space, time, periodicity and OSI layer related properties) are applicable to characterize automotive industry related cyberattacks.

To do so, a complex database has been built, based on the data of Upstream Security [35] containing all the registered automotive industry related attacks performed during last twelvemonth. Following this, the registered attacks have been individually analyzed, and the data of the certain interventions have been defined containing the attacked component of the mobility system, the space, time and periodicity aspects of the specific attacks, the targeted OSI layer and the estimated cyber incident priority level [36] of the given intervention

In the next step, the applicability of the developed reference space is evaluated by analyzing the independence of the identified attributes. According to the applied assumption, if the reference space contains only such factors that cannot be explained by some of the other basic factors, then the newly developed representation framework includes only a marginal amount of overlapping information. Contrary to this, if the dependency among the applied attributes is strong, then the developed reference space cannot be accepted as a proper framework applicable to support the description of prior and latent relationships, tendencies, and patterns characterizing cyberattacks.

Since the introduced factors can be described as categorical variables, their dependency can be characterized by the application of the traditional Chi-Square test [37]. The independence of the investigated factors is analyzed through a

pairwise comparison. Accordingly, every investigated factor has been compared to all the other factors in a pairwise evaluation. In the first step of the analysis, in case of a certain pairwise comparison, the relative frequencies related to the expected values of the independent scenario are calculated based on the below-presented equation:

$$f'_{ij} = \frac{\sum_i f_{ij} \cdot \sum_j f_{ij}}{(\sum_i f_{ij})^2} \tag{1}$$

Where,

i : is the index number of the nominal attributes representing the first categorical variable in case of the certain pairwise comparison;

j : is the index number of the nominal attributes representing the second categorical variable in case of the certain pairwise comparison;

fij : is the number of objects, characterized by attribute

f 'ij : is the expected number of objects in case of independence

After defining the independent case, it is possible to define the value of the test function, which can be defined by the following formula:

$$X^2 = \frac{(f_{ij} - f'_{ij})^2}{f'_{ij} \cdot \sum_{ij} f_{ij}} \tag{2}$$

If the investigated factor pairs are not independent, the strength of the association plays a key role in defining whether the two factors can be explained by each other. Therefore, the Cramer association coefficient is defined to evaluate the dependence.

$$C = \frac{X^2}{r \cdot \sum_{ij} f_{ij}} \tag{3}$$

Where,

r : is the smaller value from the number of rows reduced by one or the number of columns reduced by one;

In the case of dependence, the stronger the association between the analyzed factor pairs, the more significant information redundancy can be expected, which queries the applicability of the new reference space representation.

4 Results

During the evaluation, the factors regarding component, space, time, periodicity, and OSI layers related aspects have been pairwise compared by applying the Chi-square test. Accordingly, in the first step, the component factor, so the attacked component of the mobility system and the space-related aspects have been compared.

In the next step, the absolute frequencies related to the categories of the investigated nominal variables have been summarized by the contingency table below.

Table 2

Frequency data of the classified cyberattack sample

	Direct local attack	Indirect local attack	Remote Attack	Sum
Infrastructure	0	0	11	11
Production	1	0	4	5
Vehicle	9	44	8	61
Sum	10	44	23	77

Based on the absolute frequency values, it is possible to define the relative frequencies of the independent scenario, as follows.

Table 3

Relative frequency data of the classified cyberattack sample

	Direct local attack	Indirect local attack	Remote Attack
Infrastructure	0.019	0.082	0.043
Production	0.008	0.037	0.019
Vehicle	0.103	0.453	0.237

From the derived results, it is now possible to determine the elements of the X2 value, represented by the table below.

Table 4

Elements of the X2 value

	Direct local attack	Indirect local attack	Remote Attack
Infrastructure	1.429	6.286	18.112
Production	0.189	2.857	4.207
Vehicle	0.147	2.398	5.733

From this, it can be concluded that the value of the X^2 test is 41.36. The critical value of the given association concerning the degree of freedom of the problem is

0.091. The result is significant at $p < 0.05$; the two evaluated variables are not independent.

According to the introduced methodology, the next step is to identify the value of the Cramer association coefficient. If the association is proved to be strong, then the applicability of the new framework cannot be validated.

$$C = \sqrt{(41.36/2.77)} = 0.51 \quad (4)$$

Based on the performed calculation, the association between the components of the mobility system and the space-related aspects are proved to be moderate, which is higher than expected but still does not unequivocally queries the conformance of the introduced space reference approach.

To complete the investigation, all the factors have been compared, and in accordance with this, the result of the pairwise comparison is represented by the following table. Furthermore, the average value of the calculated coefficients has been defined related to certain variables to represent the average dependence of the specific factors.

Table 5

Comparison of the X2 values resulted by the association analysis

	Comp.	Spatial aspects	Timer related aspects	Period.	OSI	Aver.
Comp.	-	0.52	0.31	0.35	0.53	0.43
Spatial aspects	0.52	-	0.26	0.21	0.6	0.4
Timer related aspects	0.31	0.26	-	0.31	0.22	0.28
Period.	0.35	0.21	0.31	-	0.63	0.38
OSI	0.53	0.6	0.22	0.63	-	0.5

As observed, the results are more or less acceptable but still not completely satisfactory. However, if the output data is analyzed a little more detailed, it can be observed that variable related to the aspects of the OSI layers is represented by significantly higher association coefficients. If this variable is excluded from the comparison the results are much more convincing.

Table 6

Comparison of the X2 value resulted by the rationalized association analysis

	Comp.	Spatial aspects	Timer related aspects	Period.	Average without OSI
Comp.	-	0.518	0.313	0.346	0.392
Spatial aspects	0.518	-	0.262	0.213	0.331

Timer related aspects	0.313	0.262	-	0.309	0.295
Period.	0.346	0.213	0.309	-	0.289

According to the final results, the average values of the Cramer association coefficients are below 0.4, the investigated variables are dependent however the associations of the factors are weak moderate. This level of dependency can be expected in accordance with our baseline consideration, therefor cyber incidents are recommended to be characterized by the attacked component of the mobility system, the spatial, the time related, and the periodicity related aspects of the intervention.

Based on the evaluation of the applied classification approaches, it can be concluded that the different, more or less isolated segments of transport systems - including vehicles, production processes, connected infrastructure components, as well as, human factors - cannot answer all the cybersecurity related challenges by themselves. The reason for this is the significant probability related to the security risk of the high relevancy cyber-incidents targeting the transport sector as a whole.

To give an adequate answer to these issues it seems to be expedient to define the security requirements of the introduced components in light of their effect on the defensive competencies of the whole system.

In accordance with the above mentioned considerations it can be concluded that the introduced holistic aspects of cybersecurity related systems make it necessary to introduce a complex time, space and component based automobile industry related cyberattacks reference space. The newly introduced space is applicable to classify and represent different types of cyber-incidents, which allows us in the future to improve sector and threat specific cybersecurity solutions and to improve the efficiency of risk rate estimation.

Accordingly, we can classify the cyberattacks performed in the automotive sector in a three-dimensional reference space, where incidents can be characterized based on the type of targeted system component, the spatial relationship between the attacker and the target, and time and periodic aspects of the investigated intervention.

Where:

S axis represents the spatial relationship of the attacker and the target, including:

a) direct, local
b) indirect, local
c) indirect, remote attacks

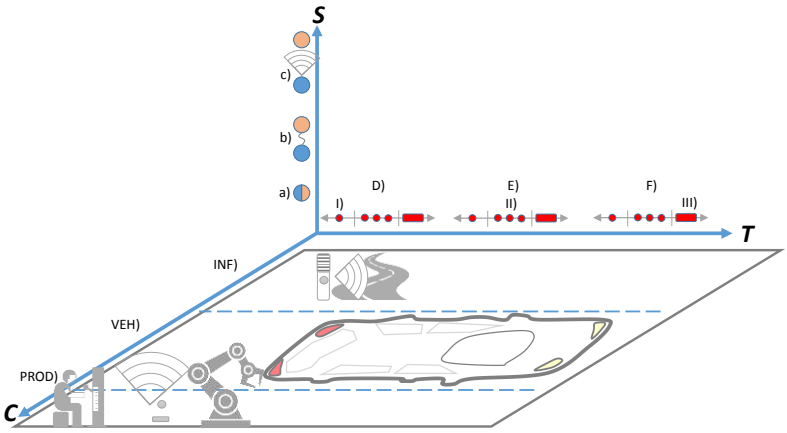

Figure 6
Time, space and component based automobile industry related cyberattack space

T axis represents the time and periodic aspects of the incident, including:

D) the attacker targets to influence a data describing a process in the past

E) the attacker targets to influence a data describing a process in the present

F) the attacker targets to influence a data describing a process in the future

I) the perpetrator performs the attack through a single intervention

II) the perpetrator performs the attack through multiple interventions

III) the perpetrator performs the attack through a continuous intervention

C axis represents the considered components of the transport system:

INF) the transport infrastructure

VEH) the moving unit of the system

PROD) the manufacturer of the system components.

As the main result of our concept, threats related to connected vehicles can also be classified based on the targeted OSI layer. However, while the introduced time, space and component related aspects, depend on the properties of the targeted process or object, the classification of cyber-incidents based on OSI layers is influenced by the type of the attack [38]. This approach can efficiently support the definition of the adequate protection concept; though, the detailed discussion of defensive strategies from a technical point of view does not comprise the subject of the study.

5 Discussion

Based on the reconsidered reference space of cyber-incidents, attacks can be classified based on their reference to the properties of the target. The evaluated system component, the time- and space-like properties of the investigated processes restrict the set of possibly relevant attack types. Accordingly, the typical characteristics of diverse attack types, can significantly vary from each other, strongly influencing the set of efficiently applicable defensive strategies.

Therefore, in the next step, the assumed profile of the possible perpetrators and targeted processes is defined based on the combination of the investigated classification factors. In light of the introduced classification factors (component, time, space) different motivations and objectives can be found behind the certain attack-types, their understanding might be critical in defining the adequate protection concept.

As the intelligence expert has summarized, the importance of understanding the surrounding world is crucial, from a security point of view. Therefore, conceptualization is a basic step in the process of defense strategy definition [14]. In other words, an effective and realistic representation of the expected security threats, can significantly improve our chance to apply the suitable prevention method. The clearer and more reliable the information we have about the security factors influencing the integrity of our system, the more an efficient prevention and reaction can be provided for the defense. To form a realistic model describing the security space of the environment, in which our system is located, it is relevant to specify the most important information gaps, which can be transformed into direct security questions. These predetermined security questions can be defined as the known-unknown components of the defense strategy. It is also substantially important to continuously provide a validation feedback about the information gained from the real world towards the model framework. This process is responsible for ensuring information about the space being uncovered by the constructed security strategy. In other words, the purpose of this system component is to answer questions which have not been asked yet. This approach can help us to detect the, so-called, unknown-unknown components of the security environment.

In view of the introduced conceptualization framework, the clear representation of motivations and objectives related to certain cyberattack types is considered to be primarily significant. Accordingly, in the next step, certain cyberattack class profiles are presented based on the combination of the introduced classification factors (component, time, space). Based on the introduced aspects related to cyber-attacks it is necessary to re-consider the traditionally applied reference-space in the field of automated vehicles related cyber-attack classification.

Introduction of Certain Cyberattacks Profiles Represented in the New Reference Space.

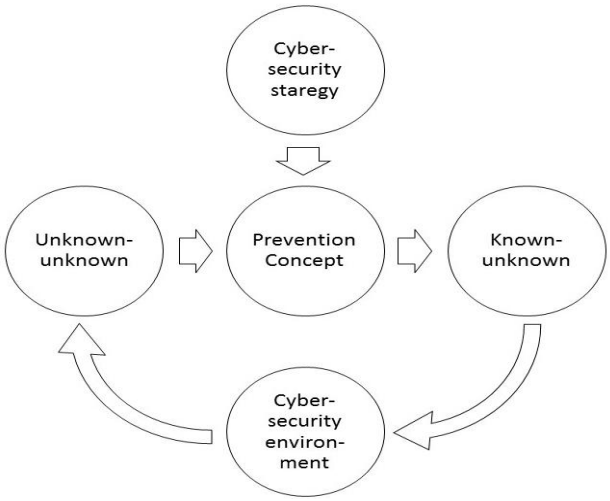

Figure 7
Conceptualization framework of cybersecurity related system

Investigating incidents in terms of time, attacks are classified into three main groups. Malicious interventions aiming to modify the recorded data of an object or process terminated in the past is classified in the first group. Influencing data related to an object or process recorded in the past can be important for attackers, due to its effect on present processes. The affected target group frequently involves specific official cases depending on data registered in official records or certain processes, which are subject to authorization. For example, in the transport sector, data of sales and purchase contract related processes, criminal cases related data or permission required activities are typical target objects of incidents intending to modify the official dataset recorded in the past. Cyberattacks performed in the present focusing on an object or processes influencing a real-time activity are ordered to the second group. This category of cyberattacks can affect a wide spectrum of the possible target objects or processes. Incidents characterized by this kind of validity period frequently aim at everyday life related processes like shopping, transportation or banking. Incidents influencing a future process or a future state of an object related to the attacked target are classified in the third group. Malicious interventions aiming to influence a process or an object in the future require well-founded, usually extremely well-founded and careful preparation. This kind of incidents are implemented frequently in an early stage of the affected project, not rarely during the strategic, planning or implementation phase. Cyber-incidents, which aim to affect a process or an object in the distant future, due to their significant resource demanding characteristic, often influence safety and security critical systems or processes strongly affecting national-security level. To discuss the characteristics and the main objective of the different attack types in light of periodicity, it is useful to form a realistic profiles related to

the possible perpetrators. One-time cyber-incidents characterized as a single attack in time can involve quick intrusions targeting for example well protected objects to violate privacy or abstract private, public or national data. In case of a multi-time incidents, attacker can assume that the previously implemented interventions have not been detected. This means that the perpetrator estimates the differences between competencies to be significant, so interventions can be repeated several times without the risk of being discovered. Attacks carried out as continuous intervention, are often implemented to influence strongly safety critical systems by moving system state from safe and secured operational circumstances to a high risk operational domain [39]. These kind of incidents can be implemented for example by denial-of-service attacks in which the attacker aims to make a system resource ineffectual to the regular user for instance by flooding it from different sources [40].

Characterizing attacks based on their spatial relationship to the target, incidents are grouped in three classes. Cyber-incidents aiming to move a system from the safe and secured state, to violate privacy or private data through a direct connection, influencing the system from inside mean a reasonably challenging security issue. The reason for this is the undercover component of the attack, which may provide reliable information on the main vulnerabilities of the targeted system and can make the weak points of the defense strategy available for the attacker. This type of intervention might be based in numerous cases on a long-winded preparation process, hence this type of attack can rather be related to safety and security critical systems or processes, which may strongly affect national-security level. Cyber-incidents carried out through an indirect connection from the surrounding environment can be implemented by the application of one directional channels (e.g. influencing sensors or detectors) or by the application of bi- or multi-directional communication channels. This kind of cyberattacks can involve different sensor-spoofing interventions or incidents using the local area communication network. This group of cyberattacks frequently affects real-time, everyday life related processes, like shopping, transportation or banking. Remotely controlled attacks, which impact targets through the WAN (Wide Area Network) can influence almost all systems characterized by almost all kinds of dimensions and complexities.

To introduce the component based classification of cyberattacks, three main groups have been differentiated in the field of transportation related malicious interventions. Attacks aiming to influence the road infrastructure related system components can principally affect road traffic [41] either from a safety or from an efficiency point of view. These kinds of incidents can have an impact on a wide spectrum of traffic related parameters or factors, such as, speed, emission, unexpected events, accidents, bottlenecks, network vulnerability or emergency reaction performance. Incidents targeting the production component might aim to violate directly the safety or security integrity of the manufacturing process or the reliability of the type approval process [42]. In addition, attacks can influence the

latter operation phase of the vehicle, affecting their safety characteristics or the conformance to their approved properties. This kind of incident can be well exemplified by the malicious modification of vehicles emission characteristics aiming to improve their performance. Malicious interventions related to the vehicle components mainly influence, directly, the transportation process. This kind of attack involve either the ramping of the decision making methods of the vehicle, by transmitting modified information to it, or the intrusion into the vehicle control unit network, taking control of the vehicle, stealing or modifying the private information related to the vehicle.

Conclusion

As observed, around the world, vehicle technology is continuously developing. This development results in numerous, challenging and novel questions, in reference to transport system security.

Accordingly, summing up the provided output, related to the investigation coordinated by ZalaZone, this work introduces the most relevant cybersecurity methodologies, based on the approaches used in the field of robotics and automation. First, the paper clarifies the applied definitions, the used models and the most relevant tendencies of the scientific community. Based on the investigation, the newly prepared classification theory and its benefits are interpreted in a detailed way. In the first section of this paper, the most relevant research results are introduced, as related to cybersecurity, in the Automotive Industry.

On the basis of the reviewed literature, it has been concluded that a new cybersecurity reference space has to be introduced, based on the discussed temporal, spatial and structural aspects. Accordingly, the next section of the paper presents the main ideas behind the developed architecture. Based on a novel method, the result of the different cyberattacks types can be highlighted from different point of views, which can substantially influence the safety and the security of the road transport system.

On the basis of the investigated classification methods, it can be summarized, that the different components of the transportation systems are not able to adequately reply all of the cybersecurity related questions by themselves.

On the contrary, the security system of transportation should be handled as a whole entity.

In conjunction with this and in accordance with the final results of the proposed validation method, cyberattacks are recommended to be characterized by the attacked component of the mobility system, the spatial, the time related and/or the periodicity related aspects of the intervention.

Furthermore, as a main output of this paper, hazarding factors, targeting autonomous transportation systems can be grouped based on the OSI layer. On the

one hand, targeted systems can be classified based on the developed time, space and component dependent reference space, while on the other hand, attack paths and channels can be differentiated based on OSI layers.

To summarize the article's achievements, we can state, that our work herein, has managed to harmonize and complement the currently applied cybersecurity framework structure. Also, we have identified a novel automotive cybersecurity reference space, which contributes to a more accurate characterization of cyberattacks. The evaluation of incidents based on the newly developed reference space, makes it possible for security experts to develop more efficient prevention methods and defense mechanisms. In light of this, the investigation's scientific aim has been fulfilled through the validation of the suggested evaluation factors, particularly considering their independence.

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ECO-ECO Recycling Models and Application of their Principles into the Circular Economy

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Abstract: Today´s global economy shows that particular markets have become much more saturated and heterogenous than ever before. They are dominated by consumer´s individual needs whose behaviour is changing under the influence of external or internal factors. Therefore, global consumption is on a constant growth. When taking into account long-term sustainability as well as our moral commitment to nature and its resources, we need to focus on environmental protection and consider reusing materials within a production process. One of the solutions is to focus on green innovations, which are applicable in the circular economy and apply ecological and economic models of initial recycling into a production process. The main goal of our paper is to define a model of application of eco-eco principles in the circular economy by providing a specific view on the model aspect of procurement of production materials from recycling as well as presenting various possibilities on how to meet eco-eco goals of businesses which are based upon circular economy principles. The main output of the paper is the proposal of three variants how to approach product recycling models while emphasising their specificities and usability.

Keywords: modeling; stock management; reverse logistics; recycling; circular economy

1 Introduction

The 21st Century has experienced a significant environmental impact of the society. This is mainly due to a growing number of inhabitants, which is directly linked to uncontrolled material consumption as well as waste production (described in more detail by Adamisin et al., 2018; Peracek et al., 2018). In order to eliminate negative human impact on nature and protect the environment, brand new green innovations have been introduced in the last decades of the 21st Century. The benefits of innovations in this field cannot be perceived only through economic parametres because economic indices are determining factors for their implementation. These innovations have to be understood in a broader context because apart from their fundamental protection function, they may also reflect a need for sustainable development of the whole society and therefore be a key competitive advantage. The application of the circular economy concept is one of those systems (Benešová, 2010; Srovnaliková et al., 2020).

The amount of waste increases by 3% each year. Suitable life conditions depend directly on the way that raw materials are exploited (Stasiak-Betlejwska, 2015). People exploit these valuable resources to transform them into various products, construct infrastructure, buildings, electronic appliances or produce energy, etc.

Environmental and economic problems are directly linked to the overproduction of waste and therefore these questions are sensitively perceived among countries. Products happen not to be fit for reuse in the production and the society is unable to process such high amounts of waste on landfills (Boďová, Gajarská, Baďurová, 2004). The above-mentioned circular economy concept could foster economic growth and influence the economy by promoting a positive attitude to environmental protection (Razminiene, 2019; Horecký, 2018). It aims at creating a new innovative process or a business model where already used materials or spare parts are returned into the production process to avoid wasting of valuable materials in economies. The constant demand for non-renewable resources generates pressure and damages the environment. However, it is crucial to pay attention to marketing communication to make the general public aware of these environmental concepts (Darnadyová, 2014). The connection of environmental and economic principles for the whole perception of economic models is often referred to as „ECO-ECO“. This term derives from the modeling approach „Eco-Eco Models“, i.e. from the English word eco(nomy)-eco(logy), i.e. economic-ecological model. These refer to economic situations that tend to meet not only economic but also ecological goals. It is often the ecological aspect of these models which is governed by specific statutes or various social requirements businesses have to comply with (Jašková, 2019).

The eco-eco approach helps solve not only simple but also more complicated economic situations of individual business entities within a particular economy. Businesses are able to adapt their production accordingly, either purchase

materials and goods or deal with transportation issues. Households are able to apply these principles when satisfying their needs and in the procurement of enviromentally friendly goods and services. Such purchase is referred to as eco-eco behaviour of a consumer as this one does not take into consideration the price, but other factors as well, such as environmental impact.

Businesses may use eco-eco optimalisation models when handling transport or transfer of materials necessary for ensuring production as well as delivery of ready goods (Zaušková, Rezníčková, 2020; Oláh et al., 2018). They can also be used in models with considerable material inputs where material or product recycling is welcome. Last but not least: we can not omit legislation, which paves the way for the implementation of the eco-eco approach in economic processes. The current economic trend leads to unsustainable exploitation of materials and energies resulting in a radical reduction of both renewable and non-renewable resources. Such a decline along with growing amounts of waste leads to serious ecological problems. Therefore it has been necessary to enact statutes forcing producers to think over their economic as well as environmental production aspects. Producers have had to consider economic and ecological ways how to ensure the transportation of a product to a customer and what is more, how to dispose of products after their expiry.

2 Theoretical Aspects of the Subject Matter

As we have mentioned in the introduction, the eco-eco principles can be looked at from both the production and consumer sphere or all through economic processes (Duľová, Spišáková, Mura, Gontkovičová, Hajduová, 2017). No matter if a business or a consumer is involved, it always has to consist of two parts – the economic and the ecological one. The subject matter is often discussed in two main areas – production and transport. These two parts have an impact on a producer on how to select materials, handle the transportation, purchase materials or how to transport them to a customer (Nascimento, Alencastro, Quelhas, Caiado, Garza-Reyes, Lona, Tortorella, 2019). They also have an impact on a consumer who is interested in what materials have been used and what means of transport has been selected. As these assumptions can not be exclusively economic, corresponding statutes have recently been adopted to handle emissions and waste disposal.

2.1 Integrated Product Policy and a Consumer

Consumers use various product materials on a daily basis. By their diversity, quality and functional ability they represent certain prospects and wealth and what is more, they influence the quality of life. Growing consumption is both a direct

and an indirect source of environmental pollution and depletion of natural resources. As most products are traded on a global or regional level, the company should achieve balanced development of its worldwide production while emphasizing quality of the global environment for future generations as enacted in the Declaration on the Environment and Development (Rio de Janeiro, 1992). One of the possibilities how to aspire to such development is to focus on a new growth paradigm and wealth distribution as well as competitiveness which can be achieved through more environmentally friendly products. Wealth refers not only to economic growth but also to limitation of exploitation of natural resources or preservation and improvement of the quality of the environment by eliminating negative environmental impacts or environmental and health-related risks (the Government Office of the Slovak Republic, 2019). Such wealth is directly linked to evolution of the society on different levels. Its main objective – to launch more environmentally friendly products in the market – has to be promoted by producers and consumers as a fundamental philosophy that has to be adopted in the initial product design phase at all points of sale. As soon as the product has been introduced in the market, there is not much we can do about any improvements hereon. In that case, all efforts of research and development workers or costs incurred may be vain if consumers do not buy or use these products in an environmentally friendly way for any reasons whatsoever.

Enhancing the environmental concept of production policy, promoting public debate and consumer orientation are all incorporated into the integrated production policy, i.e. the policy of modification and innovation of environmental behaviour of production systems for the purpose of eliminating negative environmental impact of products in course of their whole life cycle – from the exploitation of raw materials through production, distribution and use up to waste disposal (Boďová, Gajarská, Baďurová, 2004). Based on the aforementioned, it is important to enhance the identification of environmental awareness of consumers in purchasing everyday products. According to the research we carried out and which helped us to identify key factors influencing consumer purchasing behaviour, three key attributes have been defined – those that represent basic determinants having an impact on our daily purchase. By applying the factor analysis, we may assume that the decisive factors influencing a Slovak consumer when purchasing everyday products are as follows:

- factor 1 – origin, quality and product environmental footprint,
- factor 2 – product affordability,
- factor 3 – marketing communication and its impact in the point of sale.

The first factor states that at first, a Slovak consumer takes into consideration the product quality in relation to its origin and environmental footprint. The second factor indicates that the product price plays a role in the purchase and a consumer tries to buy affordable products. The third factor points to the fact that a Slovak

consumer takes a decision directly at the moment of purchase and is influenced by a set of marketing activities in the point of sale.

Table 1
Identification of factors influencing purchase of everyday products

Attributes	**Factor 1**	**Factor 2**	**Factor 3**
Packaging		0.279	0.392
Packaging size		0.677	
Affordable price	-0.213	0-717	0.182
Volume discount	0.227	0.653	
Environmentally friendly product	0.533		
Product quality	0.494	-0.192	0.121
Product made in Slovakia	0.654	0.15	0.124
Product content	0.709		-0.134
Brand	0.29	-0.366	0.348
Country of origin	0.787		
Having an option to return the product			0.415
Marketing in the point of sale		0.128	0.767
A special offer		0.39	0.686

Source: private source, 2019

Based upon these facts and tendencies we may assume that ecological features of a product or its packaging have a preference impact on a consumer´s buying process. Consumer´s eco-eco behaviour means a consumer will purchase only on the basis of the price while taking into consideration a product's environmental impact. When selecting a product, a consumer looks at distance and emissions occurring in the course of product purchase. In order to attract a consumer and be different from competitors, businesses apply various marketing tools and innovations to reach diversity and build consumer loyalty. And these is the main role of eco-eco principles. It is often not only a voluntary decision as in many cases businesses are forced to do so by legislation, which is further discussed in another chapter. The fundamental aspect should always be an attempt to fulfill economic objectives connected with corporate social responsibility and environmental protection. In this field one may focus on the ecological and economic approach of consumer purchasing behaviour, which is set to put pressure on producers the same way as the legislation does. One of the possibilities of how to succeed in today´s competitive environment is applying consumer-oriented eco-eco innovations. These innovations represent one of the most effective tools how to maintain and accelerate economic development and ensure business prosperity on both a local and a global market (Mura, Havierniková, Machová, 2017; Mucha et al., 2018). Their key feature is to offer an added value which has a considerable impact on consumer requirements during the consumption process. ECO-ECO innovations connect elimination of the

emissions and costs, which is a priority in today´s world of corporate social responsibility and consumer perception. These are the elements that are set to enhance consumer loyalty and satisfaction.

2.2 Recency of Eco-Eco Principles and Legislative Pressure in this Field

The eco-eco approach is rather usual for transport models or models dealing with the shortest transportation routes, i.e. the legislation for air pollution and emissions. Or models dealing with material issues, which is a preferred solution for material and product recycling (Gežík, Brezina, 2009). Therefore, we may observe certain social pressure on ecological thinking in process optimising. This is enacted in the corresponding legislation which governs all sets of criteria in connection with optimising or application of the ECO-ECO approach. It is mainly the European Union Legislation which is often referred to when forming ECO-ECO models and represents a basis for implementation of ecological objectives into economically-oriented processes. Every year 1.3 billion of waste are produced in the EU with approx. 40 million tons of toxic waste, which accounts for 3.5 tons per head and is still rising. It is estimated that if no changes are implemented, our waste production will have increased by almost 45% by 2020 compared to 1995. (the European Commission – Environment, [online]. Available at: http://ec.europa.eu/environment/waste/index.htm [07-06-2019]. As we have already mentioned, the core principle of the ecological approach is minimising waste, for example by reducing fuel consumption. Production of exhaust fumes is directly linked to over-consumption and therefore, the lower consumption, the fewer emissions into the air. 14.78 kg of air are needed for complete combustion of 1kg of petrol (3.4kg of oxygen) while producing 3.15 CO_2. Reduction of CO_2 emissions is a key ecological objective of our society.

The European Community legislation (the EU) is enacted in many different statutes – Directives of the European Parliament or the European Council (hereinafter referred to as „directives“) which form a legislative basis in EU member states. These directives are split into five groups:

- Framework legislation of the European Union on waste;
- EU legislation on waste disposal policies;
- EU legislation on specific types of waste;
- Information questionnaires and legislation;
- Any corresponding by-laws.

(the European Commission – Environment, [online]. Available at: http://ec.europa.eu/environment/waste/index.htm [07-06-2019]

According to Brezina et al. (2008) member states are committed to fulfill these objectives:

- minimising use of dangerous substances and plastics, some materials are to be gradually replaced,
- support of recycling-friendly design,
- producers can take over responsibility for ending the product life cycle, prepare a product for identification and provide information for processors regarding suitable recycling,
- both households and public areas have to be equipped with collection points for recycling labelled free-of-charge,
- producers have to create and finance proper systems for ensuring appropriate processing and product recycling and they become responsible herefore in collection points.

The European Community Directives are one of the most effective tools for fighting environmental pollution and emissions. These directives involve methodological guidelines of the Ministry of Environment in Slovak language. These directives and guidelines contain various restrictions and producers/importers/sellers of products (mostly electroproducts) are obliged to finance, ensure and participate in collection and liquidation of electric waste and packaging waste or they may refer to various restrictions in connection with emissions and limitations of the use of some categories of vehicles.

3 Objective, Material and Methodology

The main objective of the paper is to provide a model for eco-eco principles and their use within the circular economy by offering a specific view of the model aspect of material procurement from recycling. It is a sort of demonstration of these principles through mathematical modeling with one criteria function and that is when two parts of an eco-eco model, i.e. the economic and the ecological one are interconnected through balance in order to find the extreme of this connected function. When applying principles of eco-eco modeling of recycling in the circular economy, we focus on how to return products into their life cycle (*Savaskan, et al. 2004),* process of inventory level and return *(Schulz – Ferretti, 2008)* as well as the character of inventory *(Dyckhoff, et al. 2003).*

3.1 Eco-Eco Model

Mathematical modeling or linear programming enables clear recording and draws from the principle of aggregation of target criteria for model creation as

mentioned above, i.e. one objective consists of two parts. These two parts involve a particular balance referring to model preferences. The aggregation principle of target criteria for tasks with various purpose-made functions draws from the assumption that the aggregate purpose-made function equals to:

$f_0(x) = \sum_{k=1}^{s} v_k f_k(x) = \sum_{k=1}^{s} v_k \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ijk} x_{ij}$, where f_k, for $k \in (1, 2, \dots, s)$ represents specific purpose-made functions with an ecological objective of the set s representing all objectives of the Eco-eco model. Specific targets involve the balance v_k which equals to $\sum_{k=1}^{s} v_k = 1$. Particular functions consist of variables x_{ij} which represent connection among specific places and their corresponding evaluation c_{ijk} for $i, j \in (1, 2, \dots, n)$ referring to the set of all places interconnected with optimization. c_{ijk} equals to $c_{ijk} = c_{ijk}$ with the connection between places i and j where $c_{ijk} = 0$ and if the connection occurs within specific places, the value ∞ shall be applied.

In view of s direct demonstration of the circular economy, the model aspect is described through recycling processes while providing an ideal basis for explaining „the circle“ (Darnadyová, 2014). As mentioned above, eco-eco principles in models are mostly used in two main areas:

- transportation – models for transportation optimisation where the economic part consists of minimising transport costs and ecological minimising of emissions,
- material procurement – models connected to production optimisation including complex tasks where specific parts of eco-eco models are interlinked.

Most of the models focus on transportation optimisation or looking for the shortest ways for minimising transport costs or transport time, i.e. this reduction does not involve economic objectives. Minimum distance is an economic objective because it is connected with fuel consumption. This is closely linked to emissions as the higher consumption, the higher emissions. Consequently, each particular transport model minimising the distance or fuel consumption is said to be an eco-eco model. For this reason, the following chapters mainly deal with recycling and procurement of material for production through recycling, where the economic part of the eco-eco model lies in minimising costs for material procurement and the ecological one in minimising waste.

3.2 Eco-Eco Recycling Model Aspect

From the view of the circular economy, material procurement for production by recycling is about finding the ways how this material may be returned from consumers to manufacturers (EIS, 2019).

Ways of Return

In a truly integrated supply chain everyone in the supply chain can track a product as it moves forward through the channel (Selvefors, Rexfelt, Renstrom, Stromberg, 2019). While there are very few supply chains that really function this well, there are virtually none that work in reverse. Most firms cannot track returns within their own organization, much less somewhere outside of their firm (Hajduová, Andrejkovič, Mura, 2014). Depending on the reason of return ways the products are returned change as well. These ways depend on the subjects which are processing the return. Based on the relationship between manufacturer and retailer we can assume four possible ways of product return back to the manufacturer. First, is the closed-loop supply chain where the manufacturer collecting used products is the retailer itself, the second is when the products are returned directly to the manufacturer, which is not the retailer. In the third way, the products are returned through the retailer that is collecting used products and the fourth when the return is facilitated by a third party. These ways of product return are displayed in the figure below.

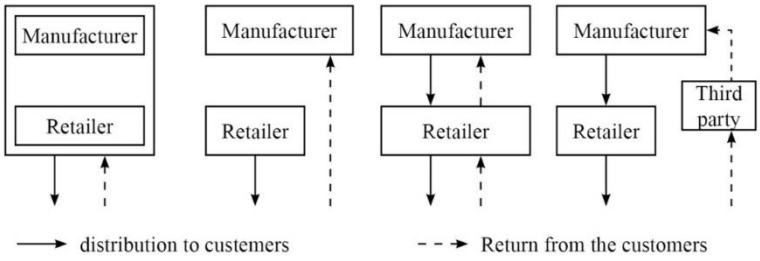

Figure 1
Ways of return

Source: Savaskan et al. 2004

It is important to remark that not only the final customers can return the products, but retailers and distributors as well. The process of reception of the returned products implies some different activities of revision and control that determine the actual state of the product. Only after that; it is possible to determine the best strategy of how to dispose of products, in the most cost-effective manner (Radu, 2018).

Material Requirements Planning

In the circle economy, as the consequence of the return flow, the inventory level between new component replenishment's is no longer necessarily decreasing but may increase (Razminiene, 2019). This loss of monotonicity significantly complicates the underlying mathematical models. A possible starting point for a closer analysis of this aspect is the cash balancing models comprising in and outbound flows. There are two alternatives for fulfilling the demand that imposes an additional set of decisions to be taken. External orders and recovery have to be

coordinated. Daniel Guide, V. et al. (2000) determine seven characteristics of the recoverable manufacturing systems that complicate the management, planning, and control of supply chain functions. They are:

- The uncertain timing and quantity of returns
- The need to balance demands with returns
- The need to disassemble the returned products
- The uncertainty in materials recovered from returned items
- The requirement for a reverse logistics network
- The complication of material matching restrictions

The problems of stochastic routings for materials for repair and remanufacturing operations are highly variable processing times. As we have mentioned before, it is possible that we have to use different parts from different returned products to produce a specific product during the remanufacturing process and also to mix them with new parts. This also complicates the production process. Guide et al (2000) shows a comparison between manufacturing and remanufacturing environment and the impact it has over the functional areas within an organization. Traditional MRP-systems are not feasible for recovery situations for several reasons. One of the main problems is the mismatch of supply and demand, due to the simultaneous release of 'wanted' and 'unwanted' components in the disassembly of returned products. A second major problem is the trade-off between reusing return components and outside procurement. In Remanufacturing, new products are manufactured using three kinds of components:

- Components that are always retrieved from return products (the quantity is unknown)
- Components that are always purchased new
- Components that can either be purchased new or retrieved from return products, depending on availability and costs.

Rate of Return

Fleischmann et al. (1997) states the following arguments, the repair operations needed to convert a returned product back to an 'as new' state depend on the actual condition of the product. This may vary from instance to instance and generally can be decided only after a number of testing and disassembly operations. Therefore, in contrast with the traditional manufacturing, no well-determined sequence of production steps exists in remanufacturing. This exposes planning in a remanufacturing environment to a much higher uncertainty. A high level of coordination required in remanufacturing is, therefore, a result of interdependence between different parts and subassemblies. (Fleischmann, 2001). Disassembly of a returned product is not a procurement source for one part but

releases various. The relationship between manufacturing and remanufacturing and their uncertainty describe figure, where is:

- d - demand
- α – rate at which products are returned to manufacturer,
- β – rate at which returned products are used,
- rtr – quantity of returned products, $rtr = \alpha d$
- rr – quantity of used returned products $rr = \alpha\beta d$
- ω – disposal (it means the quantity of products which are not returned or reused), $\omega = d - (rtr - rr)$

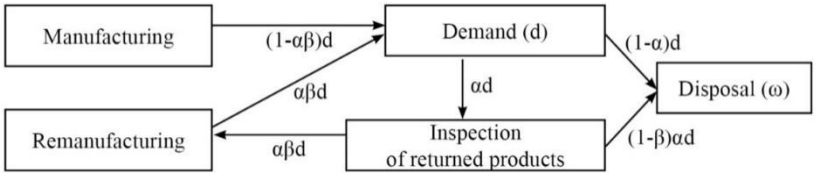

Figure 2
Manufacturing vs. Remanufacturing

Source: private source, 2019

Inventory in Process of Remanufacturing

In the process of manufacturing, there is a classic cycle stock of material needed for production and safety stock related to the fluency of production. When the returned products are used in manufacturing these two kinds of stock are supplemented by opportunity stock that is typical for remanufacturing.

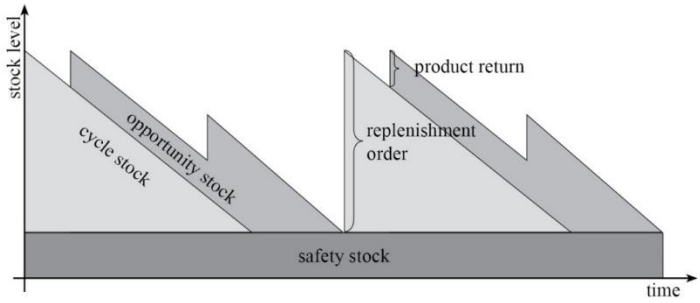

Figure 3
Material inventory

Source: Dyckhoff et al. (2003)

These opportunity stocks can be classified based on the quantity of returned products. The figure below illustrates the state where the quantity of returned products is constant in every period (a). However, the quantities of return may be

increasing in every consecutive period, (as seen in b)) or quantity is constant in every period but is returned more frequently (c)).

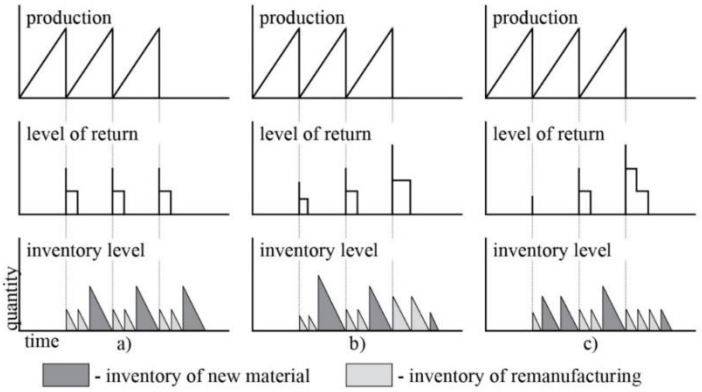

Figure 4

Inventory level in planning in a remanufacturing

Source: Schulz & Ferretti (2008)

As we can see the return of products back to the manufacturer is effective not only in economic sense but environmentally as well. Based on these two facts the companies are focusing more on the planning of processes related to the return of the end-of-life products for their remanufacturing. Options for the returned products are numerous and include processes ranging from resale, reuse or redistribution, to repair, modification, remanufacturing, refurbishment, recycling, salvage and environmentally friendly liquidation. However, the quantity and quality of returned products is uncertain which makes material requirements planning difficult. This uncertainty led to the development of models dealing with return, quantity, and rate of return, and also inventory management connected with inventory return.

4 The Concept of Fulfillment of Economic and Ecological Goals in the Circular Economy

The results of the research we carried out show that businesses need to be eco-friendly. The key objective of the paper is to point to the ways how to fulfill economic and ecological goals of businesses while respecting circular economy principles. One of the possible solutions is to apply models of reverse logistics in connection with economic and environmental goals. As a result, the term of eco-eco models has been created, i.e. models following not only economic but also ecological goals. These models consider economic affordability of recycled

materials and ecological collection of secondhand products in order to reduce the amounts of waste and protect the environment.

4.1 The Fundamental Principle of Product Return in Time

Obtaining returned products means that the goods had been sold to a consumer and this one returned them after having fulfilled the objective the goods had been originally purchased for. Therefore, the fundamental idea also implies purchasing material for initial production of the goods which are to be distributed and finally sold to a consumer. The consumer returns the goods to the manufacturer and this one will obtain the material suitable for further production. Product return is rather low at the beginning as not all products are consumed and returned right after production. We assume that not all products can be sold and consequently returned at the same time. Therefore, product return will be „transferred" to other time periods and is supposed to grow. This rise results from lower product return at its initial phase, which makes businesses purchase much more new material. These products are to be cumulated by a consumer and this one starts returning them. This principle has been described in the previous chapter and referred to as „occasional stock" as determining its amount seems to be rather difficult due to stochastic return of recycled products. Such return of recycled products in time can be modelated by specific eco-eco models. In general, all models suppose that in course of specific time periods, such hige amounts of products enter consumption that after this return period there will be more recycled product material that the new one. The difference lies in changing the amount of return or its intensity but as a matter of fact, return grows depends heavily on time frame. This growing return demonstrates itself in purchase of new products. This amount is quite high at the beginning – at first it is important to purchase new material at full amount, which is necessary for ensuring proper production. After certain time, this return will exceed material consumption and no new material purchase will be needed by the time this overproduction will have returned and purchase will have been renewed. Finally, purchase will remain at the level which equals to what has been liquidated (waste) in course of the whole process. The course of new material purchase is described below:

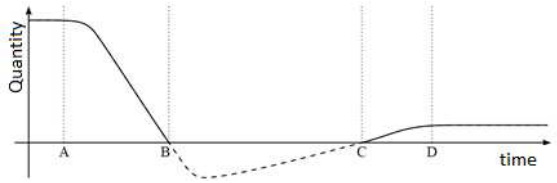

Figure 5
Process of purchase of a new material
Source: private source, 2019

Point A refers to the place where products are slowly returned. A business uses only new material to ensure production at this level. From this point products are returned and production is ensured from that material which was obtained from recycled products and simultaneously, from new material until the point B when the company starts using only the material from returned products. Since not all products are returned and certain waste is generated through the whole process, material stock from return is gradually decreasing (the return level will oscillate around one stable level). Suddenly this stock has dropped to such a level that a business will have to restart purchase – the point C. From this point purchase will grow stable to reach a constant level and will equal to the number of products that have not returned to or ended up as waste from the whole process. In the point D, a business purchases constant stock of products.

4.2 The Modeling of Product Return in Time

Prior to proper defining of the return model and its specific components, we have to clarify process dynamicity. It is all based upon the aforementioned mathematic programming, mainly optimisation by means of dynamic programming. The term „model" is relatively overvalued in this case as is it not presented as an eco-eco model with a specific complex function and a defined extreme. It is only a mere calculation of return or a sort of model, which is the term used further in our paper. This calculation can often be only a part of complex models of mathematic programming or thanks to its dynamicity and stochastic initial variables it can be a part of simulating models. And these simulating models are much more common in this case. The table below shows flexibility of modeling. Specific columns represent the periods t. As we can see, purchase is influenced by collection at the end of the third period, which accounts for three fifths of the first period, i.e. the model can adapt to demand and product return as purchase for production in the fourth period has already been influenced by collection. We can also see that in its initial phase, purchase is influenced by collection (see the scheme below). Only after certain time periods, collection will start to influence purchase. Purchase can also be influenced remaining stock from previous periods, production or production stock level in the previous period and most of all, by sale in the previous time period.

Table 2

Course of a business process

Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
I.	N	V	P	Z	Z	Z	Z	Z	Z
II.		N	V	P	Z	Z	Z	Z	Z
III.			N	V	P	Z	Z	Z	Z
IV.				N	V	P	Z	Z	Z

Legend: N – Purchase, V- Production, P – Sale, Z - Collection

Source: private sources, 2019

For this reason, shortening periods contributes to better model flexibility and better defining of adaptation and model of demand and therefore, promotes cost optimisation linked to insufficient or excessive stock. The model, apart from cost optimisation by calculating optimal stock, can also define the course of purchase in time and therefore it enables us to determine the secondary goal, i.e. defining the strategy of purchase and the number of periods the company needs until its purchase remains stable on one level. It also provides room for determining this level as well as the amount of purchased material for the specific time period and thus helps the company get information about allocation of financial resources for purchase. From the viewpoint of financial allocation, this model is much more comfortable as it is not necessary to purchase large amounts of stock for longer periods but rather opt for smaller and more effective ones. The calculation model is demonstrated in the Picture 4 where the part a) shows regular return from one specific time period. On the contrary, the parts b) and c) describe growing return. It is assumed that so many products are returned into production after several time periods that within a certain time span, the material from recycled products will exceed new material. The difference between the pictures b) and c) is the change of either the return level or return intensity, but as a matter of fact, growing return depends heavily on a time span.

4.3 Calculation Model for Growing Return

In case of single return from the previous period as shown in the part a) below, its calculation is rather simple. The number of returned products in the period t is determined by probability $PR(R)_t$, which states how many sold products are returned in the previous period *t-1* for the period *t.* After that we are able to express the product return (R_t,) by the relation $R_t = PR(R)_t D_{(t-1)}$, pre t = 1, 2, ...T where $D_{t\text{-}1}$ refers to sale of products in the period *t-1.* As far as growing return is concerned, we do not only refer to sale of products in the period *t-1,* but also for periods preceding the period *t.* Particular products are not indexed because of their general description still in reality, the number of products equals to n and therefore demand can be defined for the aggregate D_i, *where* i = 1, 2, ... n. The table 2 below compares demand to sale as the table has been drawn up for the manufacturer. The calculation assumes that sale copies demand, which is stochastic.

Variant 1

There are various possibilities how to calculate the growing return. The simplest one is the first variant drawing from the total number of products which were sold in the specific period linked to probability of return. The original $PR(R)_t$ transforms into $PR(Rx)_t$, where x refers to the number of periods t when the product is by a consumer, e.g. $PR\ (R3)_t$ refers to probability for the product being returned in the third period of sale. For x it is equal that from the interval 1 to X, 1 up to X, $x \in \langle 1; X \rangle$, where the upper value X represents „a limit“ beyond which it

is assumed the product will not return to its manufacturer and will end up as waste. Probability of return is slowly dropping as we assume that most of return is completed in the following period after sale and after that, the possibility for the product to be taken back is rather small. In this variant, the aggregate of probabilities is below 1 and it is, therefore, assumed that a certain percentage of products will never return to manufacturers and end up as waste. This percentage is determined by the difference between the sum of probabilities and the number 1 as probabilities are calculated from the total number of products that have been sold. Probability of return can be noted down as follows:

$R_t = PR(R1)_t D_{(t-1)} + PR(R2)_t D_{(t-2)} + \ldots + PR(RX)_t D_{(t-X)}$, for $t = 1, 2, \ldots T$ and X – the number of return periods. This simple variant is described in the following case study which uses fictional numbers to explain the principle determining the return volume and illustrates the return calculation on random numbers.

Variant 2

The second variant is applied when probability $PR(R)_t$ remains unchanged but the return calculation is modified - it differs from the first variant because it does not take into account the total number of products having been sold within a particular time period rather from what has remained by a consumer in a given period. This index is much more complex, but more real-based as it does not refer to those products that have been returned from previous periods and therefore provides more precise data. It means that probability is linked to remaining products which stayed by a consumer from X previous time periods plus all products which were sold in the immediately preceding period. This variant also calculates the limit X beyond which it is supposed that the product will never be returned to its manufacturer and will be considered as waste. Probability $PR(R)_t$ has to be lower[2] than 1 to ensure that after the X time period the amount of goods remaining by a consumer is equal to waste. This return probability can be noted down as follows:

$R_t = PR(R)_t D_{(t-1)} + PR(R)_t (1 - PR(R)_t) D_{(t-2)} + PR(R)_t (1 - PR(R)_t)^2 D_{(t-3)} + \ldots + PR(R)(1 - PR(R)_t)^{X-1} D_{(t-X)}$, for $t = 1, 2, \ldots T$ and X – the number of return periods.

Variant 3

The third variant combines the previous two variants. As the second variant, it does not take into account return from the total number of products having been sold within particular time periods, but only the amount having remained by a consumer. This variant also calculates with „a limit“ X, beyond which it is supposed the product will never return to its manufacturer and will end up as waste. At the same time, it defines return probability with a declining character. This decline is not so sharp as in the first variant as the return is supposed to drop gradually with the number of periods when the product is by a consumer. There is

no assumption that the aggregate probabilities are below 1. Particular probabilities have to be lower than 1 but it does not suppose that a certain number of products will never return to a manufacturer and end up as waste. Such waste is, as in the first variant, determined by the limit *X*. This determination of return can be noted down as follows:

$$R_t = PR(R1)_t D_{(t-1)} + PR(R2)_t(1 - PR(R1)_t)D_{(t-2)} + PR(R3)_t$$
$$(1 - PR(R2)_t)(1 - PR(R1)_t)D_{(t-3)} + \ldots + PR(RX)(1 - PR(R(X-1))_t)$$
$$(1 - PR(R(X-2))_t)\ldots(1 - PR(R(X-(X-1))_t)_t D_{(t-X)}$$

for $t = 1, 2, \ldots T$; $u = 1, 2, \ldots U$; X – the number of return periods.

4.4 Illustration of Calculation of Growing Return

In case of a single return from the previous period as shown in the part a) below, its calculation is rather simple. The number of returned products in the period *t* is

Case Study 1

Case study 1 is linked to the first variant and illustrates the calculation of return on random numbers oscillating around 1,000. It is supposed that the upper-value *X* is five, so after the fifth year, the product does not return to its manufacturer and turns into waste. Probabilities in the example are: *PROB(R1)* = 0.5; *PR (R2)* = 0.2; *PR (R3)* = 0.05; *PR(R4)* = 0.025; *PR(R5)* = 0.025. The study suggests that 20%[3] of products never return to manufacturers and turn into waste and the study is presented for one collection point and for one type of product. Return is calculated as follows:

$R_t = PR(R1)D_{t-1} + PR(R2)D_{t-2} + PR(R3)D_{t-3} + PR(R4)D_{t-4} + PR(R5)D_{t-5}$, for $t = 1, 2, \ldots T$ and $X = 5$.

Table 3
Case study 1

Period	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**
	1000	500	200	50	25	25	0	0
		980	490	196	49	24.5	24.5	0
			1020	510	204	51	25.5	25.5
				1010	505	202	50.5	25.25
					970	485	194	48.5
						1000	500	200
							1030	515
								1010
Amount sold	**1000**	**980**	**1020**	**1010**	**970**	**1000**	**1030**	**1010**
Material return	**0**	**500**	**690**	**756**	**783**	**787.5**	**794.5**	**814.25**

Source: Private source

Case Study 2

Case study 2 draws from the same assumptions as to the previous model while illustrating the calculation of return on random numbers oscillating around 1,000 and supposing that the upper-value *X* is five, i.e. after the fifth year the product does not return to its manufacturer and turns into waste. The study is presented for one collection point and for one type of product. Probability *PR(R)* = 0.3 and return is calculated as follows:

$R_t = PR(R)D_{t-1} + PR(R)(1 - PR(R))D_{t-2} + PR(R)(1 - PR(R))^2 D_{t-3} +$
$+PR(R)(1 - PR(R))^3 D_{t-4} + PR(R)(1 - PR(R))^4 D_{t-5}$, for $t = 1, 2, ...T$ and $X = 5$.

Table 4
Case study 2

Period	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**
	1000	300	210	147	102.9	72.03	0	0
		980	294	205.8	144.06	100.84	70.59	0
			1020	306	214.2	149.94	104.96	73.47
				1010	303	212.1	148.47	103.93
					970	291	203.7	142.59
						1000	300	210
							1030	309
								1010
Amount sold	**1000**	**980**	**1020**	**1010**	**970**	**1000**	**1030**	**1010**
Material return	**0**	**300**	**504**	**658.8**	**764.16**	**825.91**	**827.72**	**838.99**

Source: Private source

Case Study 3

Case study 3 is based upon the same assumptions as to the previous two studies while illustrating the calculation of return on random numbers oscillating around 1,000 and supposing that the upper-value *X* is five, i.e. after the fifth year the product does not return to its manufacturer but turns into waste. The study is presented for one collection point and for one type of product. Probabilities in the case study are as follows: *PR(R1)* = 0.5; *PR(R2)* = 0.4; *PR(R3)* = 0.3; *PR(R4)* = 0.2; *PR(R5)* = 0.1. Return is calculated as follows:

$R_t = PR(R1)D_{t-1} + PR(R2)(1 - PR(R1))D_{t-2} + PR(R3)(1 - PR(R2))$
$(1 - PR(R1))D_{t-3} + PR(R4)(1 - PR(R3))(1 - PR(R2))(1 - PR(R1))D_{t-4} +$
$+PR(R5)(1 - PR(R4))(1 - PR(R3))(1 - PR(R2))(1 - PR(R1))D_{t-5}$

for $t = 1, 2, ...T$ and $X = 5$.

Table 5
Case study 3

Period	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**
	1000	500	200	90	42	16.8	0	0
		980	490	196	88.2	41.16	16.46	0
			1020	510	204	91.8	42.84	17.17
				1010	505	202	90.9	42.42
					970	485	194	87.3
						1000	500	200
							1030	515
								1010
Amount sold	**1000**	**980**	**1020**	**1010**	**970**	**1000**	**1030**	**1010**
Material return	**0**	**500**	**690**	**796**	**839.2**	**836.76**	**844.2**	**861.89**

Source: Private source

Conclusion

As we have already mentioned before, current trends in consumer behaviour as well as legislation make businesses think environmentally friendly. This is why the paper points to possibilities of ecological orientation without increasing the economic burden on every day production processes. The main goal of the paper has been to provide practical modeling of eco-eco principles in the circular economy by offering a specific view of the model aspect of procurement of production material from recycling. Moreover, we were trying to define possibilities of how to meet eco-eco goals of businesses based upon the circular economy principles while keeping cost-effectivity and promoting an ecological footprint of the production process. In conclusion, it is important to say that the basis of economic and ecological models which, apart from optimising their purpose-made function, deal with minimising costs or maximising earnings or profits, and what is more, also have an environmental impact function.

This function mainly deals with the environmental impact of production processes and these are:

- minimising waste,
- minimising use of toxic materials,
- minimising negative impacts of product transport (emissions),
- dminimising use of energies.

This function is dependent on various factors and their relative significance as the environmental impact can be difficult to quantify and in reality, it is rather complicated to calculate its value. It can also be mentioned that the current state of the environment is alarming. A long-term consumption way of life of the whole society has resulted in various global ecological and economic problems which are

becoming worse every day and are having a destructive impact on end users. The only perspective is transfer from the linear model to the circular one with the purpose of minimising waste and maximising product benefits. Some businesses have already become aware of their responsibility for the environment and have already started to implement these principles into their production processes. However, the implementation is one thing and communication of this positive change to consumers still remains a challenge. As this model is mainly theoretical and rather general, all depends on its application. The variant is suitable for products with high initial returnability, which means that most of them can return right after the sale. There are various ways how to calculate return or volume of material one can obtain by recycling products after their expiry.

The given examples can serve as a basis for more complex calculations for other specific products. Therefore, it is crucial to know the product features as well as the environment to which these products will be returned. Only on the basis of these data we may draw a particular calculation or adapt specific case studies hereto. These can finally serve as simulation models for product return. The illustrations show that return modeling or the volume of returned products for their further recycling have to be properly calculated. Example 1 presents the easiest calculation. It is only about a mere index, but real implementation into an eco-eco model is often faced with complications as it is not that obvious to draw probabilities for specific time periods as well as waste probability. Example 2 demonstrates the second variant of calculation, which is more likely to be used in practice, as it helps set average return probability. This variant is suitable for simulating eco-eco models dealing with modeling or return calculation. This index is dynamically changing and can adapt to the current market situation. Another advantage is the possibility to create several variants within one simulating model and its proper verification. The last variant combines the previous ones with an estimation of particular probabilities the aggregate of which equals 1 and calculates the amount of waste by means of a similar index as the second variant. This variant is suitable for mathematical programming or dynamic programming models. Probability helps us to derive balance for the aggregation principle of purpose-made criteria and their critical function.

This study merely explains the fundamentals of a theoretical model meaning it might only obtain specific limitations when applied to a specific scenario, but not in its fundamental nature. Thus, the limitations of this model are only case-specific and will not be discussed further.

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On the Simulation of Cooling Curves Using Simple Functional Formats

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Abstract: Quenching of metal products is a complex physical process that is difficult to precisely describe by physical models. The "Heat Transfer Coefficient (HTC)" at the surface of the workpiece is a practical parameter that depends on the nature of the flow, the density, viscosity, and the thermal properties of the cooling liquid, the surface quality, shape, and thermal data of the component under quenching. Normally only numerical techniques are available for its estimation that need huge computational power. However, in the practice, on the basis of approximate quantitative data and some qualitative knowledge, often good and simple approximations can be elaborated for the description of quite complicated problems. In this paper a simple approximation is suggested for modeling the time-dependence of the HTC of an Inconel 600 alloy probe of cylindrical shape used in the standard ISO 9950. Simulation results using moderate computational power are presented to substantiate the suggestion.

Keywords: Quenching; Heat Transfer Coefficient; Finite Elements Methods; Newton-Raphson Algorithm; Julia

1 Introduction

Quenching of metal products is a complex physical process that is difficult to precisely describe by physical models. The HTC at the surface of the workpiece is a practically introduced parameter that depends on the nature of the bulk flow (laminar or turbulent), the temperature, density, viscosity, and the thermal properties of the cooling liquid, the surface quality, shape, and the thermal data of the component under quenching. Normally only numerical techniques are available for its estimation that need huge computational power. The "direct" problem, i.e. determining the temperature distribution versus time of the probe for a given initial distribution and the boundary conditions if the function $HTC(\mathbf{r},t)$ is given in advance (t denotes

the time, and $\mathbf{r}$ means the location over the surface of the sample), has an unique solution. However, the "inverse problem", i.e. finding the function $HTC(\mathbf{r},t)$ over the sample's surface in the possession of the temperature distribution $T(\mathbf{r},t)$ in certain points of the quenched sample is a more complicated task that generally is an "ill-posed" problem as it was observed by Beck et al. in 1985 [1]. Generally neither the uniqueness, nor the stability of the solution can be guaranteed.

Mathematically the problem can be defined as an optimization task in which on the basis of some assumed $HTC(\mathbf{r},t)$ distribution the cooling curves in certain points within the probe are calculated, and some cost function that measures its distance from the available measured data is minimized by modifying the assumed distribution (e.g. [1, 2, 3, 4, 5, 6, 7]).

The complexity of the task can be considerably reduced if samples of particular shapes and special locations for temperature measurements are chosen. On this reason the standard ISO 9950 [8] uses special cylindrical samples with measurement points in the centerline of the cylinder. Further simplification of the calculations is possible if during the quenching process no latent heat appears that in general can be caused by either phase transitions or chemical reactions within the probe. These advantages are guaranteed by the special alloy (Inconel 600) that is recommended by the standard, and for which well known thermal data are available in the temperature range of the investigations [9]. Since the process still has ample difficulties due to the behavior of the cooling liquid, even if geometric simplifications are applied, high computational requirements remain that make it expedient to use evolutionary techniques as well as the utilization of the various hardware components of the computers as the computational capacity of the graphical cards (e.g. [10, 11, 12, 13, 14]).

However, in the practice, on the basis approximate quantitative data and some qualitative knowledge, often good and simple approximations can be elaborated for the description of quite complicated problems. A mathematically rigorous approach is the application of fuzzy sets [15] that can be used for modeling and control applications (e.g. [16, 17, 18, 19]). The essence of this approach is that by the use of the available qualitative and quantitative information, membership functions and operators of certain particular form (e.g. [20]), special models can be constructed that well capture and mirror the essential properties of the phenomenon under consideration. Though the very particular properties of these special models are not well or uniquely determined, in the practice they can be successfully applied.

In this paper a simple approximation is suggested for modeling the time-dependence of HTC of an Inconel 600 alloy probe of cylindrical shape used in the standard ISO 9950. The basic idea is that instead trying to use some particular temporal distribution of $HTC(\mathbf{r},t)$ over the surface of the sample, on the basis of qualitative considerations it is assumed that the HTC at the surface of the probe *physically must depend on* the surface temperature of the probe as $HTC(T(\mathbf{r},t))$, and the function $HTC(T)$ depends only on a few "shape parameters". The shape of this function can be formally defined and tuned by modifying only a few shape parameters. This approach reduces the complexity of the problem to a great extent and allows the application of simple optimum seeking algorithms that can be implemented on even low ca-

pacity computers. Accordingly, simulation results using moderate computational power are presented to substantiate the suggestion. The computations were made on a **Dell inspiron 15R laptop** operated by the central processor Intel® Core™ i5-3337U CPU @ 1.80GHz × 4 under an Ubuntu ver. 13.04 operating system without using any graphical computational power. The sequential program was written in Julia Version 1.0.3 (2018-12-18). This program language is developed at the MIT, it is very similar to the MATLAB, but it runs almost as fast as a C code (benchmarking data are available at [21], Fig. 1).

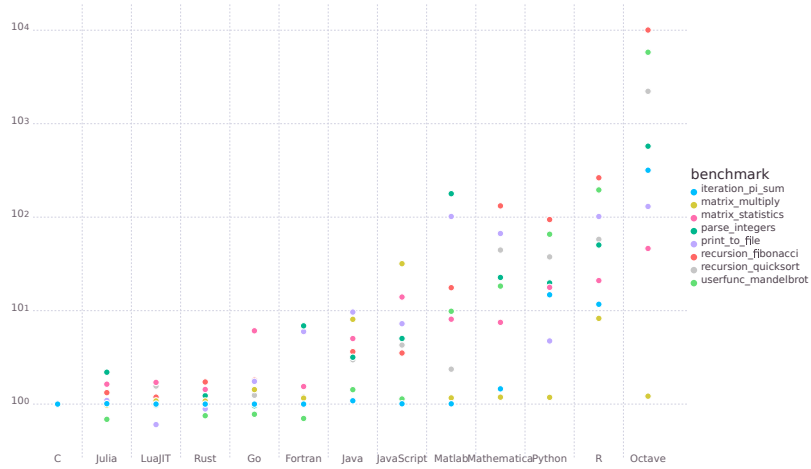

Figure 1
Some benchmarking data for language Julia (source: [21])

2 The Dynamic Model and Its Finite Elements Approximation for Long Cylindrical Samples

The quenched sample considered in the simulations was made of the alloy "Inconel 600" that, in the range of the investigations, does not produce measurable latent heat that generally can be produced by either phase transitions or chemical reactions. On this reason this alloy is used in the standard ISO 9950 [8]. This standard also determines the geometric properties of the sample: it must have a cylindrical shape in the symmetry axis in which the temperature sensors can be located. Normally, due to the cylindrical symmetry of this sample, mathematically we have to consider a two dimensional problem with the independent variables that describe the location of the considered point in the direction of the symmetry axis, and in the radial direction. However, if the sample is "long", and it is evenly immersed into the quenching liquid, at the axial level of its central point no heat drift can be assumed in the axial direction, and the problem can be reduced into a single variable one. In the sequel this model of reduced complexity is investigated under the name *"Long Cylindrical Sample"*. It is important to emphasize that this approximation cannot be applied for the description of the cooling process at the points that are not located at the cenral axial level: in this case the effects of the "upper" and "lower" boundaries of the

cylinder of finite size have nonsymmetric effects, and the problem must be treated as a 2 dimensional one. Furthermore, if the possible deformation of the sample in the three dimensional space has to be considered, too, in general a three dimensional problem has to be considered.

2.1 The "Long Cylindrical Sample" Approximation

In this approximation the concept of "long sample" means that no energy transfer in the axial direction is assumed. Furthermore, by assuming cylindrical symmetry, a single dimensional heat transfer equation can be considered as in [11, 22], and the heat conduction equation is reduced to (1)

$$\frac{\partial}{\partial r}\left(k(T(r,t))\frac{\partial T(r,t)}{\partial r}\right)+\frac{k(T(r,t))}{r}\frac{\partial T(r,t)}{\partial r}=\rho C_p(T(r,t))\frac{\partial T(r,t)}{\partial t}\quad , \tag{1}$$

in which $t\,[s]$ denotes the time, $r\,[m]$ denotes the radius from the centerline as the "independent variables" of the problem, $T\,[C]$ is the temperature. The numerical properties of the alloy Inconel 600 were taken from [9] as $\rho = 8420\,\left[kg\,m^{-3}\right] \equiv const.$ For the *"heat conductivity coefficient"* $k(T)\,\left[J\,s^{-1}\,m^{-1}\,K^{-1}\right]$ and the *"specific heat at constant pressure"*, $C_p(T)\,\left[J\,kg^{-1}\,K^{-1}\right]$ third order polynomials were fitted in the range $T \in [27, 796.45]\,[C]$ for the tabulated data as it is given in Fig. 2.

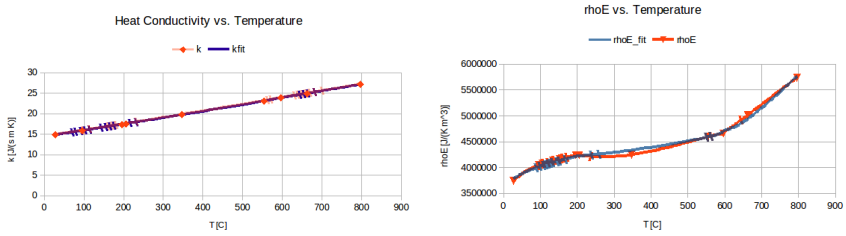

Figure 2
The dependence of the "heat conductivity coefficient" (LHS) and $\rho_E \equiv \rho C_p$ (RHS) on the temperature in (1): fitted 3rd order polynomials for the tabulated data published for Inconel 600 in [9]

For (1) the appropriate *boundary conditions* were set for the sample of radius $R = 6.25\,[mm]$ as

$$-k(T(R,t))\left.\frac{\partial T(r,t)}{\partial r}\right|_{r=R} = h(t)(T(R,t)-T_q)\quad , \tag{2}$$

in which $T_q\,[C]$ is the temperature of the bulk quenching liquid in turbulent flow, and $h(t)\,\left[J\,s^{-1}\,m^{-1}\,K^{-1}\right]$ is the *heat transfer coefficient* of the boundary layer of the liquid at the surface of the probe that is assumed to vary in time as the sample cools down. Besides the boundary condition equation (1) must be completed with the *initial conditions*. The *initial conditions* must be compatible with the *boundary conditions*. This compatibility must be guaranteed at the level of the *finite elements approximation* of the equations that are detailed in the Subsection 2.2.

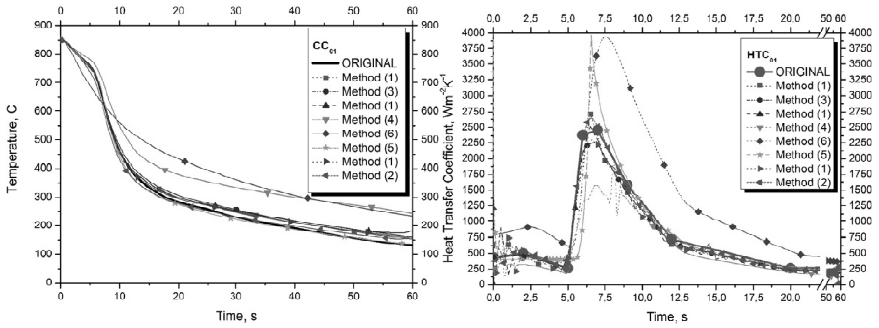

Figure 3
Cooling curves and HTC values calculated with various approximation methods for the 12.5 $[mm]$ diameter cylindrical probe made of Inconel 600 (Figs. 7 and 4 in [22])

To make the calculations realistic already known data were taken from the literature to extract qualitative and approximate quantitative knowledge for the probe considered (Fig. 3). The initial temperature $T_{ini} = 850\,[C]$ is a little bit higher than the maximal value in [9] (796.45 $[C]$), however, the small difference allowed the use of the fitted polynomials in Fig. 2 for *data extrapolation* outside the range of fitting.

2.2 The Finite Elements Approximation of The Problem

Evidently, due to the singularity of the polar system of coordinates at $r = 0$ the center of the sample cannot be numerically considered. To evade this problem instead of the *exact range* $[0,R]$ the range $[\Delta r,R]$ was so considered that the $[0,R]$ interval was divided into $N \in \mathbb{N}$ equally long intervals as $\Delta r = \frac{R}{N}$, and in the role of the center line $r = \Delta r$ was placed. For the grid points $\{r_i | i = 2,\ldots,N-1\}$ the *central estimation of the gradient* was used as in (3a). Consequently, the numerical calculation of $\nabla(k \cdot \nabla T)$ in (1) was possible for the points $\{r_i | i = 3,\ldots,N-2\}$ in (3b), and for the "center line" the approximation in (3c) was applied. This means that $\frac{\partial T}{\partial t}$, therefore the direct refreshment of the temperature values during an Euler integration, was possible only for the points $\{r_i | i = 3,\ldots,N-2\}$, too.

$$\frac{\partial T(r_i,t)}{\partial r_i} \approx \frac{T(r_{i+1},t) - T(r_{i-1},t)}{r_{i+1} - r_{i-1}} \quad i \in \{2,\ldots,N-1\} \tag{3a}$$

$$\frac{\partial}{\partial r}\left(k\frac{\partial T}{\partial r}\right) \approx \frac{k(r_{i+1},t)\nabla T(r_{i+1},t) - k(r_{i+1},t)\nabla T(r_{i-1},t)}{r_{i+1} - r_{i-1}} \quad i \in \{3,\ldots,N-2\} \tag{3b}$$

$$T(r_1,t) \equiv T(r_2,t) \equiv T(r_3,t) \tag{3c}$$

To solve the boundary conditions in (2) a *refreshed value* T in grid point r_{N-1} was estimated by using the 1st spatial derivative of the already refreshed points as in (4)

$$T(r_{N-1},t) \approx T(r_{N-2},t) + \frac{(r_{N-1} - r_{N-2})(T(r_{N-2},t) - T(r_{N-3},t))}{(r_{N-2} - r_{N-3})} \quad , \tag{4}$$

and $T(r_N,t)$ was estimated by the use of the heat transfer coefficient as in (5)

$$T(r_N,t) \approx \frac{h(T(r_{N-1},t))T_q + k(T(r_{N-1},t))/\Delta r}{h(T(r_{N-1},t)) + k(T(r_{N-1},t))/\Delta r} \quad . \tag{5}$$

2.3 Setting The Parameters of The Numerical Calculations

For the simulations the *functional format* for describing the dependence of the HTC on the surface temperature the function given in (6) was applied

$$h(T) = h_{max} \begin{cases} \exp\left(-([T - T_{max}]/w_{left})^p\right) & \text{if } T <= T_{max} \\ \exp\left(-([T - T_{max}]/w_{right})^p\right) & \text{if } T > T_{max} \end{cases}, \tag{6}$$

in which h_{max} denotes an assumed possible maximal HTC value, T_{max} denotes the surface temperature that belongs to the "location" of this maximum, and the width parameters w_{left} and w_{right} belong to asymmetric solutions. The parameter p determines the nature of the "tail" of the function, it was kept fixed when the gradient was computed. This format was selected on the basis of plausible physical considerations that are relevant in the refrigeration industry that has to cope with similar problems though in a much lower temperature range than that of the steel industry. However, this lower range allows the application of tubes made of glass allowing simple optical observations that are not available in the steel industry (e.g. [23, 24, 25]). The HTC is a *practically well measurable parameter* behind which complicated physical processes are hidden as follows.

a) The cooling liquid normally has turbulent flow that allows very efficient heat transfer between the stirred fluid layers with the exception at the boundary layer of the quenched sample. The liquid sticks on the surface of the sample, due to that a thin film (the "boundary layer") is formed around the sample within which the flow is laminar. Within this layer the heat transfer happens mainly via heat conduction that is not an efficient form of the heat transfer. This process is concerned by the quality of the surface of the probe, too.

b) The viscosity of the liquid decreases with increasing temperature, due to which at higher temperatures thinner films with better heat transfer ability are expected.

c) When the temperature achieves the boiling point of the liquid at the pressure of the operation, at the surface of the probe gas bubbles appear that act as "heat insulators", so at higher temperatures some decrease in the HTC value is expected.

Precise modeling of the above phenomena is very difficult, however, they substantiate the use of the simple asymmetric form defined in (6). It is also reasonable to expect that by fitting the 4 independent parameters in (6) good approximate modeling possibility can be created. It worths noting that in the practice complicated function expressions can be quite well approximated by simple ones. For example the normal, the epsilon, and the omega distributions were well approximated by simple function formats by Dombi et al. in [26, 27, 28], as well as the kappa regression function in [29].

Really, it was easy to find qualitatively acceptable approximation of the curves in Fig. 3 by using (6) with the "target parameters" in Table 1. By printing the results for the same graphs when in Subsection 2.2 the pairs $\{N = 50, \delta t = 10^{-3}\,[s]\}$ and $\{N = 20, \delta t = 10^{-2}\,[s]\}$ were selected (δt is the time-resolution of a simple Euler

integration according to the time variable), Fig. 4 was obtained. The differences between the results are not too drastic, therefore in the further investigations the "faster settings", i.e. $\{N = 20, \delta t = 10^{-2}\,[s]\}$ were used. (It can be noted that according to Fig. 3 obtained from the litearture, the various methods provided considerably different results.)

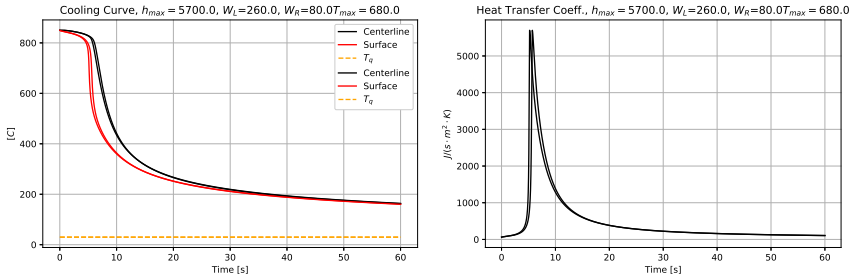

Figure 4
The "Cooling Curve" and the "HTC versus Time" functions belonging to Eq. (6), the "Target" parameters given in Table 1, and the numerical parameter pairs $\{N = 50, \delta t = 10^{-3}\,[s]\}$ and $\{N = 20, \delta t = 10^{-2}\,[s]\}$ in Subsection 2.2

Table 1
The applied "target" and "initial" model parameters in (6)

Parameter	**Target**	**Initial**
h_{max} $\left[J\,s^{-1}\,m^{-2}\,K^{-1}\right]$ HTC	5700.0	5500.0
T_{max} $[C]$ location of maximal HTC	680.0	650.0
w_{left} $[C]$ left width	260.0	300.0
w_{right} $[C]$ right width	80.0	60.0
p [nondimensional] "tail property" parameter (fixed)	2.0	2.0

3 Simulation Results

By the use of the above approximations, for the given $T_q = 30.0\,[C]$ cooling liquid temperature, $T_{ini} = 850.0\,[C]$ initial probe temperature, the cooling curve over the time-grid $\delta t[1,6000]$ a multiple variable multiple output function can be obtained with *a* 4 *dimensional input space* consisting of the input variables defined in Table 1. By defining the error as the Frobenius norm of the difference of "Target Temperature vs. Time" and the "Simulated Temperature vs. Time" functions as $E(x) : \mathbb{R}^4 \mapsto \mathbb{R}$ can be created the minimum of which has to be found for determining the $HTC(t)$ function. While the numerical implementation of the standard "Reduced Gradient Method" that originally was invented by Lagrange in 1811 [30] for use in the formulation of Classical Mechanics may result in slow algorithm if no information we have on the expected minimum of $E(x)$ (in this case no reduction of the gradient was

necessary in the lack of constraints), the classical Newton-Raphson algorithm (e.g. [31]) may result in fast solution if the assumption $\min E(c) = 0$ is made. The basic idea is as follows: select an initial point $x(1)$, calculate $\nabla E(x(1))$, and make a big step $\Delta x = \alpha \nabla E(x(1))$ so that $-E(x(1)) = \Delta x^T \nabla E(x(1))$. Then repeat the procedure at $x(2) = x(1) + \Delta x$, etc. Roughly speaking, it is expected that already the 1st step almost makes $E(x)$ well approximate zero. For this the selection

$$\alpha = \frac{-E(x(1))}{\|\nabla E(x(1))\|^2} \tag{7}$$

is needed. However, it is well known that if ∇E is not precisely computed, this algorithm easily can diverge without finding the minimum. In our case the gradient is only very imprecisely estimated, so the original Newton-Raphson algorithm was modified as its is described in Subsection 3.1.

3.1 The Modified Newton-Raphson Algorithm for the Problem Having Exact Solution

The modification of (7) is given in (8)

$$\alpha = \gamma \frac{-E(x(1))}{\|\nabla E(x(1))\|^2 + \varepsilon} \ , \tag{8}$$

in which $\varepsilon = 10^{-14}$ was introduced to evade division by zero, and the "refining factor" $\gamma = 5 \times 10^{-3}$ was experimentally set. For the estimation of the components of $\nabla E(x)$ the "actual values" in Table 1 were modified as $h_{max} \to h_{max} + \Delta h_{max}$, $T_{max} \to T_{max} + \Delta T_{max}$, $w_{left} \to w_{left} + \Delta w_{left}$, and $w_{right} \to w_{right} + \Delta w_{right}$ with $\Delta h_{max} = 10^{-3} \left[J\, s^{-1}\, m^{-2}\, K^{-1} \right]$, $\Delta T_{max} = 10^{-3}\ [K]$, $\Delta w_{left} = 10^{-3}\ [K]$, and $\Delta w_{right} = 10^{-3}\ [K]$. The differences between the neighboring values were computed for the estimation of the components of the gradient of $E(x)$.

The parameter of γ from the initial value 1 (that corresponds to the original Newton-Raphson algorithm) was decreased till the algorithm ceased to "jump" between large final errors. This solution forms a "transition" between the fast Newton-Raphson algorithm and the slower "Gradient Descent" method, and it allows a practical compromise between the precision and the running time.

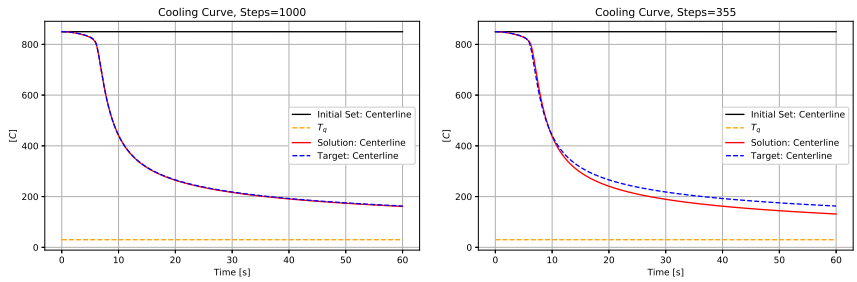

Figure 5
The operation of the modified Newton-Raphson algorithm for the problem having exact solution, i.e. the model defined in Eq. (6) with the parameters given in Table 1: the "Cooling Curves" for 1000 steps (LHS), and for limited precision achieved by stopping the algorithm at a lower error-limit 2000 (RHS)

To check the suggested method's abilities for target distributions that slightly differ from the "target form" (6), the target distribution generated by (9) was applied in which a "deformation parameter" $D = 7.5 \times 10^{-2}$ was introduced.

$$h(T) = h_{max} \begin{cases} \frac{D}{D+([T-T_{max}]/w_{left})^p} & \text{if } T <= T_{max} \\ \frac{D}{D+([T-T_{max}]/w_{right})^p} & \text{if } T > T_{max} \end{cases}, \tag{9}$$

By the use of the same common parameters in (6) and (9), the effect of the introduction of the above parameter D is revealed by Fig. 8 in which the appropriate cooling curves and the HTC vs. time functions are plotted in the same diagrams.

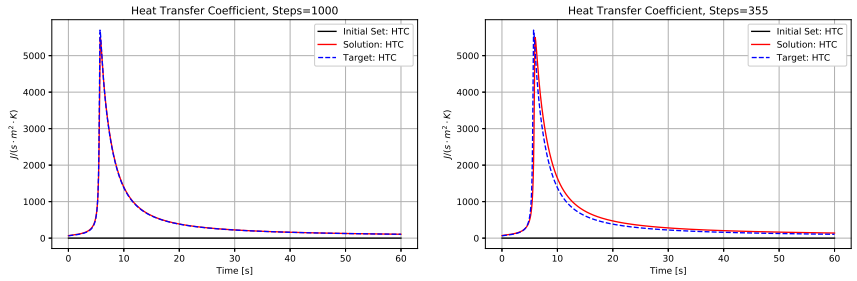

Figure 6
The operation of the modified Newton-Raphson algorithm for the problem having exact solution, i.e. the model defined in Eq. (6) with the parameters given in Table 1: the "HTC" value as the function of the time for 1000 steps (LHS), and for limited precisison achieved by stopping the algorithm at a lower error-limit 2000 (RHS)

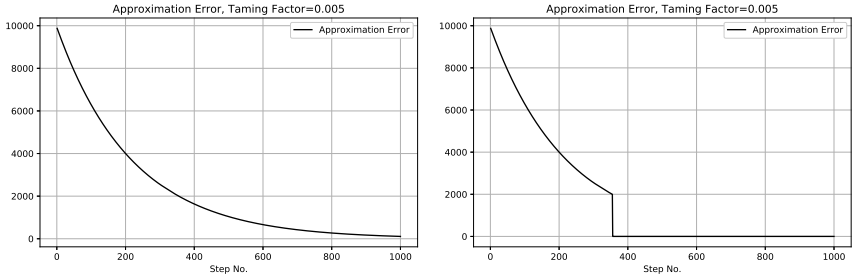

Figure 7
The operation of the modified Newton-Raphson algorithm for the problem having exact solution, i.e. the model defined in Eq. (6) with the parameters given in Table 1: the "approximation error" value as the function of the time for 1000 steps (LHS), and for limited precision achieved by stopping the algorithm at a lower error-limit 2000 (RHS)

3.2 The Modified Newton-Raphson Algorithm for the Problem Not Having Exact Solution

In these cases the "targets" and the "approximations" are generated by different format functions. Figure 9 reveals that though it was impossible to exactly reach the

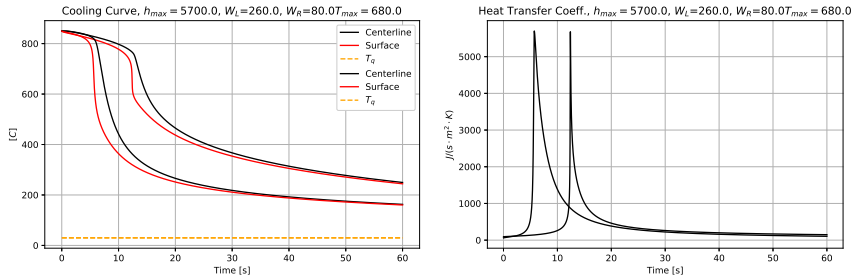

Figure 8
The effect of the "deformation parameter" $D = 7.5 \times 10^{-2}$ in the target distribution generated by Eq. (9) (LHS) and the appropriate functions $HTC(t)$ (RHS)

"target" distribution with the deformed functional shape, the algorithm well approximated the target, and the obtained $HTC(t)$ functions were comparable.

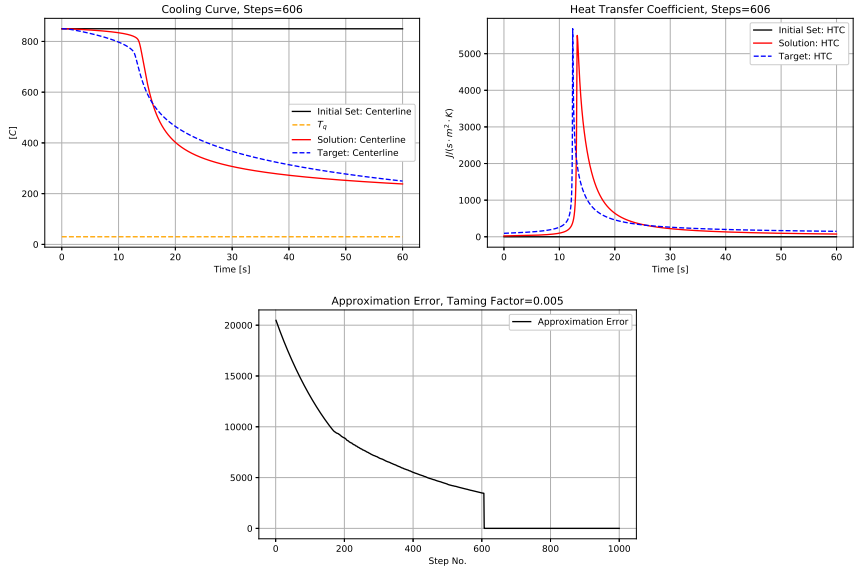

Figure 9
The operation of the modified Newton-Raphson algorithm for the problem that does not have exact solution: the lower error-limit was set to 1.0, the maximum step number was set to 1000. The algorithm stopped when further reduction of the error became impossible.

Regarding the computational efficiency of the suggested solution, the running time of the program must be measured. In the case of language Julia, the time need of the 1st execution of the program is not relevant because it contains the time necessary for the compilation of the program. However, the further runs' time need is free of the needs of the "preparatory" activities, and can be considered as a relevant measure of the speed of program execution. For obtaining the results in Fig. 9 approximately $9\,[min]\,22\,[s]$ computational time was necessary for the hardware and

software specified in Section 1.

For further improvement of the numerical approximations it seems to be a plausible way to apply asymmetric format functions. This modification of the format functions only slightly incerases the dimension of the space of the independent parameters. In the next subsection a simple example is considered.

3.3 Application of Asymmetric Format Functions

For this purpose it seems to be a plausible possibility to modify (6) by introducing different power parameters for the "left side" p_{left} and the "right side" p_{right} instead of the common power parameter p as in (10) and (9) as

$$h(T) = h_{max} \begin{cases} \exp\left(-([T - T_{max}]/w_{left})^{p_{left}}\right) & \text{if } T <= T_{max} \\ \exp\left(-([T - T_{max}]/w_{right})^{p_{right}}\right) & \text{if } T > T_{max} \end{cases}, \tag{10}$$

and

$$h(T) = h_{max} \begin{cases} \frac{D}{D+([T-T_{max}]/w_{left})^{p_{left}}} & \text{if } T <= T_{max} \\ \frac{D}{D+([T-T_{max}]/w_{right})^{p_{right}}} & \text{if } T > T_{max} \end{cases}, \tag{11}$$

Further tuning of these parameters increases the dimension of the search space only by 2 that expectedly does not mean significant effect on the complexity of the gradient-based simple approach. Typical function formats are revealed by Fig. 10 for a realizable, and Fig. 11 for an exactly not realizable case. The relaxation of the tracking error is described in Fig. 12.

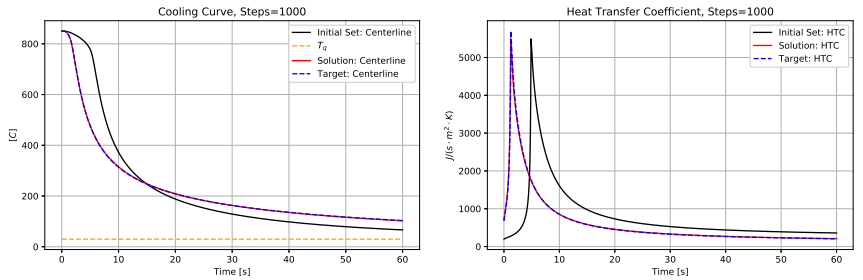

Figure 10
The operation of the modified Newton-Raphson algorithm for the problem having exact solution for asymmetric constant "tail property parameters" $p_{left} = 1.5$ and $p_{right} = 1.0$ in (10): the lower error-limit was set to 1.0, the maximum step number was set to 1000. The algorithm stopped when further reduction of the error became impossible.

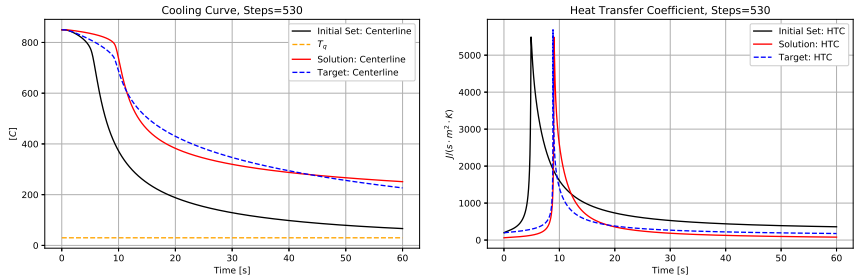

Figure 11
The operation of the modified Newton-Raphson algorithm for the problem that does not have exact solution for asymmetric constant "tail property parameters" $p_{left} = 1.5$ and $p_{right} = 1.0$ in (10) and (11): the lower error-limit was set to 1.0, the maximum step number was set to 1000. The algorithm stopped when further reduction of the error became impossible.

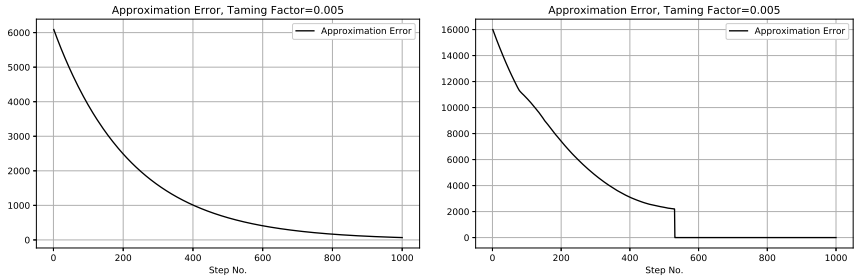

Figure 12
The error reduction during the application of the modified Newton-Raphson algorithm for asymmetric constant "tail property parameters" $p_{left} = 1.5$ and $p_{right} = 1.0$ in (10): the lower error-limit was set to 1.0, the maximum step number was set to 1000. (The algorithm stopped when further reduction of the error became impossible.) LHS: for the problem having exact solution (belonging to Fig. 10), RHS: for the problem not having exact solution (belonging to Fig. 11)

4 Conclusions

In this paper a simple computational method was suggested for the approximate determination of the HTC vs. time function from the cooling curve in the centerline of the cylindrical Inconel 600 probe recommended in the standard ISO 9950. In the applied approach "long cylinder" was considered that made it possible to use a single dimensional heat conduction equation by utilizing the cylindrical symmetry of the problem.

The main point of the approximation and problem simplification was the assumption that instead of an explicit function of the time the HTC distribution depends on the surface temperature distribution for which a simple single variable $HTC(T)$ function was introduced that contained only 4 "format parameters". The problem mathematically was formulated as a simple optimization task in which the 4 dimensional input space a scalar error function was minimized by an algorithm that corre-

sponds to a "transition" between the "Gradient Descent" and the "Newton-Raphson Algorithm". For checking the computational needs and speed of the method a fast language, the Julia was chosen for implementation that is almost as fast as a standard C code.

It was found that the problem was manageable with the given software and hardware combination. The method contains a single parameter that "tames" the originally rough steps of the Newton-Raphson algorithm and allows various compromises between the precision and computational time.

Further possibility is that instead of the scalar error $E(x)$ its gradient $\nabla E(x)$ can be driven to zero by a fixed point iteration that works on the basis of Stefan Banach's Fixed Point Theorem [32] that was already applied in "Optimal Control" or "Model Predictive Control" e.g. in [33, 34]. The expected advantage could be that while the conditions $E(x_{min}) = 0$ in the minimum cannot be generally met, therefore Newton-Raphson algorithm can stop before reaching the absolute minimum, in it $\nabla E(x_{min}) = 0$ can be taken for granted, and no "stopping problems" have to be considered. Furthermore, by the introduction of format parameters depending on the "hight" of the location cylindrical samples of finite length can be considered in the numerically treatable range.

Acknowledgement
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Thermovoltaic Effect in a Multilayer Junction Structure with an Oxide Insulation Barrier

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Abstract: The thermovoltaic effect describes the formation of electromotive force (EMF) in the absence of an external temperature gradient (in contrast to the conventional Seebeck phenomenon, which requires the creation of a temperature gradient between two semiconductor or metal connectors). In the presented research, the structure of a microgenerator using a thermovoltaic effect was proposed, in which the transport of hot electrons through an oxide insulating barrier lead to the accumulation of charge carriers and the formation of inter-layer potential. The microgenerator structures were fabricated in a multi-stage magnetron sputtering process. Planar structures were fabricated, consisting of thin layers of heavily doped degenerate semiconductor (SiC:Zr:B, Ge:Au, Ge:Ta:V, TiO_2:Nb) with a silicon dioxide (SiO_2) insulation barrier and a second silicon-metal based electrode (Ta, Mo, NiCr). The thermovoltaic effect was observed in all of the structures, and the value of the generated electromotive force (thermovoltaic voltage) and the value of effective power was determined. The presented preliminary results show that the concept of constructing of asymmetric multi-layer junction structures can be used to fabricate microgenerators using a thermovoltaic effect.

Keywords: degenerated semiconductor; insulating barrier; thermovoltaic effect

1 Introduction

In recent years, energy harvesting has become an important issue, both on a micro- and macro scale. The aim of such studies is to transform the energy available in the ambient into useable electrical energy based on various physical phenomena. For example, the thermoelectric phenomena or the photovoltaic effect are well known and used on the industrial scale. Much less information concerns the thermovoltaic effect presented in this article. It permits for the direct conversion of thermal energy into electricity, but unlike the conventional Seebeck effect, the electromotive force is generated here without the presence of the temperature gradient.

In general, in a thermovoltaic phenomenon, voltage generation occurs without the need to produce an external temperature gradient in the structure, only during uniform heating of the structure. For the first time, this effect was observed in a polycrystalline sample of samarium sulphide (SmS) [1, 2]. In this structure, the generation of electromotive force resulted directly from the artificial creation of a gradient of excess samarium ions in a parallelepipedal SmS polycrystalline sample. Subsequently, thermovoltaic effect was discovered in other materials – SmS-based heterostructures [3], ZnO-based compositions [4, 5] as well as Si- and Ge-based structures [6].

In the classic linear transport regime there is a fundamental difference between a large value Seebeck coefficient and high electrical conductivity for electrical materials conductive and many multilayer structures due to the interaction between electron density of states (DOS) and the speed of electron groups, and also due to shape of the energy distribution curve. It is known that low-dimensional structures change the density of states. For high barrier height and high doping concentration, semiconductor heat energy converters would be able to reduce this effect, thus achieving a high thermoelectric power efficiency-factor.

To obtain this effect there cannot be saved electron transverse momentum perpendicular to heterostructural barriers. This can be achieved using non-flat structures or embedded nanostructures. A comparison of thermoelectric devices and thermoelectric energy converters shows a difference in the average energy of emitted hot carriers due to the difference between the density of electron and photon states in the tested material. The use of both electrons and photons from the hot reservoir part or state density engineering can provide additional conditioning for achieving higher performance in energy conversion devices and further approaching the limit obtained by entropy generation.

The introduction of potential barriers in highly doped semiconductors or metals can increase the asymmetry between cold and hot electron transport, which could eliminate conventional optimization between electrical conductivity and the Seebeck coefficient. It is considered that not all hot electrons with energy greater than barrier height are transported above the barrier. Because of the electron states in space momentum at planar barriers, only electrons with kinetic energy higher than the threshold value can be emitted perpendicular to the barrier (Fig. 1). In the case of a planar barrier, hot electrons moving under a large one angle to the interface are completely reflected internally.

The conservation of the transverse momentum results from the symmetry of the system from the invariability of translation in a direction perpendicular to the barrier layers. By using non-flat barriers or embedded nanostructures, this symmetry can be broken.

A further beneficial technological activity in the construction of the produced layer would be breaking the symmetry without a significant reduction of the electron mean free path and mobility of electrons in the structure.

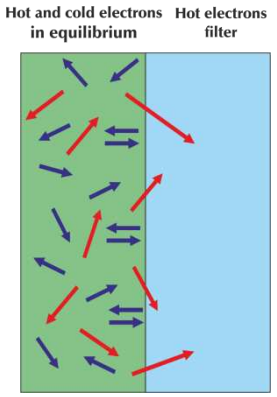

Figure 1
Graphic diagram of hot and cold electrons in equilibrium

For this purpose, high crystallinity is required close to the interface with low defect density. This is achieved by using, for example, embedded nanoparticles. If a transverse momentum block is formed, not only is the significant reduction in the number of electrons emitted, but also energy filtering is not rapid even with thick barriers. There is also a major compromise between the electron density of states and the speed of electron groups in crystalline solids. This is manifested in the fact that solids with a high effective mass of electrons have a high density of states, but at the same time have lower mobility. The electron velocity group is related to the derivative of the dispersion dependence (electron energy concerning its momentum), while the state density is related to the inverse of the energy band curvature. The shape of the density of states dominates in thermoelectric and thermonic devices and materials with heavy effective electron masses and many valleys high potentials at high temperatures.

In the presented research, the structure of a microgenerator using a thermovoltaic effect was proposed, in which the transport of hot electrons through an oxide insulating barrier lead to the accumulation of charge carriers and the formation of inter-layer potential. The design of the generators based on the thermovoltaic effect allowed for the generation of electric voltage without the need to create a temperature gradient in the structure. The first work on thin-film generators showed so promising results that it may be concluded that it is possible to build miniature energy generators using an effect other than the classic approach based on the Seebeck effect. Not requiring a temperature difference in the structure significantly simplifies the design of generator systems. The issues related to thermodynamics can thus be narrowed down to homogeneous annealing of the entire structure using a simple heating element and removing heat from the structure.

The presented research is the result of an experiment on real structures fabricated in multi-stage technological processes. The generator design was proposed based on own previous studies of thin-film thermoelectric elements and the general concept of microgenerators' fabrication.

The paper is organized as follows. The analysis of the literature in the field was presented in the Introduction. The materials, technology and general construction of investigated multilayered thermovoltaic microgenerators are described in Chapter 2. The setup for measurement of electromotive force for structures homogeneously heated from ambient temperature up to about 573 K is given in Chapter 3. The electrical properties, expressed by experimental characteristics and fitting curves of electromotive force and effective power vs isothermal temperature of multilayer thermovoltaic microgenerator, are shown in Chapter 4. The conclusions are pointed out in Chapter 5.

2 Multilayered Thermovoltaic Generator

Based on the above considerations, a microgenerator was fabricated using a ballistic passage of hot electrons through the insulation barrier. This transition causes the accumulation of charge and the emergence of inter-layer potential. Several planar structures were made, fabricated of a thin-film multilayer of a degenerated semiconductor with an oxide nanobarrier and a second layer based on selected metal silicide. Highly doped semiconductors such as SiC:Zr:B, Ge:Au, Ge:Ta:V, or TiO_2:Nb were used as an active material. One should add that previously SiC:Zr:B films were tested as NTC thermistors [7] whereas Ge:Au, Ge:Ta:V and TiO_2:Nb – as thermoelectric materials [8, 9]. The second electrode was made as to metal silicide – one of Ta, Mo and NiCr. The scheme of construction of a multilayer double junction thermovoltaic microgenerator is shown in Fig. 2.

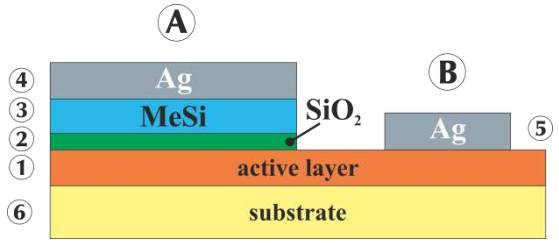

Figure 2

Scheme of construction of a multilayer double junction thermovoltaic microgenerator (**thermocouple A:** 1 - thin film semiconductive active layer, 2 - oxide barrier, 3 - buffer layer MeSi, 4 – Ag contact layer; **thermocouple B:** 1 - thin film semiconductive active layer, 5 - Ag contact layer)

All thin films used for the construction of the microgenerators' active area were produced in energetically sublime magnetron sputtering processes using the Pfeiffer Classic 570 vacuum system with WMK-100 magnetrons. Thin layers were deposited onto high temperature (573 K) Corning 7059 glass substrates. Films were fabricated with the use of alloy or mosaic targets or in a co-sputtering process with the use of two different targets onto two magnetrons. Besides, magnetron sputtering processes were carried out under conditions of minimal pressure, conditioned by the specificity of the plasma process. Thin layers were applied in an argon atmosphere (except for layers TiO_2:Nb, applied in an argon-oxygen atmosphere), while maintaining a constant operating pressure $p \leq 10^{-3}$ Tr, which allowed to obtain anode-cathode discharge voltage with a voltage above 680 V. Such conditions of the plasma process determined the appropriate energy conditions for structures punched from the target surface and forming a thin semiconductor layer.

The active layers were characterized by a polycrystalline structure with a high degree of microstructure organization and the thickness in a range of 0.4-4 μm. Besides, they showed the dominant type of electrical conductivity (hole or electron) depending on the magnetron sputtering conditions and dopant used. What's more, it was confirmed that by choosing the right concentration of dopant material and the post-process treatment, it is possible to optimize the electrical properties of thin active layers and their subsequent power efficiency. After deposition, semiconductor active layers were annealed at 573 K in air.

To form the microgenerator structure, on the surface of the active semiconductive layer, a silicide ($TaSi_2$, $MoSi_2$, NiCrSi) layer was also applied in the magnetron sputtering process. Silicon-metal targets were used to make the silicide films, which were characterized by thicknesses in the range of 4-6 μm.

During the deposition of silicide, a nanometric layer of silicon dioxide occurred spontaneously on the border between the active layer of the semiconductor and the silicide layer. It is worth to briefly explain the mechanism of this insulation layer formation. It is known that a silicon dioxide layer is formed on the surface of metal silicides in an oxygen atmosphere [10, 11]. During the thermal post-process treatment of the active layer, a semiconductor oxide layer is formed on its surface [12]. In this way, oxygen appears in the area between semiconductor and silicide, which is then supplied to produce silicon dioxide (Fig. 3).

Silver electrodes were applied to the semiconductor and silicide layers to make electrical contacts. The electrodes were prepared in the thermal evaporation process.

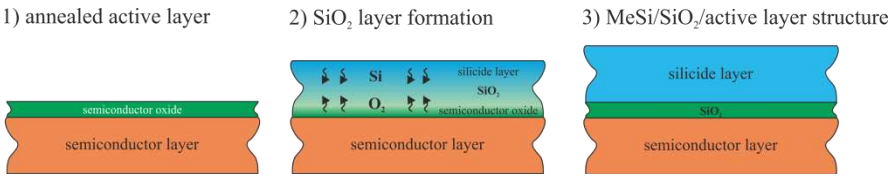

Figure 3
Mechanism of insulating oxide barrier formation

In the proposed construction of a multilayer two-junction microgenerator the junctions, in contrast to the classic thermocouple, were placed at a mutual distance of less than 1 mm. The total area of the microgenerator did not exceed 0.25 cm^2, including the area of thermocouples, which was 2 mm^2 and 1 mm^2 for thermocouple A and B, respectively.

3 Measurement Setup

Test measurements of the fabricated microgenerators were carried out under the conditions of isothermal heating of structures, and to compare thermoelectric properties – also with gradient heating of the structure. To maintain isothermal conditions, the surface of the heated plate was around 20 cm^2 i.e. much more than the total surface of the microgenerator. Symmetrical probes and electrical connections (Ag or CuSnP) were used to the peripheral measuring system. Measurements of electrical properties were carried out in open circuit conditions – loading microgenerators with the input resistance of the Fluke 8846A multimeter voltmeter, and the current-voltage characteristics at the generator load with variable resistance. Current efficiency measurements were carried out at a constant generator load with a resistance value of R = 1 Ω. All of the measurements were made without the use of external power sources, treating the microgenerator as a current-voltage source of the measuring system. The microgenerator structure is shown in Fig. 4.

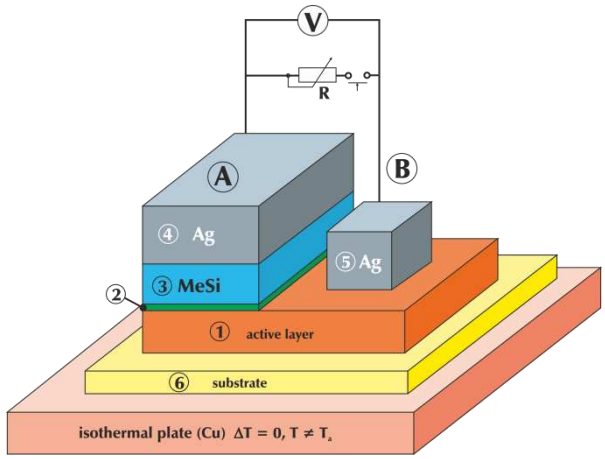

Figure 4

Scheme of construction of a multilayer double junction thermovoltaic microgenerator (in a test setup to measure thermovoltaic properties) (**thermocouple A:** 1 - thin film semiconductive active layer, 2 - oxide barrier, 3 - buffer layer MeSi, 4 - Ag contact layer: **thermocouple B:** 1 - thin film semiconductive active layer, 5 - Ag contact layer).

4 Electrical and Thermoelectric Properties

To compare the tested structures with each other, the effective power P_e was defined, i.e. the product of the short-circuit current I and the electromotive force EMF of the open circuit concerning the active surface A occupied by the thermocouple (Equation 1).

$$P_e = \frac{EMF \cdot I}{A} \tag{1}$$

For all of the tested microgenerators the electromotive force (or thermovoltaic voltage) was determined in the temperature range from 323 K to 553 K. The effective power P_e was determined for all generators, except for the structure with the TiO_2:Nb active layer, for which, on the other hand, the EMF_{TE} value generated as a result of the classic Seebeck effect (with the external temperature gradient) was compared with the value of the thermovoltaic voltage EMF_{TV}.

It was assumed that linear function describes the dependence of electromotive force vs temperature of microgenerator (formally similar as for Seebeck effect, but one should remember that in thermovoltaic effect we have a temperature of the whole structure whereas for Seebeck effect we have a temperature gradient between hot and cold junctions) and exponential function describe effective power

vs temperature. Due to the lack of a commonly accepted physical model of the thermovoltaic phenomenon, it is impossible to apply an advanced model (shown eg. in [13-15]) for the approximation of experimental characteristics.

4.1 Ge:Au Active Layer

Ge:Au active thin films, with a thickness of approximately 1.63 µm, were fabricated from the germanium-gold alloy target with 5 wt% of Au. The resistivity of Ge:Au films were measured by the four-probe method and was around 0.059 Ωcm. Figure 5 presents the relationship between the electromotive force EMF_{TV} generated in an Ag/Ge:Au/SiO2/NiCrSi/Ag structure after uniform heating it to the temperature T. The generated force increased with increasing structure's temperature, reaching the highest value $EMF_{Ge:Au}$ = 8.22 mV for T = 550 K.

The dependence of effective power P_e on the temperature for microgenerator with Ge:Au active film was determined as well (Fig. 6). The P_e value increased with increasing structure temperature was with the maximum value of 61.53 µW/cm^2 at 500 K.

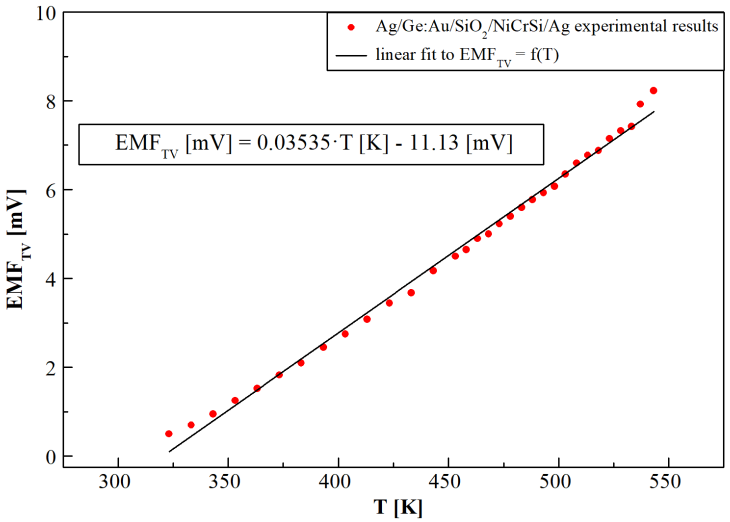

Figure 5
Dependence of electromotive force EMF_{TV} (thermovoltaic voltage) on the temperature of the microgenerator with Ag/Ge:Au/SiO_2/NiCrSi/Ag structure

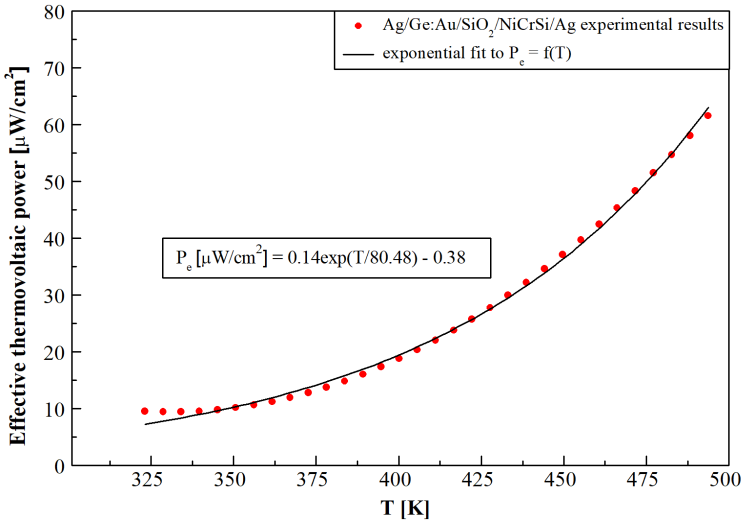

Figure 6
Dependence of effective power P_e on the temperature of the microgenerator with Ag/Ge:Au/SiO_2/NiCrSi/Ag structure

4.2 Ge:Ta:V Active Layer

The Ge:Ta:V target was made from the germanium-tantalum alloy target. Composition with vanadium was achieved by partially covering the Ge:Ta target surface with triangular-shaped tantalum pieces. The composition of Ge:Ta:V films, measured by EDS-XRD microscopy, was 88 at.% Ge, 9.5 at.% V, and 2.5 at.% Ta. The thickness of Ge:Ta:V films was about 2.1 μm and the resistivity measured by the four-probe method and was around $6.5 \cdot 10^{-3}$ Ωcm. Figure 7 presents the relationship between the electromotive force EMF_{TV} generated in an Ag/Ge:Ta:V/SiO_2/NiCrSi/Ag structure after uniform heating it to the temperature T. The generated force increased with increasing structure's temperature, reaching the highest value $EMF_{Ge:Ta:V}$ = 3.50 mV for T = 550 K.

The dependence of effective power P_e on the temperature of a microgenerator with Ge:Ta:V active film was determined as well (Fig. 8). The P_e value was also higher for the higher structure temperature, with the maximum value of 170 μW/cm^2 at 550 K.

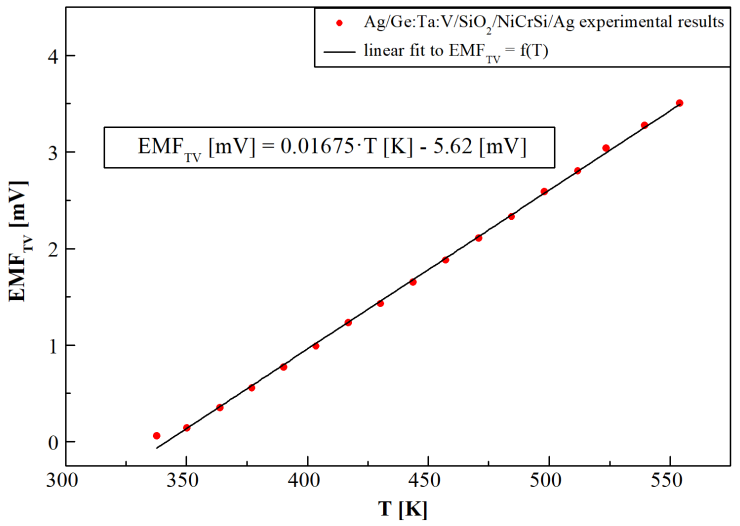

Figure 7

Dependence of electromotive force EMF_{TV} (thermovoltaic voltage) on the temperature of the microgenerator with Ag/Ge:Ta:V/SiO_2/NiCrSi/Ag structure

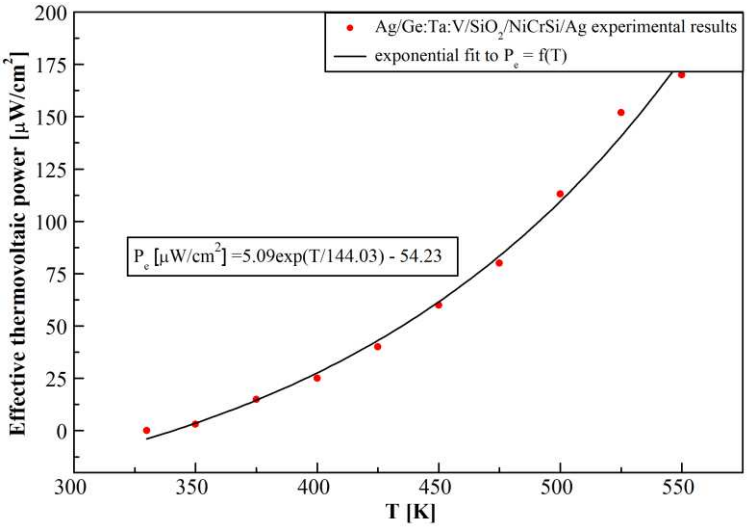

Figure 8

Dependence of effective power P_e on the temperature of the microgenerator with Ag/Ge:Ta:V/SiO_2/NiCrSi/Ag structure

4.3 SiC:Zr:B Active Layer

SiC:Zr:B active thin films were fabricated in the co-sputtering process. After the process $SiCZr_{0.07}:B_{0.12}$ layer was received. The thickness of films was approximately 4.05 µm and they were characterized by resistivity $\rho_{SiC:Zr:B}$ = 0.04 Ωcm (measured by four-probe method). Figure 9 presents the relationship between the electromotive force EMF_{TV} generated for Ag/SiC:Zr:B/SiO_2/NiCrSi/Ag structure after uniform heating it to the temperature T. The generated force increased with increasing structure's temperature, reaching the highest value $EMF_{SiC:Zr:B}$ = 4.18 mV for T = 550 K.

The dependence of effective power P_e on the temperature of a microgenerator with SiC:Zr:B active film was determined as well (Fig. 10). The higher the P_e value, the higher the structure temperature was, with the maximum value of 380 µW/cm^2 at 550 K, and it was the highest among all tested structures.

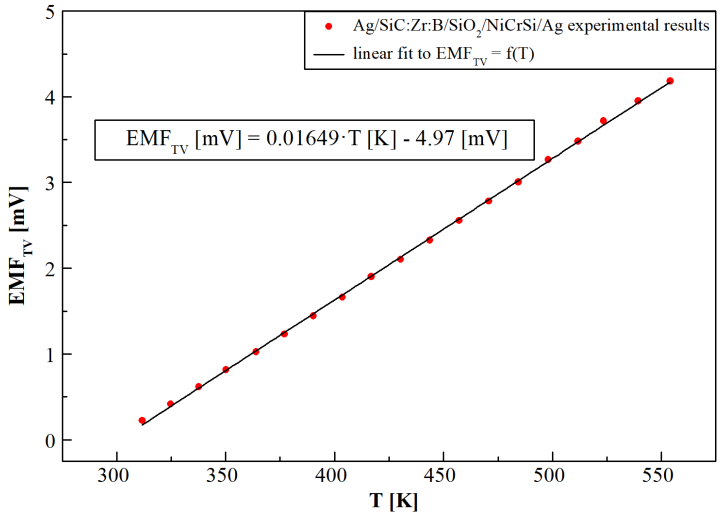

Figure 9

Dependence of electromotive force EMF_{TV} (thermovoltaic voltage) on the temperature of the microgenerator with Ag/SiC:Zr:B/SiO_2/NiCrSi/Ag structure

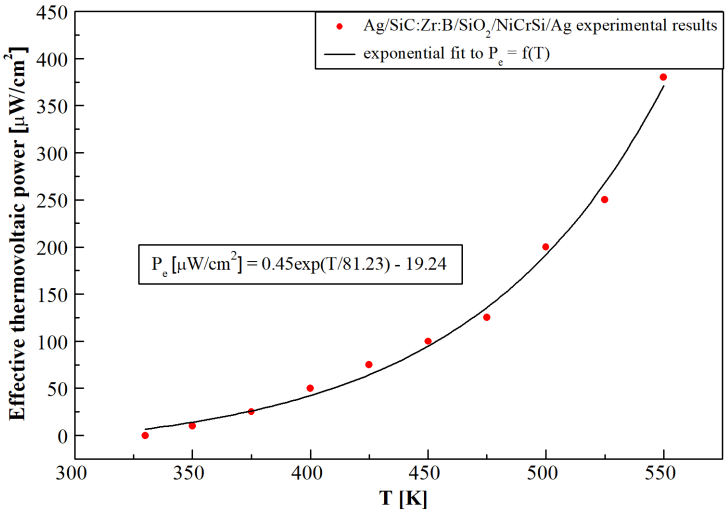

Figure 10
Dependence of effective power P_e on the temperature of the microgenerator with Ag/SiC:Zr:B/SiO_2/NiCrSi/Ag structure

4.4 TiO_2:Nb Active Layer

TiO_2:Nb active thin films were fabricated from the TiO_2:Nb mosaic target (5 at.% Nb in TiO_2). The thickness of active films were approximately 0.38 μm, and the resistivity of TiO_2:Nb films was around $2.47 \cdot 10^{-3}$ Ωcm (measured by four-probe method).

For microgenerator with a TiO_2:Nb active layer, it was examined whether there was a difference between the value of the electromotive force generated in the structure between the classic Seebeck effect and the thermovoltaic effect (Fig. 11). It has been shown that the generated electromotive force *EMF* assumes similar values in both cases – both when measuring the structure in which the temperature gradient (EMF_{TE}) was created and when measuring the uniformly heated structure (EMF_{TV}).

One should notice that similarly designed Pt silicide/silicon multilayer structured device with 3 to 12 PtSi/Si heterojunctions (i.e. without oxide insulation layer) exhibited classic Seebeck effect [16] and was used for fabrication of 3D thermoelectric energy generator consisting of 127 pairs of such legs [17].

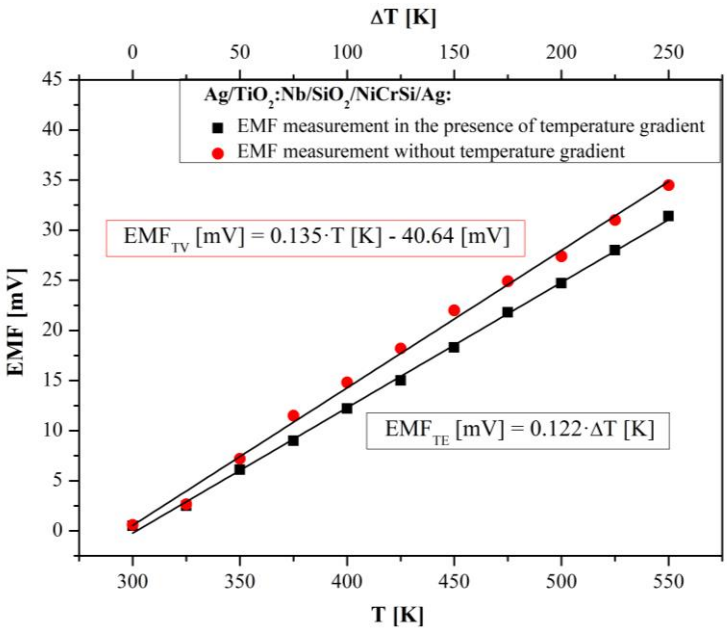

Figure 11

Dependence of electromotive force *EMF* (thermovoltaic or thermoelectric voltage) on the temperature *T* of the microgenerator with Ag/TiO_2:Nb/SiO_2/NiCrSi/Ag (thermovoltaic effect) and on the temperature gradient *ΔT* created between thermocouple joints (conventional Seebeck effect)

5 Results and Discussion

Using technological processes based on high-energy and low-pressure magnetron sputtering, it is possible to obtain functional thin semiconductive films with ordered structure and desired electrical and thermoelectric properties.

The generation of thermovoltaic voltage was observed both for semiconductor layers with large (TiO_2:Nb) and small (Ge:Au) bandgap. The EMF_{TV} value depended only on the type of conductivity obtained in the semiconductor layer. The highest value of effective power was obtained for the Ag/SiC:Zr:B/SiO_2/NiCrSi/Ag structures. It was several μW/cm^2 at ambient temperature and increased exponentially to around 200 μW/cm^2 at 500 K. About half the smaller effective power values were obtained for microgenerators with a Ge:Ta:V active layer – from several μW/cm^2 at ambient temperature to 113 μW/cm^2 at 500 K. Such measurements can lead to the conclusion that obtaining higher effective power values is possible for multi-component compounds (in this case ternary) of highly degenerated semiconductors. What's important, the high

values of effective power were obtained both for the microgenerators with active layers with *n*-type (SiC:Zr:B) and *p*-type (Ge:Ta:V) electrical conductivity.

What's interesting, a similar *EMF* value was measured for the structures, in which the temperature gradient was created (classic Seebeck effect) and the structures uniformly heated on an isothermal plate (thermovoltaic effect). However, for possible applications, operation without the need for the creation of an artificial temperature gradient in the structure should allow for increased thermovoltaic power, larger efficiency, and elimination of heating elements in the system. Such thermovoltaic microgenerators require only one heating element, which limits the number of elements in the system, reduces the number of heat sinks that remove heat from the generator, and significantly affects the simplicity of mounting microgenerators in the systems with which they are to cooperate. The use of the classic Seebeck effect makes it necessary to linearly lengthen the structure between thermal joints and optimize the thermal and energy properties of the structure that affect the power efficiency of the thermogenerator. On the other hand, thermovoltaic microgenerators are made in the form of thin-film multilayers, which affects the degree of complexity of the technological process leading to their implementation. As shown in the article, the desired electrical and thermoelectric properties can be obtained only for structures made in high-energy and low-pressure magnetron sputtering processes.

Conclusions

The designs of several microgenerators utilizing the thermovoltaic effect – the generation of electromotive force EMF_{TV} in the absence of a temperature gradient in the structure, and only under conditions of its homogeneous heating, have been described. The proposed microgenerators were fabricated in the form of thin-film multilayer structures, sputtered in the process of low-pressure and high-energy magnetron sputtering. The microgenerators differed in the active layer material – SiC:Zr:B, Ge:Au, Ge:Ta:V, TiO_2:Nb thin films were used. All microgenerators enabled the generation of electromotive force with values in the range from several to several dozen mV – changing with the temperature of the structure. The proposed concept and the constructed structures constitute a new contribution to the group of research focused on the generation of electricity in miniature structures. The use of the thermovoltaic effect is a new, another approach to building generators.

Acknowledgment

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A Multilingual Handwritten Character Dataset: T-H-E Dataset

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Abstract: The absence of handwritten special Latin character datasets prompted the creation of the T-H-E Dataset (Turkish-Hungarian-English handwritten character dataset) contributing to the recognition of multilingual handwritten texts. This paper represents a public-domain dataset including handwritten Turkish, Hungarian and English characters collected from 200 participants. The T-H-E Dataset is formed from 78 different letters represented in 156000 binary characters including both the upper and lower-case versions. The dataset can be downloaded from the web in six different versions enabling users to combine the different alphabets for different recognition purposes. The evaluation of the dataset is carried out by applying the same deep learning architecture on the T-H-E dataset and the EMNIST dataset. The dataset is publicly available at https://github.com/bartosgaye/thedataset.

Keywords: public dataset; handwritten character dataset; offline character recognition; OCR, multilingual

1 Introduction

Handwritten text datasets can be found in several forms, such as, full-page handwritten images, handwritten sentences, handwritten words and handwritten individual characters. However, the majority of the available datasets focus on a single language ignoring the existence of multilingual texts. As a result of globalization, multilingual handwritten texts are increasingly generated. By raising the number of multilingual datasets, the success on the single language

handwriting recognition could similarly be achieved for multilingual handwritten texts. It is worth mentioning that offline handwriting recognition, of a single language, remains an unresolved problem, since there is no standard form in handwriting, unlike in print documents. Despite the available datasets for English characters, recognition of offline handwriting remains a challenge for several languages, such as, Turkish and Hungarian. In the case of Turkish, some researchers used datasets of their own which are not publicly available [1]–[5]. In order to be able to develope algorithms which deliver solid performance on handwritings with puncuations, handwritten character datasets on alphabets including a high number of punctuations are needed. In this paper we present a freely available character dataset consisting of 78 classes (Table 1) referring to 52 classes for English characters (26 upper-case+ 26 lower-case), 8 classes for special Turkish characters (4 upper-case+ 4 lower-case), 4 classes for Turkish and Hungarian joint characters (2 upper-case+ 2 lower-case) and 14 classes for special Hungarian characters (7 upper-case+ 7 lower-case) [5]. The two main reasons behind creating such dataset are lack of offline datasets for recognition of languages with special characters such as Turkish and Hungarian and secondly contributing to the existing Latin character datasets with a variety of handwritings collected from Hungarian and Turkish citizens. In addition to those motives, the proposed dataset offers an easier platform for designing multilingual unified recognition systems.

Handwritings collected from merely Turkish citizens mostly contain texts which are written using discrete characters only whereas texts written by Hungarians mainly consist of cursive characters. Gathering handwritings from both nations give the diversity to the dataset and such feature is believed to provide a positive impact on the classification process. In the next section, the earlier offline handwritten English character datasets and multilingual recognition systems are going to be represented.

2 Related Works

In machine learning, having access to right data in right format allows the researchers to develop, advance and assess their learning techniques. Therefore, regardless of the language of the handwriting, the condition and amount of the input data plays a crucial part in the performance of any handwriting recognition system. In this paper, we present a digitized, preprocessed, and labeled image dataset which consists of handwritten letters from three different languages. In the literature, handwritten character datasets can be found for several languages however, when it comes to multilingual handwritten character datasets, not many can be found. In order to be able to establish a multilingual recognition system, researchers either merge single language character/word datasets or adopt existing

multilingual word datasets. The examples of multilingual handwriting recognition systems are presented in the following section. The majority of the studies focus on the recognition of English and French, due to the fact that there are existing datasets for those languages. In 2012, Wshah et al. used the IAM dataset [6] for English, the AMA dataset for Arabic [7] and the LAW dataset for Devanagari [8] together with a synthetic dataset in order to evaluate the proposed multilingual word spotting system [9]. Kozielski et al. carried out a study on recognizing real-world handwritten images in English and French in 2014 [10]. IAM, RIMES and Maurdor datasets [11] were used to train and evaluate their multilingual system. Bluche and Messina proposed a multilingual handwriting recognition system which was trained on datasets in English, French, Spanish, Portuguese, German, Italian and Russian in 2017 [12]. They used IAM, RIMES [13] and Maurdor datasets alongside with private collections they collected for those languages without available public or private datasets to evaluate their model. Lately in 2019, Swaileh et al. proposed a unified multilingual handwriting recognition system which was trained and evaluated using IAM and RIMES datasets for English and French respectively [14].

The abovementioned studies are all carried out on a combination of word or document based datasets in different languages. The following section puts forward the most popular offline English handwritten character datasets. One of the earliest handwritten Latin character dataset, the CEDAR dataset, dates back to 1994, it consists of both handwritten words, such as, city names and postal codes and characters containing separated letters and numbers [15]. The separated letters and characters were put into 62 classes (26 upper-case+ 26 lower-case+ 10 digits) consisting of approximately 50000 samples. A year later, in 1995, the NIST Special Dataset 19 Hand printed Forms and character dataset was published containing full page binary image of handwritten forms and also characters (digits and letters) segmented from those forms (128x128). In the NIST dataset there are 62 labelled classes for digits '0-9', characters 'a-z' and 'A-Z'. Later in 1998, MNIST (Modified-NIST) dataset was created containing only digits (70000 samples) and it became a benchmark for digit recognition purposes [16]. In 2016, the 2nd version of the NIST dataset was published with full page binary images of 3699 handwritten sample forms and 814255 sample digits and characters of the same 62 classes [17]. It is possible to say that NIST dataset has become a benchmark for character recognition problem. Finally in 2017, EMNIST dataset, an extension of the MNIST dataset was published [18], [19]. EMNIST dataset is superior to its previous versions by many features such as number of instances, the balanced representation of characters, grayscale representation and the variety of classes provided. It contains 814255 samples of letters and digits (28x28). In addition to NIST and MNIST, EMNIST not only provides two class hierarchies namely By Class (every character into a different class with a different label) and By Merge (similar characters into the same class with the same label) but also provide four more options namely: balanced dataset which is easy to apply due to its balanced subset of all the By Merge classes; letters dataset generated to

increase the number of errors occurring from case confusion by merging all of the uppercase and lowercase classes, to form a balanced 26-class classification task; digits dataset being a balanced subset of the digits dataset containing 28000 samples of each digit and a copy of MNIST dataset. Fig. 1 below shows the distribution of the different letters in the EMNIST By Class dataset.

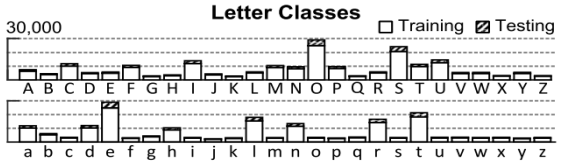

Figure 1
Representation of the letters in the EMNIST By Class dataset [18]

Finally in 2006, distinctly from previous datasets, a cursive character dataset C-Cube (Cursive Character Challenge) came out [20]. The C-Cube dataset includes 57293 characters including 26 upper and 26 lower case versions of each Latin letter. In our previous works, we adopted C-Cube data set after changing the way data was represented in the original dataset [21].

3 T-H-E Dataset

The T-H-E Dataset includes handwritten letters from multiple alphabets, namely from English (ISO Basic Latin Alphabet), Turkish and Hungarian. However, since the dataset includes many Latin characters, it is very easy for other researchers to modify the data set for their needs (add/ remove special characters) and use it as a whole. The characters included in the dataset are presented in Table 1 below.

Table 1
Characters in the T-H-E Dataset

	Lower case	Number of instances	Upper case	Number of instances
English Characters	a	2000	A	2000
	b	2000	B	2000
	c	2000	C	2000
	d	2000	D	2000
	e	2000	E	2000
	f	2000	F	2000
	g	2000	G	2000
	h	2000	H	2000
	i	2000	I	2000

	j	2000	J	2000
	k	2000	K	2000
	l	2000	L	2000
	m	2000	M	2000
	n	2000	N	2000
	o	2000	O	2000
	p	2000	P	2000
	q	2000	Q	2000
	r	2000	R	2000
	s	2000	S	2000
	t	2000	T	2000
	u	2000	U	2000
	v	2000	V	2000
	w	2000	W	2000
	x	2000	X	2000
	y	2000	Y	2000
	z	2000	Z	2000
Turkish Special Characters	ç	2000	Ç	2000
	ğ	2000	Ğ	2000
	ı	2000	İ	2000
	ş	2000	Ş	2000
Turkish and Hungarian Joint Characters	ö	2000	Ö	2000
	ü	2000	Ü	2000
Hungarian Special Characters	á	2000	Á	2000
	é	2000	É	2000
	í	2000	Í	2000
	ó	2000	Ó	2000
	ő	2000	Ő	2000
	ú	2000	Ú	2000
	ű	2000	Ű	2000
Total Number of Characters	**39**	**78000**	**39**	**78000**

In order to generate the dataset, handwriting samples were collected, in an ethical way, from 200 participants who predominantly were at that time, high school and university students (Turkish and Hungarian citizens mixed), in a controlled environment. The participants were given a blank white paper and were asked to write the given text in their native language in their own handwriting. It can be said that there was less noise found in the images, since the paper used was new and blank. Then, the papers were scanned at 300 DPI. Subsequently, the images were thickened using morphological thickening provided by the MATLAB 9.3 environment [22] and line, word and character segmentation was performed [23]. These steps usually include a noise removal step, in order to get rid of the noise

occurring in the scanned documents. However, the noise removal step was skipped in order to maintain every accent and punctuation in the images. The character segmentation phase includes several processes, namely, separating each character, getting rid of the white space around each character and binarization of the character, using Otsu's Algorithm [24]. Finally, every character is normalized to a 28x28 pixel shape. A representation of the sample characters, after the normalization step, can be found in Fig. 2.

Figure 2
Sample Characters from the T-H-E Dataset

3.1. Structure of the Dataset

Including characters from several alphabets, the T-H-E dataset is established in six versions, to provide for ease of use and flexibility when switching between alphabets, for different researchers with different approaches. The abovementioned six versions are explained below:

entire_augmented: This version represents the entire dataset. It includes all the 28x28 pixel binary characters from the three alphabets together forming a balanced dataset with 156000 characters belonging to 78 classes (Table 1).

tr_augmented: It consists of merely 12 Turkish special characters (6 upper-case and 6 lower-case). 2000 samples of each character can be found in this version forming a 24000-character dataset.

hu_augmented: Similar to the tr_augmented version, this includes 18 Hungarian special characters only (9 lower-case and 9 upper-case) forming a 36000-character dataset.

en_augmented: The fourth version includes 2000 samples of 52 English characters (26 upper-case and 26 lower-case) forming a 104000-character dataset.

This representation enables us to merge English letters with Hungarian special characters and work only on Hungarian characters by just putting two versions together. A fair warning should be provided about the Turkish alphabet; putting tr_augmented and en_augmented together does not result in the Turkish alphabet since there are no letters 'q', 'w' and 'x' in the Turkish alphabet. The users may want to exclude those 3 letters (3 lower-case and 3-upper-case) from the en_augmented in order to work on Turkish alphabet accurately.

merged_augmented: This version is derived from the entire_augmented version which includes all the characters from different alphabets together. The characters having a similar way of representation in their upper-case and lower-case form are

put into the same class in this version such as lower case ‘o’ and upper case ‘O’. The characters merged are shown in the Table 2 below. In this group there are 55 classes and 156000 samples. However, only in this version are the number of instances, in each class, not balanced. Some classes have 2000 samples, while merged ones, are represented in 4000 samples.

Table 2
Merged Characters

	Merged Classes	Number of Instances		Merged Classes	Number of Instances
1	c- C	4000	13	s-S	4000
2	i-I	4000	14	ş-Ş	4000
3	í- Í	4000	15	u-U	4000
4	ı-İ	4000	16	ú -Ú	4000
5	j-J	4000	17	Ü-Ü	4000
6	k-K	4000	18	ű- Ű	4000
7	m-M	4000	19	v-V	4000
8	o-O	4000	20	w-W	4000
9	ó- Ó	4000	21	x-X	4000
10	Ö-Ö	4000	22	y-Y	4000
11	ő- Ő	4000	23	z-Z	4000
12	p-P	4000			

entire_raw: The original handwritten characters (1000 instances for every 78 classes) are put forward in the sixth version. Using this version, it is possible to experiment different distortion techniques and their impact on the classification performance can be tested. 78000 characters from 78 different classes, can be found in this version.

One important point to be noted is that there are 4 special characters (ü, ö, Ü and Ö) which are used both in Turkish and Hungarian, therefore, they repeat in tr_augmented and hu_augmented versions. Another crucial point was discovered during the handwriting collection process concerning those 4 joint characters. In the Hungarian alphabet, there are two special characters ‘ő’ and ‘ö’ which are apparently represented in one single character ‘ö’ in Turkish alphabet (Similarly, letter ‘ü’ and ‘ű’ are presented as ‘ü’). The shape of the accent over the letter does not make a difference in the Turkish alphabet (based on the handwritings collected), however, they represent two different characters in the Hungarian alphabet. Therefore, it is crucial to understand the differences before carrying out the recognition. In order to avoid confusion, in this dataset, the Turkish and Hungarian joint characters, ‘ö’ and ‘ü’, were carefully segmented by adding only short slanted versions into these classes, by avoiding some of the Turkish participants’ handwritings. Users might want to merge the classes ‘ö’ and ‘ő’ into

one single class, if they are training for a Turkish recognition, instead of just discarding the letter ‘ő’ (the same applies for ‘ü’ and ‘ű’).

3.2. Data Augmentation

Augmenting the input image by applying distortions in order to increase the variance and therefore, performance, is a very common use both in character and text recognition [25]–[27]. Examples of different distortions such as shifting, scaling, skewing, and compression is represented in the popular MNIST dataset.

As represented in the previous section, the T-H-E dataset contains 2000 samples of every character. However, this number includes 1000 original handwritten characters and 1000 generated characters from those 1000 original characters. The number of handwritten characters was increased, by augmenting the existing characters by applying distortions on the original characters.

The augmentations include affine transformations and elastic distortions. Every single handwritten character is distorted randomly once using one of the distortions. If it is desired to have an even larger dataset, the same random distortion algorithm can be run on the original set time after time, generating 78000 randomly distorted character images at every attempt (the source code used for randomly generating images can be downloaded together with the dataset). The distortion methods applied on two different characters can be seen in the Fig. 3 below.

Tilting randomly to the left or right using Piecewise Linear Transformation: tilting right (50% chance) refers to moving the top left corner to the right randomly by 7 to 14 pixels and lowering it randomly by 5 to 12 pixels; tilting left (50% chance) refers to moving the bottom right corner to the left and top randomly by 1.1 to 1.5 times 28. After the tilt operation image is resized to the 28x28 pixel keeping the aspect ratio [28].

Adding Fisheye Effect: This effect was given by applying either barrel (50% chance) or pincushion effect (50% chance) randomly to the original image with a random distortion amount between 0.1 and 0.9 [29].

Rotating: Rotation of the images randomly to the left (50% chance) or right (50% chance) is applied by MATLAB [22]. Rotating to the left and right refers to randomly rotating the input by 5,10,15,20 or 25 degrees then resizing the result to fit the 28x28 matrix.

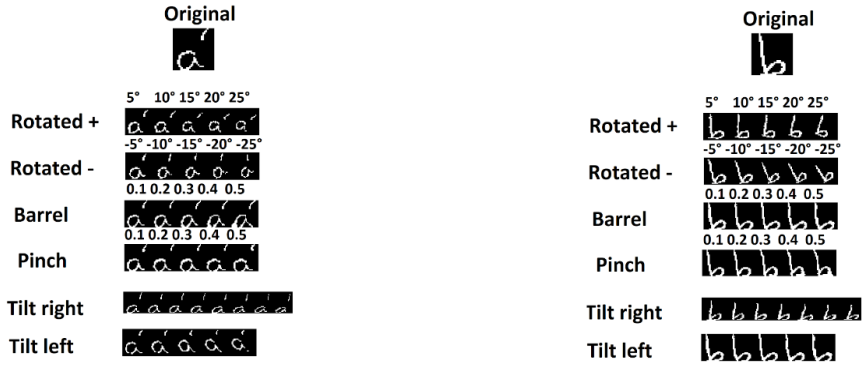

Figure 3
Adopted Distortion Methods Applied to Two Different Characters

3.3. Evaluation of the T-H-E Dataset

Deep learning is subtopic of machine learning that is capable of performing both supervised and unsupervised learning, using a feature, similar to the human brain, which is the ability to grasp patterns and recognize things accordingly [30]. Recent studies propose that deep learning algorithms outperform the traditional machine learning algorithms in the case of image classification since they do not deal with handcrafted features as can be seen in the Fig. 4 [31]–[35].

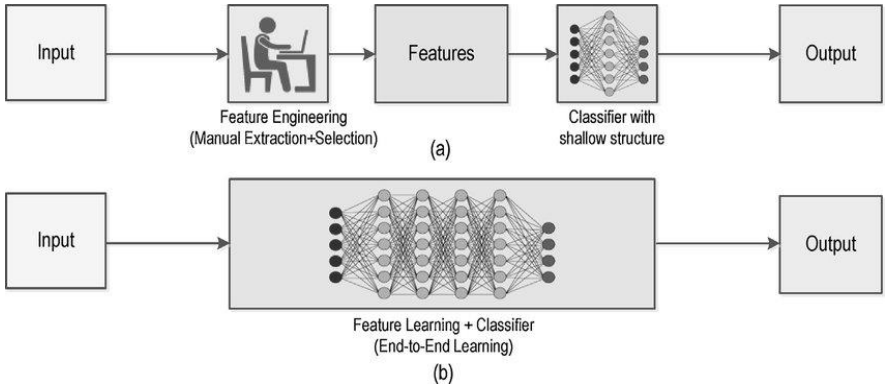

Figure 4
(a) Traditional Machine Learning Workflow vs. (b) Deep Learning Workflow [32]

Deep learning is made of multiple processing layers in order to learn representations of data with multiple levels of abstraction [36]. It is based on a hierarchically layered system, in which, each layer of nodes, is responsible for extracting distinct features using the previous layers' output. The further you go with the layers; the more advanced features can be extracted. In this study, a deep

learning algorithm called Convolutional Neural Networks (CNN) is going to be adopted in order to evaluate the T-H-E dataset [37], [38].

A CNN architecture consists of an input layer, an output layer and hidden layers. An input can be a 1D signal, 2D image or 3D video. Thereafter, the input goes through a serious of hierarchical layers including convolutional layers, pooling layers in order to extract distinct features in the input. Finally, extracted features form the input layer of a Fully Connected MLP at the very end of the architecture for recognition. A brief CNN architecture can be seen in Fig. 5 below.

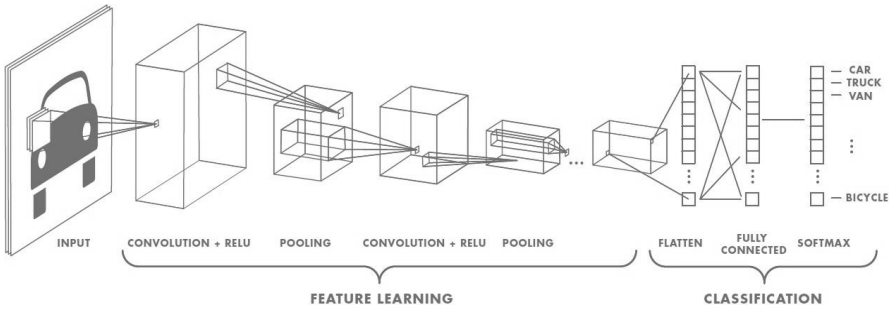

Figure 5

Convolutional Neural Network Architecture [39]

Classic CNN architectures include popular models such as LeNet-5 [16], AlexNet [40], GoogLeNet [41] and VGG [42]. Out of these models, LeNet-5 is the most suitable model for the recognition of images with small input sizes and widely adopted for the field of handwriting recognition [16].

Convolution Layer: In this layer, a convolution filter is applied to the input matrix to generate feature maps as can be seen in Fig. 6. The size of the filter is pre-determined according to the input matrix [43].

Activation Layer (ReLU): ReLU operation replaces all negative pixel values in the feature map by zero [44]. Thus, it allows faster and more effective training.

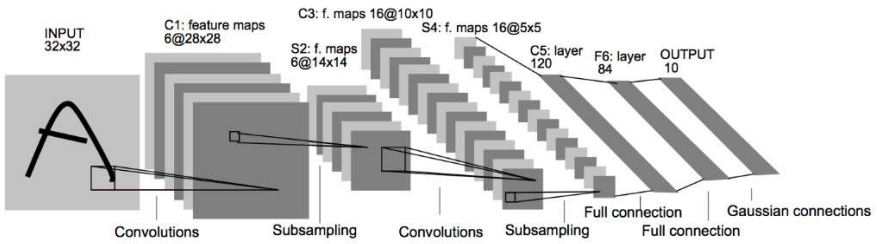

Figure 6

LeNet-5 Model [16]

Pooling Layer: Pooling layer aims at reducing the size of the feature maps for the next convolution layer generally by applying a sum, average or max filter to the feature map. However, the reduction does not necessarily result in data loss, but eliminates the least significant data resulting in easier computation in the upcoming layers [44], [45]. The operation performed by this layer is also called subsampling or downsampling.

3.3.1. Experiments

In this section two small scale experiments are represented, to confirm the validity and applicability of the proposed dataset. Additionally, third experiment compares the entire_augmented and merged_augmented datasets. As mentioned in the related works section, EMNIST dataset [18] has become a standard benchmark for handwriting character recognition purpose. Therefore, in order to evaluate the proposed dataset, the same LeNet-5 architecture was applied on both on the proposed dataset and EMNIST By_Class dataset with 20 epochs in the MATLAB 9.3 environment [22]. One important point to mention is, LeNet-5 architecture requires 32x32 pixel images as the input. For that reason, all 28x28 images were widened to 32x32 images by adding black pixels to the margins of the images (left, right, bottom and top). Another point to mention is the difference in the color of the input images in two datasets. The proposed dataset consists of characters 28x28 pixel binary images for every 72 class. However, the EMNIST By_Class dataset includes 28x28 grayscale images for 52 classes representing the lower and upper case of English Alphabet (see Fig. 1).

In terms of validation parts, a similar validation partition to the evaluation of the EMNIST dataset [18] is applied. Every class was divided into two parts namely train and test parts without using validation. The training part consists of 900 and testing part 100 characters (90% and 10% for the experiment 3).

It should be noted that the first two experiments are carried out in order to evaluate the usability of the T-H-E dataset by comparing its results with a part of the EMNIST dataset which is the benchmark in the field. Having comparable results with EMNIST dataset is the main goal of the experiments. Therefore, the performance of the recognition is not paramount.

Experiment 1

The first experiment represents the comparison of en_augmented set and EMNIST By_Class dataset under equal conditions in terms of the input size and the colors of the input images. In order to have the same sample size for both datasets, 1000 characters out of 2000 characters for each class label in en_augmented set were randomly picked (52x1000=52000). As mentioned above, in EMNIST dataset characters are represented in 28x28 grayscale images in comparison to the binary 28x28 images in the T-H-E dataset. Therefore, for the first experiment, randomly chosen 1000 characters from all 52 letter classes (26 upper case and 26 lower

case) from the EMNIST By_Class dataset were binarized using Otsu's algorithm [24].

Experiment 2

The second experiment is carried out very similarly to the first one. The only difference being that the original grayscale input images from the EMNIST dataset are kept as they are.

Experiment 3

In the last experiment entire_augmented and merged_augmented datasets are compared using the LeNet-5 architecture. Although the input sizes are the same in both versions (156000), entire_augmented has 78 class labels whereas merged_augmented only has 55 class labels. The difference in the size of the output is expected to result in the favor of the merged_augmented version with smaller class labels however, it should also be noted that merged_augmented is an unbalanced set referring to the fact that not every class has the same number of instances (some have 2000 characters and others 4000). One of the previous studies conducted by the authors showed that the unbalanced nature of the dataset has a negative impact on the classification performance [21].

3.3.2. Results

This section puts forward the results of abowementioned three experiments. MATLAB 9.3 environment was used for carrying out the experiments using the LeNet-5 architecture for feature extraction and classification. In first two experiments, the input was classified into 52 classes, whereas in the third experiment, two inputs had a different number of output sizes (78 and 55). Although, 20 epochs were set for the network, the experiments stopped after the 17th epoch in all 4 cases. The Fig. 7 below is a screenshot from the results of the en_augmented version of the proposed dataset in the 1st experiment. In the image, every column represents an epoch and it can clearly be seen that the accuracy does not change significantly after the 3rd epoch.

The classification accuracies, 95% confidence intervals and highly misclassified letters, for all five inputs, in all three experiments, are shown in the Table 3 below. By looking at the results of Experiment 1 and 2, it can be seen that the portion randomly picked from the en_augmented dataset performed the best under such conditions compare to the randomly picked 52000 characters from the EMNIST By_Class dataset. Having the same input size and number of classes, the difference in the results could be explained by the fact that characters in the T-H-E dataset mainly consists of the handwritings of high school and university students. This may have brought about a more standardized way in handwriting. Although, the classification accuracy is slightly lower than 80%; as can be seen in the Table 4 below; misclassified letters are predominantly the same letters with their upper- or lower-case versions.

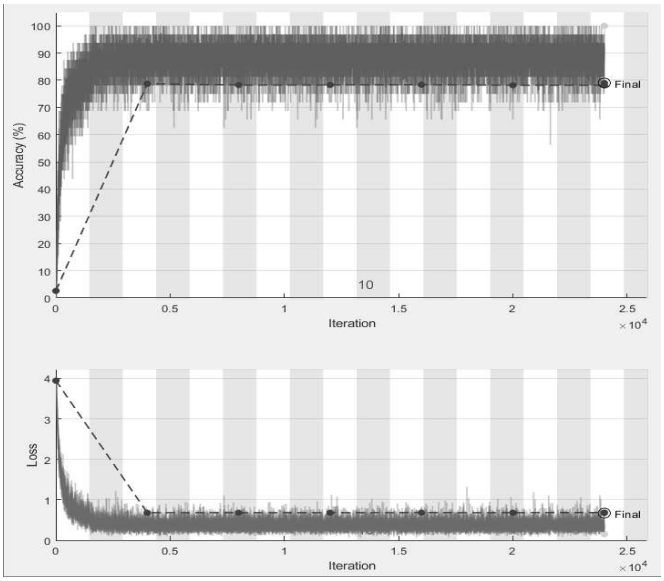

Figure 7
Classification Performance of the T-H-E Dataset

Looking at the different representations of EMNIST by_class dataset in Experiment 1 and Experiment 2, grayscale representation of the input images gave slightly better performance than the binary versions of the same images. As mentioned earlier, in this section the performance of the classifier was not crucial since the comparison was on the input not on the classifier. We believe that, adopting more sophisticated methods for classification and using a larger input set, with the participation of a more diverse group of people, rather than substantially students, could have a positive impact on the classification performance.

Table 3
Classification Performances

	Input	**Input Size and #Classes**	**Classification Accuracy**	**95% Confidence Interval**	**Misclassified Letters**
Exp.1	en_augmented	52000- 52	79.12%	1.10%	y-Y, z-Z, x-X
	EMNIST binary	52000- 52	74.77%	1.18%	p-P, t-T, J-m
Exp. 2	EMNIST grayscale	52000- 52	75.58%	0.75%	p-P, t-T, J-m
Exp.3	entire_augmented	156000- 78	71.65%	0.60%	x-X, y-Y,p-P, ő-Ő

	merged_augmented	156000- 55	82.49%	0.71%	(i-I)-(í-Í), (ö-Ö)-(ő-Ő), (z-Z)-(x-X), r-(v-V)

The comparison of the 78-class entire_augmented set and 55-class merged_augmented set in the experiment 3 resulted in favor of the merged set. The overall accuracy for the entire_augmented version was recorded 71.65% whereas; the merged_augmented version had 82.49% accuracy. The performance difference in both datasets was mainly caused by the misclassification of the upper and lower-case letters. More specifically in the entire_augmented version, the letters 'x', 'y', 'p' and 'ő' were highly misclassified with their uppercase forms as can be seen from Table 3. However, in the merged_augmented form of the dataset, most of the misclassification was caused by inaccurately classifying similar letters such as 'ö' and 'ő'. A clearer and more detailed representation of the highly misclassified letters are demonstrated in the Table 4 below.

Table 4
Detailed Description of the Highly Misclassified Letters

Input	Letter	Accuracy	Letter	Accuracy
en_augmented	c	72.8%	C	90.1%
	x	53.9%	X	48.2%
	y	25.6%	Y	5.6%
	z	68.4%	Z	62.1%
EMNIST binary	p	52.5.%	P	54.1%
	t	51.9%	T	52.3%
	m	54.7%	J	53.3%
EMNIST grayscale	p	47.8%	P	49.4%
	t	56.0%	T	52.5%
	m	58.7%	J	55.6%
entire_augmented	x	50.3%	X	50.2%
	y	53.2%	Y	67.5%
	p	31.2%	P	79.8%
	ő	41.7%	Ő	26.5%
merged_augmented	i-I	81.8%	ı- İ	73.8%
	ö-Ö	87.7%	ő-Ő	82.2%
	z-Z	89.6%	x-X	75.6%
	r	86.3%	v-V	61.9%

Looking at the results, it can be said that merging upper and lower-case characters, have a positive effect on the class performance. Additionally, application of more sophisticated classifiers might contribute to the elimination of the errors as well as increasing the size of the input images for the merged version. An interesting point is seen by looking at the results as the letter 'Y' only has 5.6% accuracy rate

for the en_augmented input, whereas, it has 67.5% accuracy rate for entire_augmented input. Considering that both inputs are derived from the same characters, such a difference stands out. By looking deeper into the results, it can be seen that 83.3% of the letter 'Y's in en_augmented, are misclassified as the letter 'y'. The only apparent explanation for such gap can be the variation in the sample size in two inputs. As can be seen in Table 3, entire_augmented has 2000 samples of each character forming a 156000-character set whereas en_augmented used in the experiment 1 has only 1000 samples of each character forming a 52000-character set. The difference in the input size of the classifier and the sample size for each character may explain the difference in the recognition performance of the letter 'Y'. By carrying out the three experiments, the usability of the proposed dataset was evaluated in this section.

Conclusions

In this paper, a free-to-use, multilingual handwritten character dataset, compatible with different platforms and classifiers, is presented. The handwritings were collected in an ethical way, from 200 participants, representing a diverse mixture of Turkish and Hungarian citizens. The pre-processing and segmentation phases were described and in addition to those steps, the augmentation techniques used for the letters, are described herein. Finally, the evaluation of the T-H-E dataset is carried out in three different experiments. In the first two experiments, the English letters proposed in the T-H-E dataset, are compared to the EMNIST by_class dataset, which is the benchmark for English handwriting recognition. The results of the experiment 1 and 2 demonstrated that the T-H-E dataset outperformed the randomly chosen part of the EMNIST by_class dataset. This could result from the fact that the handwritings in the T-H-E dataset, may be more standardized, since the people contributing to it were mostly high school and university students or alternatively, the T-H-E dataset might include a greater variety in handwritings since it is collected from Turkish and Hungarian Citizens, thus, presenting more distinct examples for the deep learning algorithm, to learn from. Besides outperforming the other dataset, the en_augmented version, presented very few misclassifications between different letters. Having a 79.12% accuracy rate, a majority of the errors were caused by misclassifying the same letters, with their upper- and lower-case versions. This could easily be overlooked by merging the upper- and lower-case classes or at the post processing phase, of the recognition, by using a dictionary. As for the last experiment, the same LeNet-5 architecture was applied to two out of six different versions of the proposed dataset, namely, the entire_augmented and merged_augmented versions. Both versions had the same 156000-character input size, however, the output sizes differed. The version representing letters from three different alphabets separately both in upper- and lower-case classes included 78 letters whereas, the merged version had only 55 letters, merging similarly written upper- and lower-case letters into one class. Naturally, merging two classes into one, resulted in imbalance in the dataset, having 2000 samples for unmerged classes and 4000 samples in merged classes.

Although merged_augmented has an imbalanced nature, it outperformed the entire_augmented version with over a 10% difference in accuracy rates, having only a 0.71% confidence score. As mentioned for the en_augmented version above, lower- and upper-case versions of the same characters form the highest misclassifications in the experiments. Therefore, having both versions put in the same class as in the merged_augmented version eliminates such inaccuracies. Having the six different versions provided in the T-H-E dataset makes it possible to test the performance of a classifier using the entire dataset, as well as, carry out more specific tasks, such as, effects various distortions of characters, Turkish handwriting recognition and Hungarian and English mixed handwriting recognition.

Consequently, it is possible to say that the T-H-E dataset can be an alternative for earlier datasets, in terms of English character recognition, and outperforms those in terms of the variety of letters provided. In addition to being an alternative, it is the only handwritten Turkish and Hungarian handwritten character dataset in the field. The T-H-E dataset could be adopted for single language recognition purposes, namely, Turkish, Hungarian or English character recognition systems, as well as, multilingual recognition systems. We believe, creation of multilingual character datasets will contribute to advancements in recognition systems, thus to the recognition of multilingual texts. Alongside with handwriting recognition, it could be used as an input, to evaluate other supervised and unsupervised learning systems.

In the next versions of the T-H-E dataset, we will aim at increasing the number of handwritten characters, as well as, augmentation with meta-data regarding the participants, namely, the age, gender, occupation, left or right-handed, level of education and nationality of the participants. It should be noted that finding a large number and diversity in participants, for such a purpose, is a major challenge, since the collection of the handwriting should be in person. While overcoming such a challenge, it may be possible to add other special characters from different languages, such as, Portuguese and/or French. We plan to add more alphabets to widen the scope of the dataset and we, in conjunction, plan to generate a handwritten document dataset consisting of handwritten documents in Turkish, Hungarian and English.

Dataset Availability

All the data generated in this study including the paper are publicly available at https://github.com/bartosgaye/thedataset [46]. Additional data related to this paper may be requested from the authors.

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Influence of Quality Management Practices on the Business Performance of Slovak Manufacturing Enterprises

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Abstract: The purpose of the paper is to point out the current state of using selected quality management practices in Slovak manufacturing enterprises. The research was focused on the application of selected practices of quality management, which can ensure that the customers' needs are met and thus contribute to the higher performance of the business. Selected practices of quality management – TQM, Kaizen, Six Sigma and Controlling of quality were considered such approaches. A specific aim of the paper is to find out the level of their real use and potential effects on business with relation to business's performance measured by the Return on Equity. The major research method was the primary quantitative research through a questionnaire. The survey data from 461 enterprises were analysed by the means of descriptive and inferential statistics. Since the variables of our interest are categorical in nature, we used appropriate nonparametric statistic technique – Pearson´s chi-square test. The 95% confidence intervals for proportions were also calculated. The results indicate dependence between the business size, capital structure and use of quality management practices. At the same time, it can be concluded that businesses applying at least one of the quality management practices achieve higher performance measured by the ROE (above 7.5%). Using the quality management practices, businesses can increase their economy and efficiency, reduce the unwanted variability in the processes and associated non-productive costs for increasing the production quality and customer satisfaction. Furthermore, these findings partially contribute to extension of knowledge in this research area.

Keywords: quality; quality management practices; performance; return on equity

1 Introduction

The term of quality management is quite wide and complex. The first paradigm of quality management – product quality with aim of assuring a sufficient quality of products and avoiding of complaints from customers was extended the focus from product quality to process quality. The triangle of "Quality, Cost and Time" was applied not only on products but also on processes. It means that it is only possible to manufacture products at low costs and swiftly through capable and efficient processes [64]. Implementation of quality management practices in every type of enterprise requires managers and employees to adjust to new processes, methodologies and overall thinking. It is interesting that enterprises with a strong customer orientation are more able to implement the quality initiatives [61] [8] [41] [4].

In 2010, the EU along with the European Commission and Council of Europe created a successor to the Lisbon Strategy – the Europe 2020 Strategy containing of the transition to knowledge based economy and society and it means a challenge for most countries [12] [6]. Its main target is to provide support for inclusive and sustainable economic growth. Quality management is one of the factors that can contribute to these goals. The issues of quality, like production quality, management quality, and process quality, play an important role because constant quality improvement is one of the essential principles anchored in the ISO 9000 standard [24] as well as in the total quality management (TQM) philosophy. The TQM is seen as a quality operational enhancement model that is able to generate performance [23] [22].

Globalization and ever-rising customer demand forcing organizations and decision makers to come up with strategies to improve process and products continuously. To do that, they need a commitment from all stakeholders and the effective implementation of continuous improvement tools and techniques. From the point of quality management practices these three selected tools can be included: Six Sigma, Kaizen and Controlling of quality. Six Sigma shows a proven approach for businesses and organizations in how to improve their performance, through reducing variability in any process, reducing costs in manufacturing and services, and also, increasing customer satisfaction. According to Khan et al. [27] Kaizen is a Japanese terminology and means "change for the better." The Kaizen improvement focuses on the use of value-added and non-value-added work activities. Nowadays, according to Bieńkowska [7] controlling is understood as "a method of management support used mainly in the areas of planning and controlling – for the implementation of functions such as information supply, coordination, supervision, monitoring or participation in management; enabling managers – through its measurable and economical overtone – for making rational decisions, and thus aimed at achieving the goals of the organization as a whole and also at the area of quality." Through applying the principles of quality management, it is possible to achieve the sustainable development of a business,

and ensure that the customers' requirements are met and thus promote the sustainable development of the whole society. Some of the benefits of using quality management practices are financial (savings, increasing revenue, etc.); qualitative (reduction of in-process defect levels, improving productivity); procedural (reduction of turnaround time, maintenance inspection time, etc.) [31]. From the study of Rahman, Shokshok, Wahab [48] it's evident that quality management practices have a positive effect mainly on improving product quality, improving the working environment, improving operational performance and improving customer satisfaction. The aim of this study is to review the current application of the selected quality management practices in the Slovak manufacturing enterprises that mostly rely on the enterprise size and their capital structure. Specific intention is to find out their real use, potential benefits and effects to the business performance measured by Return on Equity.

2 Theoretical Background of Quality Management Practices

Nowadays, almost every enterprise is trying to ensure sustainability. For partial achievement of this goal the use of quality management practices can be useful. It means that these practices can improve the quality of products, processes, and raw materials, and also reduce claims of customers, etc. That can ultimately have a positive impact on the running and sustainability of the business. To achieve sustainability in an enterprise it is necessary to focus not only on the results of the enterprise but also on its processes [21] [34]. The results of many studies [51] [40] indicate that the best management principles, models, and practices are those that positively contribute to sustainable development. Such principles also include quality management practices based on the use of the practices and methods such as TQM, Six Sigma, Kaizen, and Controlling of quality. Quality management and its future direction will be influenced by the changes and trends in an enterprise environment. A current trend is sustainable development that affects many areas of life. Global problems are part of solving the issue of sustainable development. These problems present great economic and social problems for everyone [3]. Quality management and sustainable development both have an emphasis on: stakeholders as customers and employees, their safety and satisfaction, their monitoring and self-evaluation for continuous improvement, waste reduction, employee engagement and training, and so on [28]. Except of the challenges of sustainable development, the requirements of Industry 4.0 are coming to the core of interest. In this context, research on quality managers' expectations related to the use of smart technologies is very actual [65].

Total quality management is one of the most significant management procedures of the 20th Century. There have been numerous studies conducted in the field of

TQM procedures and their impacts on businesses performance. Several studies [26] [39] have shown the relationship between total quality management practices and their effects on business performance. The implementation of TQM procedures is a way of increasing quality and reducing costs [11]. Mahmud and Hilmi [35] concluded that TQM is generally associated with the business process and management procedures. These procedures help to improve the efficiency and responsibility to meet the customers' needs through providing quality products and services. Total quality management contains several principles that are important in implementing it successfully. These principles include: understanding the customers' expectations, minimizing the costs for product modifications, supporting employee engagement, building reliable relationships with suppliers, and measuring the results and benchmarking that are used by most organizations [62]. Talib et al. [59] confirmed that the mentioned principles and their application certainly affect the evaluation of business performance.

The Six Sigma methodology (SSM) is an organized and systematic method of strategic processes based on the philosophy of statistics about a non-existent error rate of 3.4 defects per one million opportunities when considering the products and processes [32]. According to the research results [16] [25] the Six Sigma is a statistical indicator of the process capability, which is equivalent to 99.99966% of defect-free outputs. According to Töpfer [60] Six Sigma is project management with reliable statistical foundations and effective practices for quality management, it contains systematic methodology DMAIC (Define-Measure-Analyse-Improve-Control) and DMADV (Define-Measure-Analyse-Design-Verify), process management, and a set of processes analysis practices to solve problems, statistics, philosophy, and quality culture at a zero-defect standard. Sujová et al. [58] stated that SSM is used as the process quality assurance and improvement method, as its implementation has achieved significant cost reduction, mainly in the machine, automotive, and electricity industry. Research studies [52] [14] [67] indicate that Six Sigma should be integrated in TQM to achieve synergistic effects for quality improvement. The impact of SSM on business performance is not questionable.

Kaizen is a creative and innovative operational strategy for increasing the competitiveness of businesses in the current turbulent environment [20] [38]. The key target of Kaizen is to build up a company's well-designed work culture to achieve continuous improvement of quality effectiveness and productivity. In addition, the Kaizen practices mainly focus on improvements without costs or only with low costs. In most scenarios, no costly equipment or sophisticated techniques are involved [1]. Kaizen procedures require all employees to participate in identifying the non-efficiency operations at all enterprise levels and subsequently take appropriate measures for continuous improvement [5]. Procedures of these quality management practices can help enterprises minimize the employee movements fluctuation of employees, costs, and errors, and improve the operators' skills, which will encourage employees to achieve the enterprise´s

key targets that in return can provide products and services with an economic value for their customers.

Control as a management tool is used in several business areas. According to Preißler [45] in theory there is no generally valid definition for the term of controlling, and therefore, one can encounter different opinions and definitions of this term. Quality controlling was created following the findings that quality, along with costs and delivery time, is considered one of the essential factors of success. Therefore, this concept using the economic aspect is used as a support for quality management [17]. Controlling of quality is one of the practices that can ensure, transform, and complete the information on economic results into a form suitable for management. The economic aspect of quality is becoming more important, and its aim is to make quality measurable, plannable, and manageable [54].

The production quality and its management have a great impact on businesses performance. Recent study has also confirmed that enterprises benefited from the incorporation of quality management practices [46]. The study of Nguyen et al. [40] investigate the relationship between quality management practices and sustainability performance as well as the moderating effects from a quality management implementation timeline, type of industry, and business size on this relationship. From the point of view of connecting the quality management practices with the economic performance this topic was discussed by several authors. Koc [29] in his study presented an alternative methodology to assess not only the direct impact of TQM on business performance, but the indirect impact on performance via internal and external failures. Within the economic performance following the quality management, it is recommended to focus on indicators such as financial return, financial expense, and market expansion. Samson and Terziovski [53] studied the relationship between the total quality management practices and operational performance of a large number of manufacturing enterprises individually and collectively. Many other studies [10] [43] support that quality management practices improve organizational performance in enterprises. Moreover, the implementation of organizational innovations demonstrable influence managerial work in different areas, at all levels of management [66].

In case of Slovakia, or Czech Republic some authors only partially (mainly in relation to TQM philosophy) payed attention to the effect of quality management practices on business performance [57] [44] [49]. Because there has been no similar research study in issue of effect selected quality management practices on manufacturing enterprises conducted either in Slovakia or abroad, the authors used their expertise in the branch characteristics, as well as the logic behind measuring the performance and quality management practices to formulate the working hypotheses (WH) and research question (RQ):

Working hypothesis 1 (WH1): The authors suppose that enterprises use the selected quality management practices depending on the size of the enterprise.

Working hypothesis 2 (WH2): The authors suppose that enterprises with the prevailing part of the foreign capital structure apply the selected quality management practices to a greater extent than enterprises with prevailing domestic capital structure.

Working hypothesis 3 (WH3): Enterprises using the selected quality management practices achieve higher performance measured via the Return on Equity (ROE).

Research question 1 (RQ1): What particular changes or benefits do enterprises register by applying the quality management practices?

3 Methodology

The research methodology was comprised of three independent phases that followed one another. In the first phase, the methods of summary, synthesis, and analysis were used and a short review was prepared. In the second phase, a questionnaire was administered to generate empirical data from Slovak manufacturing enterprises. To evaluate the results of the research, the statistical program STATISTICA 12 was used. The third phase included the results in relation to business performance.

3.1 Data Collection and Sample Size

The subject of the research was manufacturing enterprises in the Slovak business environment. The object of the research was the application of the selected quality management practices such as TQM, Kaizen, SSM and Controlling of quality in these enterprises. These practices can ensure that the customers' needs are met and thus contribute to the higher performance of the business.

The primary data were collected through a questionnaire. Identification data of the enterprises included:

- The size of the enterprise based on the number of employees (small enterprises – up to 49 employees, medium-sized enterprises – up to 249 employees, and large enterprises – over 250 employees);
- Capital structure (prevailing ratio of the domestic or foreign capital);
- ROE: From a number of available methods, the ROE was selected for measuring the performance due to data availability. The level of ROE was divided into: negative value, value up to 7.5%, and above 7.5%. This index is available within the statistical databases of Slovak enterprises.

The major research method was primary quantitative research using a questionnaire. The research was focused on the current state of quality management practices in the Slovak business environment. Proper guidelines and questionnaires with objectives of the study were distributed through e-mail, which were collected during January through March 2017. According to the Statistical Office of Slovak Republic [56] the population of our interest was contained of 21,605 manufacturing enterprises.

The minimum sample size was determined according to Eq. 1 for estimating the population proportion [37],

$$n = (z/e)^2 \times p \times (1 - p) \quad (1)$$

where z is the value associated with degree of selected confidence, e is the maximum allowable error, and p is the estimated proportion (p = 0.50 in the case of no logical estimate).

Under conditions of a 0.95 degree of confidence and the maximum allowable error of 5%, the sample size of 385 was a sufficient minimum.

3.2 Methods of the Research Evaluation

The survey data were evaluated based on descriptive, graphical, and statistical analyses. Because the variables of the authors' interest were categorical in nature – nominal or ordinal level of measurement, the authors used appropriate nonparametric statistic techniques.

The Pearson´s chi-square test is one of the most commonly used nonparametric tests concerned with categorical variables. In the authors' research hypotheses, it is important to know whether two such variables are statistically independent of one another or whether these variables are statistically dependent where the probability of the occurrence of one is affected by the occurrence of the other. The chi-square statistic provides a careful measure of such relation [30]. The data were cross-classified into a contingency table. We also constructed 95% confidence intervals for population proportions. The interval estimate states the range within which a population parameter of proportion probably lies. All appropriate calculations were performed using statistical software STATISTICA 12.

4 Results and Discussion

As we mentioned in relation to sample size in part 3.1 our research sample of 461 questionnaires exceeded the required minimum and was thus considered satisfactory. At first we evaluated the current state of application of quality management practices that are characterized the sample via descriptive statistics.

The frequency distribution of the 461 enterprises according to selected variables of size, capital structure, ROE value, and application of quality management practices, are indicated in Table 1.

Table 1
Frequency distribution of investigated enterprises according selected criteria

Evaluation criterion	Evaluation sub-criterion	Relative value
Size of enterprise	Small	71.80%
	Medium-sized	14.97%
	Large	13.23%
Capital structure	Domestic	86.98%
	Foreign	13.02%
ROE value	Negative	7.16%
	Value up to 7.5%	71.58%
	Value above 7.5%	21.26%
Application of quality management practices	Practices are not used	70.07%
	Practices are used	29.93%

From the overall number of 461 enterprises in the sample the most represented were small enterprises (71.80%), enterprises with domestic capital (86.98%) and enterprises with ROE value up to 7.5% (71.58%). We assume that representation of enterprises has also caused less use of quality management practices (only 29.93% enterprises).

4.1 Results of Testing Hypotheses

The first step in data analysis was to classify the 461 units into two-way distribution tables. For the needs of hypothesis testing, the expected frequencies were determined. Subsequently, Pearson´s chi-square was applied. The 0.05 level of significance was used in the testing of all statistical hypotheses.

The first WH anticipated the businesses to use selected quality management practices depending on the size of the business. The observed and expected frequencies and also the values of the test statistics, as well as the degrees of freedom and corresponding p-level for all variables are presented in Table 2.

The null hypothesis about no relationship between two categorical variables is rejected at the significance level $p = 0.05$. There is a statistically significant dependence ($p = 0.000$) between the size of the business and the use of practices, which met the authors' expectation as defined in WH1.

Table 2
Size enterprise and use of practices: observed (expected) frequencies and results of chi-square test

Two-way distribution		Application of practices		Total
		Did not use	Used	
Size of enterprise	Small	257 (231.92)	74 (99.08)	331
	Medium-sized	39 (48.34)	30 (20.66)	69
	Large	27 (42.74)	34 (18.26)	61
	Total	323	138	461
Pearson´s chi-square = 34.461; degrees of freedom = 2; p-level = 0.000				

Residual frequencies enabling a more detailed description of the specific dependence are presented in Fig. 1. The predominant feature (represented by residual frequencies) related to the use of quality management practices is marked in red. From this Figure it is evident that quality management practices are applied mainly in the large or medium-sized businesses. On the contrary, managing small businesses is characteristic by the use of quality practices was absent. These findings presented a logical outcome of the pragmatic aspect on the issue in question. A larger business had a higher need for overhead operations associated with production quality management and business management. This fact was supported by a high ratio of overhead costs in managing other supporting activities. These activities include marketing support, financial analyses and prognoses, research and development, and building a long-term image of the businesses.

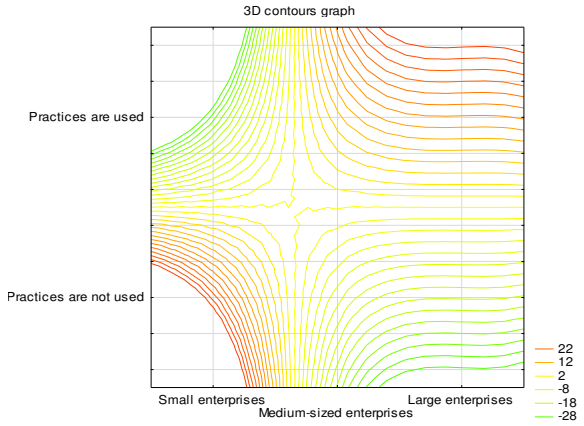

Figure 1
Size of enterprise and quality management practices – the residual frequencies

The WH2 studied the relationship between the share of foreign capital structure of the business ownership and the use of selected quality management practices. The results of hypothesis testing are presented in Table 3.

Table 3

Capital structure and use of practices: observed (expected) frequencies and results of chi-square test

Two-way distribution		Application of practices		Total
		Did not use	Used	
Capital structure	Domestic	293 (280.96)	108 (120.04)	401
	Foreign	30 (42.04)	30 (17.96)	60
	Total	323	138	461
Pearson´s chi-square = 13.241; degrees of freedom = 1; p-level = 0.000				

Following the Pearson's test statistics and corresponding p-level, the null hypothesis about independence was rejected (p = 0.000). There was a significant dependence between the capital structure and the application of practices, which confirmed the authors' expectation from WH2.

Businesses with a prevailing share of foreign capital structure tended to use the quality management practices; whereas the businesses with a prevailing share of domestic capital structure did not use the quality management practices. This statement is based on the results in Figure 2, in which is indicated the dominant feature related to domestic and foreign capital structure of businesses and it is marked in red.

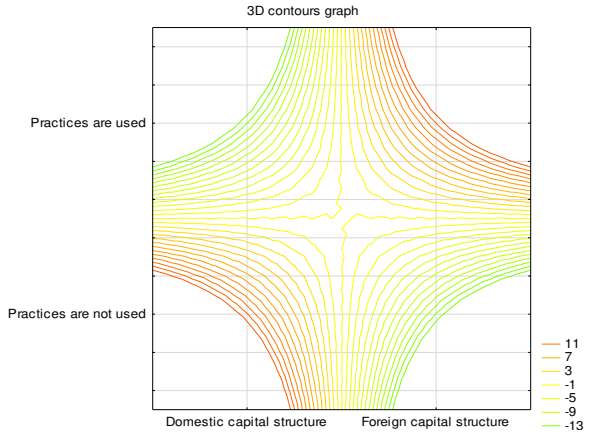

Figure 2

Capital structure of enterprise and quality management practices – the residual frequencies

It can be stated that these results were associated with a certain degree of constant increase in the share of foreign capital in Slovak enterprises, which brought the verified know-how in the sphere of management. Many businesses in the field of mechanical engineering, the electrotechnical and automotive industry, and a huge amount of trade companies have brought elements of precision, flexibility, and results orientation into management. As shown in Table 1, in the Slovak business environment one can find businesses with a prevailing share of domestic capital,

which also use the selected practices of quality management. These practices were established in the business environment via benchmarking principles or through the natural development and requirements within the market approach.

The WH3 studied the relationship between the use of selected quality management practices and the performance measured via the level of ROE. The results of testing and also observed and expected frequencies are presented in Table 4.

Table 4

ROE value and use of practices: observed (expected) frequencies and results of chi-square test

Two-way distribution		Application of practices		Total
		Did not use	Used	
ROE value	Negative	25 (23.12)	8 (9.88)	33
	Value up to 7.5%	242 (231.21)	88 (98.79)	330
	Value above 7.5%	56 (68.66)	42 (29.34)	98
	Total	323	138	461
Pearson´s chi-square = 9.993; degrees of freedom = 2; p-level = 0.007				

Statistically significant dependence (p = 0.000) was also confirmed for the relationships between the ROE value and the quality management practices.

When studying the given dependence in more detail by using the residual frequencies (Fig. 3), it can be stated that the businesses applying quality management practices achieved higher performance measured by the ROE (above 7.5%). This tendency is visible by red-highlighting. In contrast, businesses that did not use any of the analysed practices of quality management achieved a lower level of ROE (below 7.5%), or the ROE value was negative.

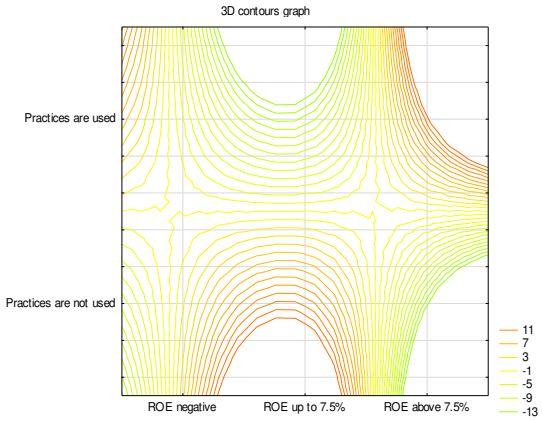

Figure 3

ROE value and quality management practices – the residual frequencies

Based on the aforementioned claims, the authors confirmed WH3. The Slovak manufacturing enterprises that used the selected quality management practices achieved higher performance measured by ROE. When studying and evaluating the businesses' performance, several indicators were used. The most often used indicator was the ROE. The ROE has been used in many research studies for several years in connection with different areas: the effect of ROE on trading volume [19]; the effect of capital structure on profitability [2]. Rajnoha et al. [49] studied the ROE in connection with the business performance and the use of individual practices of strategic management. According to Finstat, the average value of ROE in the economic sectors in Slovakia for the year 2013 was 5.86% [42]. In 2015, the ROE value was already at 7% [15]. Therefore, the ROE value was anticipated to be 7.5% for the current average performance of enterprises in the Slovak business environment.

The practical use of the selected quality management practices definitely supports a higher production quality, as well as business management with an appreciable impact on its performance and building the competitive position. A common feature of a successful application of quality management principles is the constant effort to increase quality. Sujová et al. [58] stated that the use of TQM, Kaizen, and mainly Six Sigma can reduce unwanted process variability, which is a natural process component, nevertheless, its absolute uniformity cannot be achieved. The effect of the variability is that the efficiency of these processes is very low and not identical products are produced. Using the quality management practices (e.g., DMAIC model with the SSM) one can reduce the unwanted variability and the associated non-productive costs, thus improving the production quality and the customer satisfaction, which leads to an increase in the profit as suggested in research studies of various authors [18] [47] [50] [36] [55].

4.2 Results of Research Question

Through RQ1, we have focused our attention on the benefits of using quality management practices. The 95 percent confidence intervals presented in Table 5 indicate that the most common benefit is quality improvement, which is seen in the context of increasing the quality of products and their technical parameters, improving the quality of services provided, or supplying input materials. We estimate that this benefit has been recorded from 80 to 92 percent of manufacturing enterprises operating in Slovakia in 2017. From 30 to 47 percent of manufacturing enterprises consider an important benefit reducing customer complaints. Further results are given in Table 5.

Table 5
The interval estimate for population proportion of enterprises which recorded individual benefits

Individual benefits	Quality improvement	Improvement process performance	Lower costs for non-compliance products	Lower number of customer complaints
Point estimate of proportion	0.8623	0.2971	0.1304	0.3841
Interval estimate – lower limit	0.8048	0.2209	0.0742	0.3029
Interval estimate – upper limit	0.9198	0.3733	0.1866	0.4652

In relation to RQ1 our research has focused attention on the issue of quality cost monitoring in the conditions of Slovak manufacturing enterprises. From the sample (n = 461), the largest number of enterprises (38.18%; 176) monitors internal and external failure costs and appraisal (control) costs (140; 30.37%). An interesting finding is that many businesses (110; 23.86%) still do not monitor quality costs at all. To a lesser extent, the costs of prevention (103; 22.34%) or the cost of lost investments and opportunities (61; 13.23%) are monitored. Less than 10% of businesses monitor costs are related to environmental damage, non-compliance and compliance costs. From the point of view the size of enterprises, the results of the monitoring of the quality costs are presented in Fig. 4.

Figure 4
The quality of costs monitored by enterprises

The situation with regard to dependence of the enterprise size and monitoring of quality costs is similar. However, we can conclude that the largest proportion of enterprises monitoring the failure costs, appraisal costs and prevention costs is from the category of large enterprises.

Conclusions

In conclusion it can be stated that quality management practices can positively influence the increasing of production quality and process performance, reducing the number of complaints with a secondary cost reduction for nonconforming products. Furthmore. our findings show the impact of using quality management practices on business performance. In this case, it was important to conclude that the business's performance also depended on other factors, besides those quality management practices analysed within this study. The significant impact on the business's performance can be quantified depending on the experience and knowledge of the human capital, applying the strategic practices of decision-making support, the degree of technologization supported by the information technologies, and production automation. The branch, its specifics and future trend in the research and development are also appreciable issues. Nevertheless, the field of measuring the performance, with the possibility of applying the procedures based on the evaluation and development of the level of Economic Value Added, Market Value Added, Shareholder Value Added, remains questionable. Several studies [9] [13] [33] [63] have been published on this specific topic. Nonetheless, it can be claimed with certainty that the field of quality management practices can significantly help to build, maintain, and improve the businesses' competitiveness and performance.

This study investigated the current state of using selected quality management practices in Slovak manufacturing enterprises in relation to the business size and capital structure. In accordance with WH1, the results revealed that quality management practices were applied as the business strategy mainly in large or medium-sized Slovak enterprises. With statistically significant dependence ($p = 0.000$) between the size of the business and the use of quality management practices, WH1 was accepted. From the capital structure perspective (WH2), the results showed that the increased use of the selected quality management practices in Slovak manufacturing enterprises depended on the capital structure. Most large and some medium-sized businesses with the prevailing share of foreign capital employed a combination of several analysed quality management practices. The decreasing share of foreign capital structure caused a decrease in the amount of surveyed practices. The results of the Pearson's test statistics and corresponding p-level confirmed WH2. Finally, enterprises that used the selected quality management practices achieved higher performance measured by the ROE (above 7.5%) in which WH3 was also confirmed. This value can even increase when combined with the practical use of the analysed practices. In contrast, businesses that practically did not use any of the analysed practices, or they only minimally applied the practices, achieved significantly lower or negative values of ROE.

The limitations of the present research can be seen in the possibility of extending the analysed respondent sample with the specification to define the dependencies from the aspect of regional, branch, and organizational structure of the businesses. At the same time, the authors are aware of the possibility of using quantification

of the business performance via other methods (Economic Value Added and Benchmarking, methods on principles Activity Based Management or Balanced Scorecard), as well as other quality management practices (EFQM model, Process and Lean management). This field is intended to be the focus of further research studies by the authors. These practices, in combination with the already analysed ones, can support achieving business results regarding the customers' requirements and quality of the competitors. They can add an economic aspect to more technically oriented quality management and contribute to the business strategy that encourages the business' sustainable development and increasing performance.

Acknowledgement

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The Possibility of Creating a Low-Cost Laser Engraver CNC Machine Prototype with Platform Arduino

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Abstract: Some of the advantages of CNC machine use are high processing quality and the speed of the final machining of the product. In the paper we present the low cost solution while the goal was to design and implement a 3D model of a CNC machine based on laser engraver that does not contain too many parts (not only because of the price but also because of defectiveness) and to optimize it for easy production use. When implementing, those parts were focused on that are easily accessible for ordinary consumers or they can produce them themselves. Arduino has been used as a microcontroller. The software part was a created GUI that allows direct communication with the laser engraver machine based on the designed 3D model of the processed product, generating and sending a G-code to the machine through the USB port. In the paper we compared the results of laser engraving by our designed engraver CNC machine and the professional solution Akshar Fiber-Pro Laser.

Keywords: laser engraver; CNC machine; Arduino; Prototype; G-Code

1 Introduction

CNC is an abbreviation for Computer Numeric Control. It is based on the automation of machine tools. They operate with program commands uploaded on a memory medium. The introduction of such machines brought a revolution in production processes [1].

Currently there is no need to worry about the precision of the final product because all the CNC machines have been designed to fulfill the specific requirements [2].

The CNC machines have changed in the last 20 years not only from the point of view of output quality but also of total reassignment. By implementing and using various microcontrollers in the field of automated technology, new types of machines have been developed that fix the problem of previous generations. In the methodological part of our submission, we describe our in-house designed prototype of laser engraving machine built on the principle of CNC machine controlled by an Arduino platform. The prototype we designed represents a microcontroller controlled intelligent system for laser machining of various materials up to a thickness of 1cm. Laser machining (or engraving) of material depends on input parameters such as the power output of the laser, laser frequency, wavelength, and the speed and number of (repeated) passes. Our aim within the experimental research was to compare 3 input parameters (laser frequency, speed and number of passes) of our prototype with parameters of a professional solution Akshar Fiber-Pro Laser Engraving Machine. The output parameter is the quality of the machined material in terms of surface roughness and groove depth depending on the set parameters. Experimental results of the professional Akshar Fiber-Pro Laser Engraving Machine solution match the effect of different frequencies (20, 40, 60 kHz), different engraving speeds (100, 200, 300 mm/s), and varying number of passes (10, 15, 20) over a 1.5 mm thick steel plate (304). The Akshar Fiber-Pro Laser Engraving Machine uses a 1060 nm wavelength fiber laser with nominal power output of 20 W. Our proposed solution uses a 405 nm wavelength laser with nominal power output of just 2 W. In the experiment we've focused on the question, whether our prototype can process a product resulting in the same quality as a professional solution, depending on the same input parameters.

In the section Related Work, multiple solutions are presented which do not represent just prototypes but introduce solutions implemented into operation. In the next section Material and Methods we describe the hardware part of designed prototype (mechanical and electronic part). The Section 4 with the name "The preparation of the user's environment and the settings of the engraving process" is focused to the software part (settings of prototype for engraving process). Section Discussion and Results describe realized experiment. The experiment is focussed to identify and evaluation various parameters that has impact adverse effect on the quality of the material being machined.

2 Related Work

Nowadays, precision in processing the output product is an important factor of the CNC machines.

Chen et al. [3] worked on using the Taguichi experimental method in optimizing laser microgravure photo plates that are needed to create the patterns required in

the production of small LCDs. In their study they focused on these parameters: focus length, average power of the laser, pulse repetition rate and the engraving speed relative to the engraving width. The results showed that it is possible to create a groove with the width of 18 μm under these parameters: beam expansion ratio of 5x, focal length of 50 mm, laser average power of 0.4 W, pulse repetition rate of 5 kHz and engraving speed of 5000 mm/min.

Genna et al. [4] were researching the influence of the process parameters on the material removal rate (MRR) and on the surface roughness in engraving operation by using C45 carbon steel. They used a 20W laser (Q-Switched) with the wavelength λ = 1070 nm. The parameters studied were pulse frequency, beam speed, and the number of replications of the geometric pattern. The study confirmed that a laser with a wavelength λ = 1070 nm can be used to machine steel, with the MRR parameter and roughness dependent on the input parameters of the machining process.

Agalianos et al. [5] investigated the effect of using laser engraving on the quality of the machined surface. Laser engraving technology removes the material layer by layer and the layer thickness is usually in the range of several microns. The parameters examined were pulse frequency, beam velocity and layer thickness. The surface quality was determined by the surface roughness for each set of parameters. Experimental results on Al7075 showed that surface roughness depends on the frequency and scan speed used. Furthermore, it has been shown that the resulting roughness depends less on the layer thickness. Taking into account all experimental research data, the best surface roughness was achieved using a frequency of 20 kHz, a scanning speed in the range of 600 to 700 mm/s and a layer thickness of 4 and 6 μm. In their research, they used a laser with a wavelength λ = 1064 nm and a power of 100 W (Q-Switched).

Linggarjati & Hedwig [6] designed and created an inexpensive CNC machine equipped with a replaceable laser head. Their CNC machine is flexible in its usage, being able to use CO2 laser and thus to work with different kinds of materials. In a precision machining experiment, they used plywood, acrylic, cardboard and PCBs with a maximum thickness of 5 mm, 3 mm, 5 mm, and 1 mm (in that order). Machining accuracy was around 0.1 mm. They used a 40 W laser as standard.

According to Kasman [7] laser engraving is the most efficient technique for machining hard materials with complex geometry. In his study he investigates the machinability of hard metal produced with powder metallurgy and puts forward and new approach to the laser engraving of P / M metals for Vanadis 10. The required input parameters of the machining process were effective scan speed, frequency, and laser effective power on the surface roughness (Ra) and engraving depth (D). Kasman found that the scan speed has a statistically significant effect on both Ra and D. To minimize Ra, the scan speed should be at a high level (800 mm/s), while in order to maximize D, the scan speed should be at a low-level (200 mm/s).

In the past, CNC machines were suitable for machining metal or non-metal materials using 3 or more axes. The problem of such CNC machines was their high complexity, cost and weight (problems with relocation).

The paper of Yuen & Altintas [8], introduces the methodology of error correction that may occur in the three-axis process. The authors used a geometric error-free ideal forward kinematic model of the nine-axis machine. The model has been designed via the utilization of a homogeneous transformation matrix. The geometric errors of each linear axis, which include positioning, straightness, pitch, roll, and yaw errors, are measured with a laser in a terferometer and fit to quintic polynomial functions in the working volume of the machine.

In her paper Navrátilová [9] has concentrated on the rebalancing within the multi-directional principle of each axis of the laser. When cutting the product, a certain deviation might develop that in the end causes imprecision on the output. To determine this deflection, she used a laser tracer that records the measured data in spherical coordinates. Every deflection is described as signal quality to best signal quality ratio gained from the measurement.

The disadvantage of current industrial CNCs is their high price. The teaching on this type of device is a long-term process and schools do not have enough money to buy them. That is the reason that low-cost solutions are preferred.

To overcome these problems, we designed a prototype of a two-axis CNC laser machine tool that is lightweight and compact in size compared to previous solutions. The only limitation is the size of the material to be processed (up to 1 cm). The materials to be processed can be metal materials but also all non-metal materials such as wood, foam, plastic, rubber, paper. The prototype design was inspired by the following case studies.

The paper of Peixoto & Monteiro (2019) [10], proposed this solution to ensure the technical training in Portugal. As an example of the control unit, they propose the use of Raspberry Pi3 or the platform Arduino. They refer to various works including Antunes et al. [11] that have already been created in UMinhoLabs for technical training of future professionals. According to a paper written by Quatrano et al. [12], on assembling a low-cost CNC machine, a discarded 3D printer was used. This way they lowered the related expenditures. As a control unit Arduino Mega 2560 has been used. The main idea was to build a low-cost CNC machine which can be capable of machining precise various shapes or sizes of the subject. Considering the stepper motor parameters and operating conditions, a need developed for a control system of the actuators using open-loop control laws (the communication takes place in these cases in one direction only: from the controller to the motor). The use of low-cost devices was combined by the use of open source software. The open source software was deployed for creating a tool path from the 3D model. The used 3D model was developed in SolidWorks software as the authors used the CamBam application to create the G-code from the 3D model.

Michael [13], agrees that low-cost devices are nowadays used mostly for teaching to understand the principle of the CNC machine's operation along with testing it. Basically, it was a final project of two students. According to one of the authors, he planned to buy a laser cutter, but soon he realized that this kind of device was too expensive for domestic use. He had decided to build his own CNC machine. His solution represents a proposition and production of a laser cutter with a laser performance of 40 W. The cutter had a space of 1000x600 mm for cutting and it also had a touchscreen for operation. The control unit was made up of Arduino with GRBLShield and a microcomputer Raspberry Pi with a touchscreen connected to it. Thanks to the microcomputer it was a separate device. It means that it does not need a computer to send files to the machine. The cover of the machine was designed in a way that it was not possible to turn on the laser until the cover was shut. These arrangements were important because of the laser's performance (the reflection of the beam is dangerous for the eyes). The total set of the project cost around 1900 €.

Khanna et al. [14] and Desai & Patel [15], proved with their prototypes that it is possible to build a low cost CNC machine. Paper [14] reports on the development of a low-cost CNC system with 6 axes (problem of this solution is low accuracy in pulse repetition rate and engraving speed). The lower cost is achieved by incorporating the Arduino. The authors used G-Code parser where in the G-code is first converted to the canonical code and then interpreted on the microcontroller from a USB key. In their draft, the authors of paper [15] used Arduino 2560 and three unipolar stepper motors for three-axis machining. The axes X and Y were used for two-dimensional interpolation. The axis Z was used to control the deep cut and was not interpolated. As a standard code of part programming the G and M codes were used.

Currently it is possible to come across various architectures, e.g. using the CNC with Cloud Computing. The study by Hui et al. [16] proposed a system that locates its front end in a cloud virtual machine and provides the front end as a service. The application program for interaction with the client can be easily integrated into smartphones or tablets. The cloud communicates with the back end via the Internet or an intranet. Various tasks in real-time are run on the back end, while other tasks are executed on the cloud-enabled front end (not in real-time). The computing ability and intelligence of CNC systems can be, therefore, improved by a switch to the cloud architecture.

3 Material and Methods

In the last five years, various low-cost CNC machines have appeared. They hardly ever reached the high-quality level of professional machines. In this case, they have been used as teaching equipment to prepare future professionals. Some of

them had various numbers of axes to process the material. However, it is not always necessary to use a large number of axes for processing. For the model, the axes X and Y have been used. The basic construction of the proposed CNC laser engraving machine (Figure 1) has three axes X, Y, Z. Since the cutting tool was a laser, there was no need to implement the axis Z. This way the construction got simplified and the price was reduced partially. The axis Z might have been needed in the case the depth had been cut.

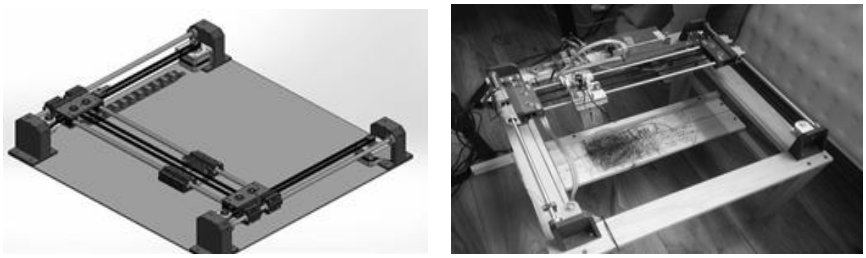


Figure 1
Left - Proposal 3D model of the laser engraving machine, Right – Real CNC laser engraving machine

The 3D model of the machine with the H-bot set is shown in Figure 1 (the name comes from the model's design that has a shape of the letter 'H'). As long as the coordinate recorder is concerned, a similar principle was used so it is a motion in XY space (motion on a plane). The construction of the set was easy because it consisted of two stepper motors – a timing belt and two perpendicularly mounted rails. On the one hand the stepper motors were fixed and in motion they cooperated. The motors are stationary, but these motors work together as they move. The fact that both motors are connected by one belt complicates programming this robot. Movement by one motor causes an oblique movement at a 45° angle. If we rotate both motors at the same time and at the same speed, we get the required linear motion. Depending on which motor is activated, we can realize the move as shown in the Figure 2.

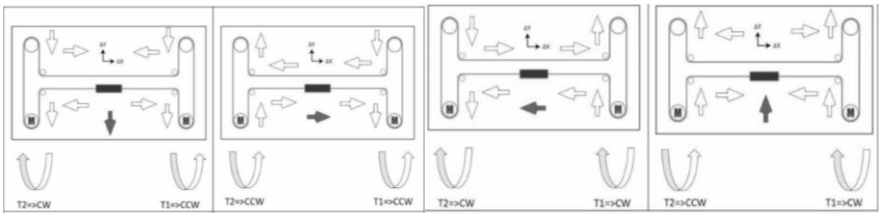


Figure 2
Way of H-bot movement

The size of the machining area was 210x290 mm (A4 format). Some of the parts designed in the 3D model were not possible to buy because they were unique. It was easier to make them. A 3D printer was used for this purpose because it uses

plastic that has low weight and is rather firm. The machine had two holders for the axis Y that are identical and were combined from two plastic plates. There were two bearings that held two holders for the guide bars and two belt pulleys interconnected by steel bars with the bearings. The head of the machine consisted of the laser from the plastic plate and of four linear trolleys mounted on the top. The distance between the trolleys had to be the same as the distance between the holders for the bars on the Y-axis. A complete CNC machine is shown in Figure 4. The whole machine was linked up with the belt and both endings were attached to the machining head where the laser diode was found. Table 1 lists the mechanical parts and their price.

Table 1
Part list for mechanical part of the machine

Name	**Number of pieces**	**Total cost (€)**
Unsupported bars	4	15
Belt	1 (3m)	2
Pulley	8	4
Ball trolleys	8	15.5
Bearings	12	5.5
Wooden frame	1	12
Connecting material	60	8
3D printed parts	20	80
Sum		**142**

The basic set of the machine was made of mechanical parts that required manual skill. However, when linking all the electronic parts (Figure 3), it was necessary to have basic knowledge from the field of electrical engineering.

To secure the motion, two stepper motors NEMA 17 were used which were mounted during the mechanical building process. To set the starting position of the head, the same principle was used that had been practiced in printing companies for a long time. For this purpose, limit switches were used which reported to the control unit if the machine got into an unauthorized or an error position. The control unit stopped the machine immediately and sent a warning to the program that operates the machine. The CNC model contains four limit switches, two for the axis X and two for the axis Y. From the safety point of view, the limit switches represent the basic security element. The machine head contained the most expensive part – the laser diode. Through testing it turned out that the Blue Laser Diode 200 nW 405 nm was not applicable as intended because of its low performance. After another test and research, it was obvious that there was a need for a laser 1000 mW at least for machining. In the end, the decision was made for a laser with a performance of 2000 mW that works on the wavelength of 405 nm. The laser used on the model contained an active cooling and an aluminum coat that helped with temperature drain.

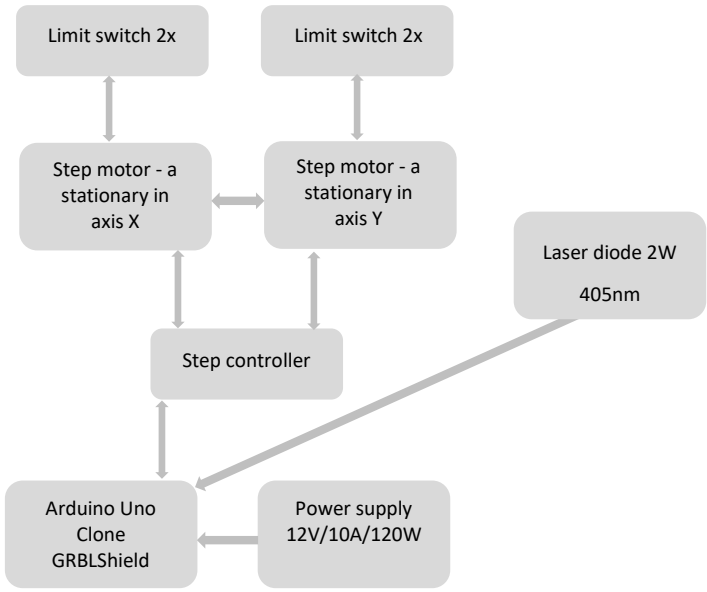


Figure 3
The block scheme of the electronic part

The laser was linked to the control unit (entry 12 V) but the control unit sent from 0 to 5 V to the laser as output. A TTL technology was implemented which based on the entry signal from the control unit changed the 12 V to any value from 0 to 5 V. This meant that the laser's performance was possible to control by the software. For this, pulse width modulation (PWM) was used. This way, the voltage between turning on (5 V) and turning off (0 V) could be simulated by changing the ratio of the time when the entry was turned on (as a duty cycle). Usually, values from 0 to 255 were set that matched with the output signal of 0-5 V.

By analysis of the current state in the Related Work, it can be concluded that it was not primarily necessary to spend large amounts of money on CNC machines if open-source architecture was used. Many constructors prefer this solution, and they often use the existing open-source solution based on Arduino. The use of Arduino in the domestic environment and in the industry brought another development of not only the microcontroller itself but also of various extensions that are possible to connect to the microcontroller. One of these extensions is the GRBLShield. The board was designed to fit into the Arduino UNO's board. Depending on the model, it was possible to control the four-step motors with the board. Each motor controller could be replaced separately and rather quickly. The stepper motors could be linked quickly without soldering. The use of pins made it possible pins to attach the limit switches and the PWM port to which the laser was attached. It was necessary to bring the voltage of 12-36 V to the board. It enabled the user to set micro stepping for each controller. A power supply of 12 V was

used that supports a maximum of 10 A power. Table 2 lists the electronic parts and their price.

Table 1
Part list for electronic parts of the machine

Name	Number of pieces	Total cost (€)
Stepper motor Nema 17	2	22.5
Limit switches	4	2
Arduino Uno clone	1	5
GRBLShield V3	1	10
A4988 Step controller	4	2.5
12V 10A 120W PSU	1	9
Blue Laser Diode 2W	1	43
Sum		**94**

4 The Preparation of the User's Environment and the Settings of the Engraving Process

New educational methods such as e-learning and "edutainment" may have emerged as a result of digital development. Edutainment is based on the idea of disseminating information to students in an entertaining audio-visual environment provided by multimedia equipment. This approach is based on conclusions that have been drawn from the latest findings of education science. It is a fact that the effectiveness of traditional teaching methods supported by the use of electronic devices is increased when placed within an entertaining framework (especially with regard to oral presentations). The interest of students may be continuously maintained by stimulating presentations in which information transfer is aided by animations or visuals utilized at given points in a lesson, facilitating emotional identification, active participation, and, later, the retrieval of information from the memory [17], [18], [19].

An awareness of new ICT (Information and Communications Technology) trends and their constructive applications are essential in modern teaching and learning.

To program the Arduino boards, Arduino IDE was used by which the program was compiled and uploaded to the board. The result of the compilation was a hex file where all the programmed instructions were uploaded. The smooth operation of the stepper motors and thus the whole machine was ensured by a software called G-code interpreter. The essence of the program was simple. On entry, it obtained the coordinates in a form of a text which was then translated into motion. The text was set in a standardized form and was called G-code. Since the programming of the interpreter was a demanding task for only one programmer, a

group of programmers published their long-time work on the interpreter as an open-source providing free access to everyone. To make the machine work, programs needed to be installed that facilitated the drawing of the picture that was set to be engraved. Then, a G-code had to be generated that was intelligible for the CNC machine. Finally, the program was installed that connected to the machine, set the zero point and loaded the G-code file. Considering the open-source solutions, those programs were chosen that were free of charge: Ubuntu (Distribution of OS Linux), to which the programs Inkscape and UGS (Universal G-code Sender) were installed. To use UGS, it was necessary to install Java Virtual Machine as well. UGS was an intuitive program with a native support for the work with the GRBL software.

Before setting the precision of the machine, it was necessary to understand how the stepper motors worked. The stepper motor was a synchronous rotating machine, connected by a direct current pulse. The magnetic field was generated by gradual linking of each pole pair. The rotor vibrated during lower speed, moved among the stable positions in a certain angle. This is called step motion. The stepper motors were characterized by high mechanical resistance and a long lifetime without maintenance. Some of the disadvantages were a so-called step loss that occurred after exceeding the limit load and a tendency to mechanical deceleration that might have led to instability in the motion. Both negative features could be possibly avoided by selecting the right stepper motor and controller in regard to the torque characteristics of the drive. The stepper motors controller was a special electronic circuit generating pulses in a certain order and length. The pulses were made through the power section in an exact order of each rotor boring. The frequency, the order and the length of the pulses from the control circuit controlled the number, the direction of the rotation and the torque of the machine. The stepper motor NEMA 17 used in the machine had a step size of 1.8°. If 360° is divided by 1.8°, it meant 200 steps per motor rev. The increase in the number of steps could be achieved by using a step controller with the support of micro-stepping. According to the settings, it was possible to reduce the step of the motor to 1/2, 1/4, 1/8, 1/16 of the original motor step. In the case when all three jumpers were added, the number of the steps increased by 16 times meaning from 200 steps to 3200 using the same motor. By increasing the number of steps, the machine was more precise and it was possible to get rid of the undesired vibrations that might have appeared in the slower motion of the motor. With the help of the program, the inner settings could be changed which would be saved in the memory of the Arduino board. After the successful link on Arduino, the information about the GRBL version and with the command $$, all the settings were shown that had been saved in EEPROM. The values changed in the following way $x=val where x was a particular setting that was needed to be changed and val was a new value, for example $100=120 changed the number of the steps to millimeters for the axis X to 120. To begin with the cutting of the product, Extensions>Generate Laser Gcode>J Tech Laser Tool had been selected from the extension offer and a G-code was generated. With the help of the

program UGS, the G-code was loaded into the machine. If needed, values for X and Y it was advisable to recalculate. This initial setting was necessary to perform because the picture drawn in Inkscape might have had different resolution while the parameters were needed to adapt to G-code.

In the experiment, we focused on the comparison of the resulting parameters of laser machining of stainless steel material using a professional solution and a prototype designed by us. The experiments were performed on an Akshar Fiber-Pro Laser Engraving Machine which operates with a 5% deviation in the machining process. This laser engraving machine uses 1060 nm wavelength fiber laser with nominal power output of 20 W. The prototype we designed (Figure 1) uses a laser with a wavelength of 405 nm with a nominal power output of 2 W.

As a material to be processed (engraving process) we used a stainless steel (304) plate from the company Ocelex with a thickness of 1.5 mm. The maximum engraving depth (groove depth) was set to 0.9 mm. The chemical composition of SS 304 is in the website http://ocelex.sk/old/pages/213.htm. The input parameters of the experiment were Frequency: 20, 40, 60 kHz, Engraving speed: 100, 200, 300 mm/s and Number of pass: 10, 15, 20. The observed output parameters of the experiment were surface roughness and groove depth (μm). The results of the experiment are listed in the Discussion and Results section. The surface roughness parameter was measured with the MarSurf PS10 Elcometer 7062. The groove depth parameter was measured with the Universal PIG Elcometer 121/4.

5 Discussion and Results

The aim in the present is to identify the sources of vibration under various operating conditions so as to minimize the adverse effect on the quality of the material being machined, stop vibration from occurring and slow down the rapid wear of the cutting tools [20], [21], [22].

Table 3 shows the measurements of Surface roughness and Groove depth for the professional Akshar equipment and the Prototype.

Table 3

Measured input and output parameters in the machining process

No.	Frequency (kHz)	Engraving Speed (mm/s)	No. of pass	Variance of groove depth (μm) Akshar	Variance of groove depth (μm) Prototype	Surface roughness (μm) Akshar	Surface roughness (μm) Prototype
1	20	100	10	61.852	59.349	2.562	2.314
2	20	100	15	61.992	59.456	2.848	2.524
3	20	100	20	62.018	59.711	2.831	2.519

4	20	200	10	61.124	60.236	1.423	1.269
5	20	200	15	61.356	60.255	1.678	1.381
6	20	200	20	61.547	60.308	1.236	1.332
7	20	300	10	63.475	61.403	1.582	1.269
8	20	300	15	63.684	61.496	1.547	1.281
9	20	300	20	63.324	61.502	1.00	1.369
10	40	100	10	71.751	61.655	1.256	1.186
11	40	100	15	71.792	61.699	0.985	0.884
12	40	100	20	71.801	61.704	0.954	0.864
13	40	200	10	71.568	62.406	0.993	0.837
14	40	200	15	71.583	62.463	1.214	0.974
15	40	200	20	71.607	62.488	1.201	0.942
16	40	300	10	72.429	65.571	1.035	0.937
17	40	300	15	72.471	65.589	1.126	0.917
18	40	300	20	72.783	65.635	1.287	0.906
19	60	100	10	83.578	71.127	0.487	0.368
20	60	100	15	94.367	71.218	0.469	0.344
21	60	100	20	98.741	71.283	0.471	0.339
22	60	200	10	96.586	71.714	0.712	0.671
23	60	200	15	96.627	80.789	0.697	0.585
24	60	200	20	96.685	80.795	0.736	0.634
25	60	300	10	95.814	80.963	0.461	0.356
26	60	300	15	95.829	80.985	0.831	0.614
27	60	300	20	95.895	80.992	0.814	0.609

The aim of our experiment was to engrave an image with the inscription (Figure 4) at various input parameters on a stainless steel plate.

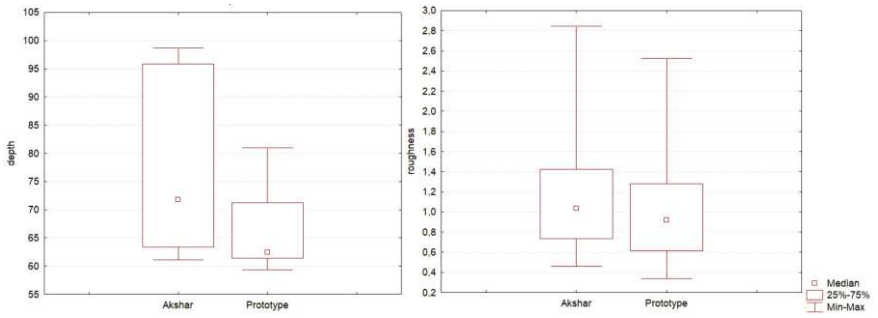
Figure 4
Example of engraving image on stainless steel plate

The aim was to cut to a depth of 900 μm (0.9 mm). Therefore, a new variable, the Variance of Groove depth (μm) was created for both devices in Table 5 to reflect the deviation from the expected depth of cut. The aim is to verify that the cut accuracy with Prototype is better than with Akshar. We therefore need to verify that there is a statistically significant difference between the deviations. Therefore, we are verifying the H0 hypothesis: *The distribution of the Variance of groove depth variable in both groups (Akshar, Prototype) is identical.* We test the hypothesis at the 5% significance level of the Mann-Whitney U test, which works with serial numbers (Table 4, Figure 5a).

Table 4

Mann-Whitney U test for variable Variance of groove depth and Surface roughness (μm)

Variable	Rank Sum Akshar	Rank Sum Prototype	U	Z	p-value	Valid N Akshar	Valid N Prototype
Variance of groove depth	918	567	189	3.036	0.002	27	27
Surface roughness	810	675	297	1,168	0,242	27	27



(a) (b)

Figure 5

Mann-Whitney U test for variable Variance of groove depth (a) and Surface roughness (b) (μm)

The test verifies whether the difference in the order of the two groups / variables is statistically significant or only random. Based on the results of the Mann-Whitney U test and the extracted p-value, which is less than 0.05, we reject the H0 hypothesis at 5% in terms of significance. This means that there is a statistically significant difference between the values of Variance of groove depth (μm) Akshar and Variance of groove depth (μm) Prototype. Based on the fact that the Rank Sum Prototype (567) from Table 4 is lower than the Rank Sum Akshar (918) and the analysis showed that there is a statistically significant difference between these variables, we can say that the Variance of groove depth of our Prototype is statistically significantly lower compared to Akshar. This is also evident from the box plots in Figure 5a. This confirms that the prototype we have created has a

smaller variation in the depth of cut compared to a commercially available device (Akshar) and has a higher accuracy in this regard. Similarly, we have verified whether there was a statistically significant difference between the Surface roughness values after using the Akshar and the Prototype. The H0 hypothesis was verified (Table 4, Figure 5b) here: *The distribution of the Surface roughness variable in both groups (Akshar, Prototype) is identical.*

In case, we reject the hypothesis, it would mean that the measured values are not identical and therefore statistically significantly different. On the basis of the p-value of the Mann-Whitney U test, we do not reject the H0 hypothesis. This means there is no statistically significant difference in surface roughness when using Akshar and our Prototype.

Based on our measurements, we further verified whether the values of the variables Variance of groove depth and Surface roughness were affected by changing Frequency, Engraving Speed and No. of passes. In terms of the number of measurements, we used a non-parametric alternative to the analysis of single sort variance, namely Kruskal-Wallis ANOVA [23]. We verified it at a 5% confidence level. Verification results for H0 hypothesis: *The medians of Variance of groove depth variable are the same for all Frequency settings as* shown in Table 5 below.

Table 5
Kruskal-Wallis ANOVA for variable Frequency in relation to Variance of groove depth

Frequency	Valid N	Rank Sum
20	18	198.0000
40	18	501.0000
60	18	786.0000
		p-value ≈ 0.000

We reject the H0 hypothesis, which means that the Frequency setting has a statistically significant effect on Variance of groove depth.

Verification results for H0 hypothesis: *The median values of the Surface roughness variable are the same for all Frequency settings* as shown in Table 6 below.

Table 6
Kruskal-Wallis ANOVA for variable Frequency in relation to Surface roughness

Frequency	Valid N	Rank Sum
20	18	814.0000
40	18	500.0000
60	18	171.0000
		p-value ≈ 0.000

We reject the H0 hypothesis, which means that Frequency has a statistically significant effect on Surface roughness.

Using the same method, we verified whether the results in Variance of groove and Surface roughness differ statistically significantly at different Engraving Speeds as well as different No. of passes. Kruskal-Wallis ANOVA (Table 7, Table 8) was also used here. In none of these four combinations did the analysis confirm statistically significant differences between the measured values.

Table 7
Kruskal-Wallis ANOVA for variable Engraving Speed in relation to Variance of groove depth and Surface roughness

Engraving Speed	Valid N	Rank Sum (Variance of groove depth)	Rank Sum (Surface roughness)
100	18	441.0000	500.0000
200	18	471.0000	494.5000
300	18	573.0000	490.5000
		p-value = 0.341	p-value = 0.995

Table 8
Kruskal-Wallis ANOVA for variable No. of passes in relation to Variance of groove depth and Surface roughness

No. of passes	Valid N	Rank Sum (Variance of groove depth)	Rank Sum (Surface roughness)
10	18	471.0000	484.0000
15	18	495.0000	504.0000
20	18	519.0000	497.0000
		p-value = 0.879	p-value = 0.977

Based on the comparison of the commercial Akshar equipment and our constructed prototype we've found that at the 900 μm (0.9 mm) cutting depth setting, the deviation between the specified depth and the actual cutting depth was statistically significantly lower when using our constructed prototype. This means that the equipment we've created is paradoxically more accurate in this respect. The results also suggest that at higher Frequency, surface roughness decreases and Variance of groove depth increases, both by a statistically significant degree. Other uploaded input parameters have no statistically significant effect on these values. The measured results can be explained by our use of a different wavelength and lower power laser. At the same time, we've concluded that at a lower frequency and low number of passes the Surface roughness increases. Our proposed solution is not intended for commercial purposes but serves as a teaching aid for students. When testing the prototype, we were able to successfully cut various types of material to a depth of 1.5 cm (rubber, wood, veneer, plastic). However, we do not recommend using the designed prototype as a cutting or

machine tool, as the laser power is only sufficient to carry out the engraving process.

Conclusion

The aim of the paper was to show the possibility of creating a low-cost laser engraver CNC machine prototype that was able to engrave into a 210x290 mm surface. The machine itself had a low consumption and worked with high precision thanks to the precise control of stepper motors. Compared to other CNC devices, the expenses to create it were not that high (Akshar Fiber-Pro Laser Engraving Machine with 20 W laser, price starting at 1900 € compared to the 236 € price of the prototype). It was made of easily accessible parts so there was no problem of getting spare parts. Although it meets the parameters of industrial machines, we would not recommend it for commercial use. However, it would do very well in educational institutions. It was designed to be simple and could be moved easily everywhere. The automated programming of the device can be learned in a fast and easy way by using the appropriate methodology. [22] In the control unit Arduino, an open-source software was used. As part of the project, Inkscape was used to create the content and then a plugin to generate a G-code. Universal G-code Sender facilitated manual operation of the machine, its visualization and G-code loading. As planned and recommended refinement, two lasers with lower performance could be used showing perpendicular lines. The zero point of the machine was then found where these lines crossed. The team managed to build the low cost prototype of the laser engraving machine (total 236 €) and to operate it without bigger complications.

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Keeping Talents in the Transport and Logistics Enterprises: Case Study from the Czech Republic

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Abstract: The aim of the article is to identify the motivation preferences of Czech managers on critical management positions of transport and logistics enterprises and to determine the method for the effective setting of the motivation factors in the interest of keeping them in an enterprise. The article is based on research outcomes from transport and logistics enterprises where the focus is on managers identified as talents by the enterprises. Research was conducted in 2018 in the Czech Republic using a questionnaire. In research, 154 managers were interviewed. Data were processed using basic descriptive statistics. The proposed effective setting of motivational elements is based on the use of a method for determining an appropriate variant - AHP multicriteria decision making method. The results of the article can serve to help entrepreneurs not only in the field of transport and logistics services. Other enterprises also have the potential to gain a strong system not only to retain their talents in society, but also to create satisfaction and commitment to the enterprises. The presented way of setting motivation factors is universally applicable to any sector and regional location.

Keywords: talents; managers; transport and logistics enterprises; AHP decision method

1 Introduction

Current labour market is changing along with business environment in a very high pace. Companies own significant amount of intangible assets, i.e. human resources, high-quality and qualified labour force, whose value may be improved further [1] [2]. Such perspective employees have the potential to help enterprises in overcoming hard economic times and affect economic growth in a positive way [3]. Considering the actual situation in labour market, it's becoming more demanding for companies and entrepreneurs to hire, educate and keep the talents [4] [5]. For the companies to keep such employees, they are forced to create attractive work environment [6] [7] [8]. Companies are aware of the fact how important it is to have talented employees. Such talent means an individual with high potential – his/her own combination of certain extraordinary capacities and personal properties that distinguish him, also bringing added value to the company [9]. In the corporate practice, talent is considered as an ability to achieve performance above standard as the performance is the aspect such company requires, measures and appreciates [10]. Talents are educated, in particular, for critical management positions, having significant impact on company performance as a whole. To get and educate a talent, it requires significant effort from the company as well as time and costs. Their loss and even shift to competitors may weaken the company markedly [11]. Therefore, talent management area grows in importance within a wider spectrum of organisations and it's becoming a key challenge in the human resources area companies face in different industries [12] [13] [14]. This trend is fueled by the incoming 4th industrial revolution, when the paradigm of human resources management is changing [15]. Coming new technologies and concepts such as automation, creation of a global cybernetic space (GCS) [16], process digitalisation, system integration, autonomous robotics and vehicles, digitalisation or systems of artificial intelligence modify the already implemented procedures and mindset in companies, in particular in the area of industrial production [17] [18] [19]. Also, the demands on human resources are changing markedly. Although the estimates count on a decrease of demands on the volume of human resources, companies will be facing the need of change to their structure of employees by the implementation of more intelligent systems – automation. According to Dočkalová [20], development of technologies may lead to a mass unemployment. On the basis of its research, the German Ministry of Industry and Development stated that the changes to structure of labour positions brought more than 10% increase in work positions in operation companies as a consequence of automation [21]. Subsequently, by an increase in the volume of production, completely new work positions were created, but a high demand for highly qualified IT employees, able to control and program software for majority of machines [21], as well. Research of the Czech Ministry points to a decrease in work positions by one third and to an increase of new positions by one eight [22].

On the other hand, specific need is being created for higher management that will be able to react on the shift process within implementation of elements and system changes in the industry flexibly 4.0 [15] [23]. Subsequently, they will be able to control the processes and change their current management mindset in accordance with the modification of management paradigm [24]. This requirement will have the highest importance for managers at key (or critical) management positions, ideal for the so-called talents in this case. Within the context of industrial revolution 4.0, talent may be flexibly adjusted to the requirements for implementation of technological elements in enterprise and has necessary competences for the management of intelligent systems, new procedures as well as human resources [25]. Critical positions (designated also as key positions) are such positions that are decisive for the achievement of success in organisation. Non-timely occupation of such positions may lead to a serious disruption to enterprise functioning [10] [25]. Therefore, it's necessary to reveal and define key positions and to plan the employees for these positions sufficiently in advance so unexpected complications are thus avoided. Key positions may be identified from the analysis of organisational structure. These are, in particular, strategic positions of higher management [8].

1.1 Keeping Talents in Enterprise

Implementation of elements of the industry 4.0 is considered risky by enterprises in the CR, in particular due to the insufficiency of successful exemplary business cases. The problems are the shortcomings of studies for the integration of elements for industry 4.0 for top management and insufficient confidence in new procedures [26]. This is a hard task and this process could be critical without high-quality workers of the "talent pool." Creation of appropriate conditions for talents at key positions represents a reduction or the risk of their loss and potential improvement of loyalty towards respective enterprise [27]. According to Grenčíková et al. [28], number of experts are focusing mainly on the identification of talent pool in organisation, on their planning and development. However, their motivation and keeping them is also an important element [25] [29] [30].

The trends stated above are related also to the area of transportation and logistics within the Central Europe [24]. Transportation enterprises struggle with shortage of qualified and high-quality human resources. Significant shortage of necessary human resources are often solved by the employed of riskier groups of workers – graduates and older applicants. An important source are foreign workers from Ukraine, Russia, Mongolia and other countries [31] [32]. Another and also an innovative solution at the same time is the implementation of automation and smart systems into respective procedures, where it's possible to substitute human resources. A huge problem is to find and keep high-quality qualified and talented workers for the positions of higher management. Here, it's appropriate to use a targeted motivation system increasing the satisfaction of this group of workers,

and according to Jigjiddorj et al. [27], it will also provide loyalty towards enterprise secondarily. Hitka [33] states that a targeted motivation program for specific categories of workers has a higher efficiency and it's financially and timely more effective. This statement is also supported by the fact that if the applied motivational element is strongly preferred by workers, it's more effective than the combination of other elements that may be financially or timely more demanding. An appropriate choice and application of motivational program, with regard to the preferences of certain group of workers, creates opportunities for number of companies to develop a long-term competitive advantage [34] and for the security of competitiveness in global environment. This article follows the studies focused on motivation of workers and supplements the knowledge by a specific group of workers, representing a key element of success not only in the area of transportation and logistics. Presented results enrich the knowledge base by practical application within a case study from transportation and logistics environment of the Czech Republic.

2 Methodology

The objective of this article is to identify the motivation preferences of Czech managers at critical management positions (identified as talents by the enterprises) of transportation and logistic enterprises, and the determination of method for effective setup of effects of motivation factors for the purpose of keeping them in such enterprise. This article is based on the outcomes of research within enterprises active in the transportation and logistics industry where the attention is paid to managers at critical positions. Research was held in 2018 in the Czech Republic through a questionnaire. Within the research, 154 managers were interviewed, such enterprises marked as key high-quality employees at critical positions or planned for these positions in the enterprise, so-called talents (these are selected workers of middle and top management). 32 enterprises were engaged in this research. Characteristics of research sample was presented in the Table 1.

Table 1

Characteristic of research sample

			Gender				Total	
			Women	%	Men	%	Count	%
Age	Up to 30 years	Count	15	42.9%	20	57.1%	35	100.0%
		% within Gender	20.3%		25.0%		22.7%	
	31-40 years	Count	18	37.5%	30	62.5%	48	100.0%
		% within Gender	24.3%		37.5%		31.2%	
	41-50 years	Count	27	54.0%	23	46.0%	50	100.0%
		% within Gender	36.5%		28.8%		32.5%	
	51 and above	Count	14	66.7%	7	33.3%	21	100.0%
		% within Gender	18.9%		8.8%		13.6%	
of	Less than a 1	Count	8	53.3%	7	46.7%	15	100.0%

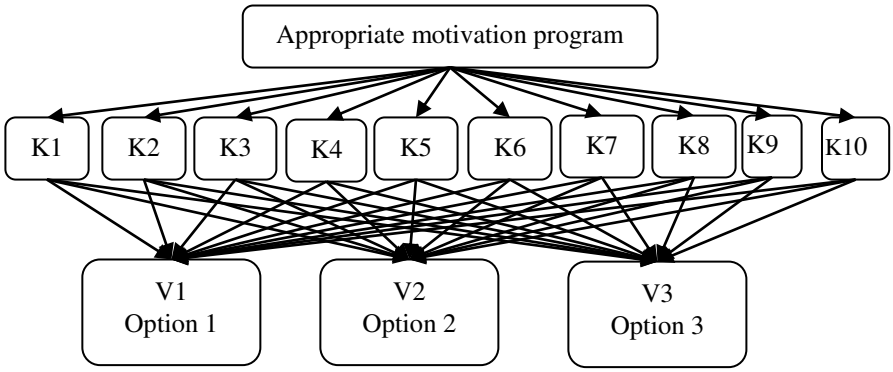
	year	% within Gender	10.8%		8.8%		9.7%	
	from 1 year to 3 years	Count	12	42.9%	16	57.1%	28	100.0%
		% within Gender	16.2%		20.0%		18.2%	
	from 4 years to 6 years	Count	11	35.5%	20	64.5%	31	100.0%
		% within Gender	14.9%		25.0%		20.1%	
	from 7 years to 9 years	Count	11	42.3%	15	57.7%	26	100.0%
		% within Gender	14.9%		18.8%		16.9%	
	10 years and above	Count	32	59.3%	22	40.7%	54	100.0%
		% within Gender	43.2%		27.5%		35.1%	
Total		Count	74	48.1%	80	51.9%	154	100.0%

The portion of men and women in the sample is relatively balanced, while in case of women, higher age categories prevail as well as their period of practice in comparison to men. This is probably caused by the fact that the Czech Republic belongs to masculine culture [35], preferring men for leading positions, in particular within top management. It takes more time to women to get to such positions [36] [37]. This questionnaire consisted of two basic parts – fundamental data about respondents (age, assignment, region in the Czech Republic, period of practice) and part for the evaluation of important of motivation factors. Respondents could evaluate 30 motivation factors on the basis of their subjective opinion on the importance at the Likert scale form 1 to 5 (1 – unimportant to 5 – the most important). Data were processed by the use of basic descriptive statistics and the verification of their significant differences was performed by the ANOVA test.

Suggested effective setting of motivation elements is based on the use of multi-criteria method of evaluation of options. Within the nature of input data and decision task, it's possible to use different methods of multi-criteria decision-making, e.g. the Decision matrix method, weighted sum approach method, TOPSIS or AHP method. The Decision matrix method [38] is a relatively simple and fast method of choosing the right option. With this method, options for each criterium within the range of 1-10 are evaluated, where 1 means inappropriate and 10 ideal). Following multiplication of this evaluation by the use of weight of criterium importance will determine the most optimal option. An analogical method is the weighted sum approach method, evaluating options according to their benefit within criteria from 0 to 1, when 0 means no benefit and 1 means maximum benefit [37]. The TOPSIS method works with an ideal and basal value of option and with a calculation of distance of options from these values. This method is more accurate than the weighted sum approach method and eliminates its defficiencies. The AHP multicriteria decision making method, based on a pair comparison of option appropriateness according to respective criteria, is more comprehensive and unbiased [39] [40]. Also, the use of pair verbal evaluation allows an easier decision and the requirements for consistency of the Sattyho matrix ensure more accurate setting of pair comparison of options. Its disadvantage is based on a relatively high time demanding nature in case there are more criteria and options used. In this article, selection of appropriate option will be solved by the use of the AHP method, while the hierarchy of decision-making

task is illustrated on Figure 1, where K1-10 is the criterium in a form of motivation factor and V1-3 is the evaluated option. Weights of criteria (motivation factors) are recalculated on the basis of results of the preferences' research of respondents according to gender. Within the solution of decision-making task, 10 most important criteria are considered for a group of men and separately for a group of women. This task application is solved in an environment of specific transport enterprise that submitted three options of motivation programs. The appropriateness of respective options according to each criterium is evaluated by three expert evaluators, consisting of top management workers and human resources department of the enterprise.

Figure 1
Hierarchy of solved task by AHP



In accordance with the principle of the AHP method, evaluators assign the weight of appropriateness of option in the range of 1 to 9 (1- both options take part on objective intervention in the same portion, 3 – first option is more appropriate than the second option to certain extent, 5 – first option is significantly more important than the second one, 7 - first option is far more important than the second one, and 9 – absolute preference of first option against the second one according to certain criterium). If the first option is less important than the other, this relationship is expressed by the inverse of the scales (1 / 1-9). This evaluation is expressed in formula 1, where "k" represents the number of all options and "p" means the evaluation on the range of importance for respective option. Consequently, as the assigned value i-th criterion is marked as pi, it is possible to estimate scales (Eq. 1) by calculation [38]. Consequently, the final evaluation can be entered in Saaty´s matrix, where each element Sij (Eq. 2 - 4) can be obtained as the ratio of estimating of weights for the i-th and j-th option [41]:

$$v_i = \frac{p_i}{\sum_{i=1}^{k} p_i} \; i = 1,2,\dots,k \; (1) \qquad s_i \approx \frac{v_i}{v_j} \; (i,j = 1,2,3,\dots.k) \; (2)$$

$$v_i' = \left(\prod_{j=1}^{k} s_{ij} \right)^{1/k} \quad i = 1,2, \ldots\ldots, k \ (3) \qquad v_i = \frac{v_i'}{\sum_{i=1}^{k} v_i'} \ i = 1,2, \ldots, k \ (4)$$

Substitution of calculated elements [42] of matrix into the Eq. 3 and 4 allows the calculation of weights of appropriateness of each option. Saaty´s method is the most appropriate form of determination [43] of options' appropriateness for the purpose of identification of appropriate motivation program in our case study for transport enterprise, as it respects comprehensive relations between respective criteria and alternative options. Within the research, following work hypotheses were set:

H1 From the perspective of gender of workers, marked as talents by transport enterprises (working in middle or top management), the evaluation of importance of motivation factors has no statistically important differences.

H2 The most appropriate option for workers marked as talents in transport enterprises, is the motivation program with the highest level of base wage.

3 Results and Discussion

Acquired data from the research were processed by the use of basic descriptive statistics, whose results are presented in the Table 2. Average evaluation of preferences of respective motivation factors states the arithmetic mean value. Within the results, it is diversified into the groups of women and men. Standard error of mean value lies within the range from 0.077 to 0.138, confirming the interpretability of calculated mean values. Following the results of average evaluation of importance of motivation factors (Table 2), the most important factor at workplace for key workers in top management, considered as talents according to their employer, is the atmosphere in workplace for both groups – men (arithmetic mean value 2.29) and women (4.58). Subsequently, preferences of men and women differ. Men consider the base wage (2.25) as the second most important factor while women placed it to the 5th place in importance (4.43). For women, a factor of the same importance as the atmosphere at workplace, are good colleagues (4.58), seen by men only at the third place of importance (4.20). As the third most important factor, seen by women, is the approach of superior employee (4.54). The fourth, most important factor, is identical for both gender categories, and that's the communication at workplace (4.51 for women and 4.19 for men) and also the application of their own skills (4.41 for women and 4.16 for men). Subsequently, women see fair evaluation as important (4.39), subject and type of work activities (4.35), work environment (4.35) and safety at workplace (4.27). In case of men, they assign then the highest importance to the subject (4.15) and type of performed work, certainty of such workplace (4.14), work environment (4.10)

and education and personal growth (4.06). On the basis of results of questionnaire, it may be stated that, from the gender point of view, the highest importance is not assigned to the motivation factor in a form of base salary.

Table 2

Basic statistical characteristics of the importance of motivational factors

Number of MF	Motivational factor (MF)	Women				Men				Total Mean
		Mean	Std. Deviation	Std. Error of Mean	Variance	Mean	Std. Deviation	Std. Error of Mean	Variance	
1	Workplace atmosphere	4.58	0.844	0.098	0.713	4.29	1.105	0.123	1.220	4.43
2	Good working team	4.58	0.794	0.092	0.630	4.20	0.947	0.106	0.896	4.38
3	More financial rewards	4.09	0.953	0.111	0.909	3.98	1.102	0.123	1.215	4.03
4	Physical demands of work	3.45	0.953	0.111	0.908	3.38	1.084	0.121	1.174	3.41
5	Job security	4.26	0.908	0.105	0.824	4.14	1.064	0.119	1.133	4.19
6	Communication	4.51	0.832	0.097	0.692	4.19	0.901	0.101	0.813	4.34
7	Prestige / company name	4.03	0.936	0.109	0.876	3.65	1.104	0.123	1.218	3.83
8	Applying own abilities	4.41	0.739	0.086	0.546	4.16	0.920	0.103	0.847	4.28
9	The content and type of work	4.35	0.801	0.093	0.642	4.15	0.901	0.101	0.813	4.25
10	Performance feedback	4.24	0.791	0.092	0.625	3.98	0.886	0.099	0.784	4.10
11	Working hours	4.24	1.018	0.118	1.036	4.04	0.974	0.109	0.948	4.14
12	Working environment	4.35	0.784	0.091	0.615	4.10	0.949	0.106	0.901	4.22
13	Work performance	4.26	0.795	0.092	0.632	4.00	0.842	0.094	0.709	4.12
14	Career advancement	4.15	0.828	0.097	0.685	4.03	0.886	0.099	0.784	4.08
15	Competences	4.05	0.905	0.105	0.819	3.94	0.891	0.100	0.794	3.99
16	Prestige of a job	4.12	0.793	0.092	0.629	3.89	0.955	0.107	0.911	4.00
17	Senior / supervisor access	4.54	0.666	0.077	0.444	4.01	1.037	0.116	1.076	4.27
18	Separate decision making	4.24	0.808	0.094	0.652	3.86	0.978	0.109	0.956	4.05
19	Self-realization	4.26	0.861	0.100	0.741	4.00	1.055	0.118	1.114	4.12
20	Social benefits	3.84	0.966	0.112	0.932	3.56	1.157	0.129	1.338	3.69
21	Fair evaluation	4.39	0.889	0.103	0.790	3.95	1.231	0.138	1.516	4.16
22	Workplace Safety	4.27	0.816	0.095	0.666	3.78	1.273	0.142	1.620	4.01
23	Psychic load	4.04	1.053	0.122	1.108	3.71	1.127	0.126	1.271	3.87
24	Company vision	3.96	0.943	0.110	0.889	3.72	1.085	0.122	1.178	3.84
25	Region development	3.70	1.131	0.132	1.280	3.30	1.226	0.137	1.504	3.49
26	Education and personal growth	4.09	0.995	0.116	0.991	4.06	1.035	0.116	1.072	4.08
27	Ecological approach	3.78	0.983	0.114	0.966	3.50	1.243	0.139	1.544	3.64
28	Free time	4.05	0.920	0.107	0.846	3.95	1.200	0.134	1.441	4.00
29	Recognition	4.11	0.915	0.106	0.837	3.88	1.236	0.138	1.528	3.99
30	Basic salary	4.43	0.938	0.109	0.879	4.25	1.061	0.119	1.127	4.34

Within the research, differences between men and women, tested by the ANOVA test at the level of significance of 5% (Table 3), were detected. Statistically significant differences were determined within motivation factors according to genders: good colleagues, communication at workplace, prestige – names of company, feedback to work results, approach of superior, individual decision making, fair evaluation of employee and regional development.

Table 3
ANOVA test of evaluation of the importance of motivational factors by gender

Number of motivational factor		Sum of Squares	df	Mean Square	F	Sig.
1 Workplace atmosphere	Between Groups	3.313	1	3.313	3.394	0.067
	Within Groups	148.401	152	0.976		
	Total	151.714	153			
2 Good working team	Between Groups	5.583	1	5.583	7.264	**0.008**
	Within Groups	116.814	152	0.769		
	Total	122.396	153			
3 More financial rewards	Between Groups	0.550	1	0.550	0.515	0.474
	Within Groups	162.288	152	1.068		
	Total	162.838	153			
4 Physical demands of work	Between Groups	0.193	1	0.193	0.185	0.668
	Within Groups	159.034	152	1.046		
	Total	159.227	153			
5 Job security	Between Groups	0.547	1	0.547	0.555	0.457
	Within Groups	149.609	152	0.984		
	Total	150.156	153			
6 Communication with colleagues	Between Groups	4.086	1	4.086	5.416	**0.021**
	Within Groups	114.674	152	0.754		
	Total	118.760	153			
7 Prestige / company name	Between Groups	5.464	1	5.464	5.186	**0.024**
	Within Groups	160.146	152	1.054		
	Total	165.610	153			
8 Applying own abilities	Between Groups	2.268	1	2.268	3.230	0.074
	Within Groups	106.725	152	0.702		
	Total	108.994	153			
9 The content and type of work performed	Between Groups	1.559	1	1.559	2.133	0.146
	Within Groups	111.065	152	0.731		
	Total	112.623	153			
10 Performance feedback	Between Groups	2.766	1	2.766	3.908	**0.050**
	Within Groups	107.572	152	0.708		
	Total	110.338	153			
11 Working hours	Between Groups	1.627	1	1.627	1.643	0.202
	Within Groups	150.509	152	0.990		
	Total	152.136	153			
12 Working environment	Between Groups	2.429	1	2.429	3.181	0.077
	Within Groups	116.065	152	0.764		
	Total	118.494	153			
13 Work performance	Between Groups	2.534	1	2.534	3.772	0.054
	Within Groups	102.122	152	0.672		
	Total	104.656	153			
14 Career advancement	Between Groups	0.603	1	0.603	0.818	0.367
	Within Groups	111.292	151	0.737		
	Total	111.895	152			

15 Competences	Between Groups	0.522	1	0.522	0.648	0.422
	Within Groups	122.471	152	0.806		
	Total	122.994	153			
16 Prestige of a job	Between Groups	2.107	1	2.107	2.717	0.101
	Within Groups	117.893	152	0.776		
	Total	120.000	153			
17 Senior / supervisor access	Between Groups	10.719	1	10.719	13.882	**0.000**
	Within Groups	117.366	152	0.772		
	Total	128.084	153			
18 Separate decision making	Between Groups	5.573	1	5.573	6.880	**0.010**
	Within Groups	123.109	152	0.810		
	Total	128.682	153			
19 Self-realization	Between Groups	2.534	1	2.534	2.710	0.102
	Within Groups	142.122	152	0.935		
	Total	144.656	153			
20 Social benefits	Between Groups	2.914	1	2.914	2.550	0.112
	Within Groups	173.742	152	1.143		
	Total	176.656	153			
21 Fair evaluation	Between Groups	7.506	1	7.506	6.430	**0.012**
	Within Groups	177.435	152	1.167		
	Total	184.942	153			
22 Workplace Safety	Between Groups	9.429	1	9.429	8.118	**0.005**
	Within Groups	176.545	152	1.161		
	Total	185.974	153			
23 Psychic load	Between Groups	4.137	1	4.137	3.469	0.064
	Within Groups	181.266	152	1.193		
	Total	185.403	153			
24 Company vision	Between Groups	2.163	1	2.163	2.084	0.151
	Within Groups	156.752	151	1.038		
	Total	158.915	152			
25 Development of the region	Between Groups	6.234	1	6.234	4.464	**0.036**
	Within Groups	212.259	152	1.396		
	Total	218.494	153			
26 Education and personal growth	Between Groups	0.040	1	0.040	0.038	0.845
	Within Groups	157.025	152	1.033		
	Total	157.065	153			
27 Ecological approach	Between Groups	3.096	1	3.096	2.444	0.120
	Within Groups	192.541	152	1.267		
	Total	195.636	153			
28 Free time	Between Groups	0.416	1	0.416	0.360	0.549
	Within Groups	175.584	152	1.155		
	Total	176.000	153			
29 Recognition	Between Groups	2.089	1	2.089	1.746	0.188
	Within Groups	181.885	152	1.197		
	Total	183.974	153			
30. Basic salary	Between Groups	1.279	1	1.279	1.270	0.262
	Within Groups	153.162	152	1.008		
	Total	154.442	153			

Note: statistically significant differences within the motivation factor are marked thick

Results of the ANOVA test demonstrated that the atmosphere at workplace has the same importance for both groups without statistically significant difference, dependent on gender. In case of women, good colleagues, approach of superior and communication at workplace were evaluated at a significantly higher level as

in case of men. It proves the fact that for women the interpersonal relations within work procedure enjoy clearly higher importance. They consider it as more important than the system of basic financial evaluation. On the other hand, men consider the base wage as the second most important factor. From the perspective of importance, both groups see then the utilisation of their skills and the subject and type of work as important the factor, demonstrating the need of working in their profession and use of their knowledge and experiences. At the same time, it's also significantly more important for women to get feedback to their performance as well as the possibility to decide on their own, what men consider as less important. This fact may be connected to higher self-confidence in management. On the basis of results of the ANOVA test, we may state that the workers, marked as talents, show statistically significant differences in the context of preference of motivational factors according to gender. Thus, we refuse the H1 work hypothesis for the benefit of the alternative one.

For the determination of appropriate tool to select an optimal motivation program from more options, the AHP method looks as appropriate. This method seems to be appropriate for the reason that it provides the possibility of comparison of options in words on the basis of weight of determined criteria (motivation factors) by expert evaluator. In this case study, three workers of selected enterprise are in the role of expert evaluators. These are workers of human resources department and top management, proposing three options of motivation programs. Research will evaluate the possibility of use of the AHP method in this case. Following the suggestion of one of the investigated enterprises, we will apply selection from these three options of motivation programs:

- **Motivation program V1**: Motivation program is focused mainly on the diversification of higher amount of personal evaluation according to work performance with the determination of lower base wage. This is determined in a very specifically prepared evaluation system for fair evaluation and strong feedback to work results. It provides high possibility of education and personal growth (targeted plan of talents' education), taking the high potential of career growth into consideration. This system is based rather on competitive atmosphere and mutual rivalry, where the impact on higher performance is expected. Social benefits are also strongly diversified according to status in hierarchy and credit in enterprise. There's a strong feedback to performance in a form of evaluation interviews, held biannually. Work hours are fixed and controlled, workers have the possibility to get refreshment at workplace (juics, mineral waters, teas, coffee and sandwiches) besides lunch. Safety at workplace is solved in compliance with EU legal rules and assessed in regular intervals.
- **Motivation program V2**: This motivation program is focused on the setting of lower wage evaluation in comparison to competitors, while there exists a higher portion of personal evaluation, dependent on work results, fixed for a longer period of time (year). This setting should create fair evaluation of workers without strong pressure on rivalry and competition. In particular, cooperation,

collaboration, open communication and friendly atmosphere are supported. For this purpose, informal meetings and activities, formation of project teams through hierarchy and coaching approach of managers become tradition. Coaching management style is supported also by the need of self-fulfillment, individual decision-making and utilisation of own skills of individuals. At the same time, management style supports regular bidirectional feedback between the superior and subordinated employees. Career growth is slower and based on proven abilities and education while personal growth is executed according to a targeted and individually focused plan for talent development in enterprise. Significant attention is paid to work environment – configuration of work space, offices, light, entry into building and its surrounding area. Safety at work is solved in compliance with EU legal rules and assessed in regular intervals.

- **Motivation program V3**: This motivation program is based on a higher portion of base wage (in comparison with competitors) without any additional evaluation portion. Fairness in evaluation is solved by feedback to performance and the possibility to get wide social benefits and by program for education, personal and career growth. Management is solved by a strong structure of hierarchy with clearly set formal competences and subject of work. The approach of superior is very formal, but subordinated employees may participate on solution and decision-making process of departments. For the purpose of collective integration, mutual meetings are created in a form of corporate breakfasts and sport activities. Subordinated employees get maximum feedback over year, always on quarterly basis in a form of assessment interview, where they can provide comments. Safety at work is solved in compliance with EU legal rules and assessed in regular intervals.

With regard to the scope of this article, ten most important criteria (motivation factors) are considered for the selection of appropriate option of motivation program within a group of women and men. Table 4 shows the calculation of importance weights of ten most preferred criteria within motivation of women and men. This calculation is based on the recalculation of final values of arithmetic mean value, gained by the evaluation at Likert scale from talents in the transportation and logistics industry.

Table 4

Weights of criteria for men and women - the most important motivational factors

	Women´ weight of criteria			Men weight of criteria		
code	criterion		weight	criterion		weight
K1	1	Workplace atmosphere	0.103134	1	Workplace atmosphere	0.103127
K2	2	Good working team	0.103134	30	Basic salary	0.102225
K3	17	Senior / supervisor access	0.102221	2	Good working team	0.101022
K4	6	Communication with colleagues	0.101612	6	Communication with colleagues	0.100722
K5	30	Basic salary	0.099787	8	Applying own abilities	0.100120
K6	8	Applying own abilities	0.099179	9	Content and type of work	0.099820
K7	21	Fair financial remuneration	0.098874	5	Job security	0.099519
K8	9	Content and type of work	0.097962	12	Working environment	0.098617

K9	12	Working environment	0.097962	26	Education and personal growth	0.097715
K10	22	Workplace safety	0.096136	11	Working hours	0.097114
Total			1.000000	Total		1.000000

Table 5

Saaty´s matrix for variants of motivational programs according to criteria for women

K1	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K6**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.12	0.21	0.29516	0.06552	**V1**	1	0,27	1,00	0,64850	0,15194
V2	8.33	1	3.67	3.12630	0.69394	**V2**	3,67	1	8,33	3,12630	0,73249
V3	4.67	0.27	1	1.08371	0.24055	**V3**	1,00	0,12	1	0,49324	0,11557
K2	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K7**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.14	0.19	0.29460	0.06747	**V1**	1	0.33	1.33	0.76314	0.21972
V2	7.33	1	3.33	2.90220	0.66467	**V2**	3.00	1	3.00	2.08008	0.59890
V3	5.33	0.30	1	1.16961	0.26787	**V3**	0.75	0.33	1	0.62996	0.18138
K3	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K8**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.12	0.23	0.30254	0.06744	**V1**	1	0.43	0.96	0.74286	0.21555
V2	8.33	1	3.67	3.12630	0.69688	**V2**	2.33	1	3.67	2.04526	0.59347
V3	4.33	0.27	1	1.05726	0.23568	**V3**	1.05	0.27	1	0.65818	0.19098
K4	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K9**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.12	0.19	0.28231	0.06216	**V1**	1	0.43	0.43	0.56844	0.17082
V2	8.33	1	3.67	3.12630	0.68836	**V2**	2.33	1	2.33	1.75921	0.52866
V3	5.33	0.27	1	1.13303	0.24948	**V3**	2.33	0.43	1	1.00000	0.30051
K5	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K10**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	1.00	0.13	0.50000	0.10000	**V1**	1	1.00	1.00	1.00000	0.33333
V2	1.00	1	0.13	0.50000	0.10000	**V2**	1.00	1	1.00	1.00000	0.33333
V3	8.00	8.00	1	4.00000	0.80000	**V3**	1.00	1.00	1	1.00000	0.33333

Table 6

Saaty´s matrix for variants of motivational programs according to criteria for men

K1	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K6**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.12	0.21	0.29516	0.06552	**V1**	1	0.30	1.67	0.79370	0.21780
V2	8.33	1	3.67	3.12630	0.69394	**V2**	3.33	1	3.67	2.30347	0.63210
V3	4.67	0.27	1	1.08371	0.24055	**V3**	0.60	0.27	1	0.54697	0.15009
K2	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K7**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	1.00	0.13	0.50000	0.10000	**V1**	1	1.00	1.00	1.00000	0.33333
V2	1.00	1	0.13	0.50000	0.10000	**V2**	1.00	1	1.00	1.00000	0.33333
V3	8.00	8.00	1	4.00000	0.80000	**V3**	1.00	1.00	1	1.00000	0.33333
K3	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K8**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.14	0.19	0.29460	0.06747	**V1**	1	0.43	0.43	0.56844	0.17082
V2	7.33	1	3.33	2.90220	0.66467	**V2**	2.33	1	2.33	1.75921	0.52866
V3	5.33	0.30	1	1.16961	0.26787	**V3**	2.33	0.43	1	1.00000	0.30051
K4	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K9**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.12	0.19	0.28231	0.06216	**V1**	1	0.43	2.33	1.00000	0.28686
V2	8.33	1	3.67	3.12630	0.68836	**V2**	2.33	1	3.33	1.98131	0.56836
V3	5.33	0.27	1	1.13303	0.24948	**V3**	0.43	0.30	1	0.50472	0.14478
K5	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$	**K10**	**V1**	**V2**	**V3**	$\mathbf{v_i'}$	$\mathbf{v_i}$
V1	1	0.27	1.00	0.64850	0.15194	**V1**	1	4.00	8.00	3.17480	0.71335
V2	3.67	1	8.33	3.12630	0.73249	**V2**	0.25	1	3.33	0.94104	0.21144
V3	1.00	0.12	1	0.49324	0.11557	**V3**	0.13	0.30	1	0.33472	0.07521

Comparison of options appropriateness in pairs for women and men according to respective criteria is presented in the Table 5 and Table 6. In this comparison, values from 1 to 9 are assigned to expert evaluators (in our case, 3 evaluators from selected enterprise) within evaluation in words, where 1 means that options are equally appropriate and 9 means that the first option is absolutely more appropriate than the second one. In the event of opposite ratio, a converse value of this expression is used, like 1/9. The condition of matrix consistency through the value λmax is necessary, being equal to the number of compared "k" elements under full consistency of matrix. The evaluation of adequate level of consistency is solved by the C.I. (consistency index), reaching the values up to 0.1 for a sufficiently consistent matrix. Results of the consistency index within the matrix for women and men reach values within the range from 0.0046 to 0.0465 their value does not exceed the limit of 0.1, and therefore, we may consider the results of matrixes as interpretable.

Table 7

Evaluation of the suitability of variants using AHP method for women

Crit.	The weight of the variants of motivational program			weight of criterion	Evaluation results of the programs		
	V1	V2	V3		V1	V2	V3
K1	0.06552	0.69394	0.24055	**0.10313**	0.00676	0.07157	0.02481
K2	0.06747	0.66467	0.26787	**0.10313**	0.00696	0.06855	0.02763
K3	0.06744	0.69688	0.23568	**0.10222**	0.00689	0.07124	0.02409
K4	0.06216	0.68836	0.24948	**0.10161**	0.00632	0.06995	0.02535
K5	0.10000	0.10000	0.80000	**0.09979**	0.00998	0.00998	0.07983
K6	0.15194	0.73249	0.11557	**0.09918**	0.01507	0.07265	0.01146
K7	0.21972	0.59890	0.18138	**0.09887**	0.02173	0.05922	0.01793
K8	0.21780	0.63210	0.15009	**0.09796**	0.02134	0.06192	0.01470
K9	0.17082	0.52866	0.30051	**0.09796**	0.01673	0.05179	0.02944
K10	0.33333	0.33333	0.33333	**0.09614**	0.03205	0.03205	0.03205
Total evaluation					0.14381	**0.56890**	0.28729
The order of suitability of the variants					3	**1**	2

Table 7

Evaluation of the suitability of variants using AHP method for men

Crit.	The weight of the variants of motivational program			weight of criterion	Evaluation results of the programs		
	V1	V2	V3		V1	V2	V3
K1	0.06552	0.69394	0.24055	**0.10313**	0.00676	0.07156	0.02481
K2	0.10000	0.10000	0.80000	**0.10222**	0.01022	0.01022	0.08178
K3	0.06747	0.66467	0.26787	**0.10102**	0.00682	0.06715	0.02706
K4	0.06216	0.68836	0.24948	**0.10072**	0.00626	0.06933	0.02513
K5	0.15194	0.73249	0.11557	**0.10012**	0.01521	0.07334	0.01157
K6	0.21780	0.63210	0.15009	**0.09982**	0.02174	0.06310	0.01498
K7	0.33333	0.33333	0.33333	**0.09952**	0.03317	0.03317	0.03317
K8	0.17082	0.52866	0.30051	**0.09862**	0.01685	0.05214	0.02964
K9	0.28686	0.56836	0.14478	**0.09771**	0.02803	0.05554	0.01415
K10	0.71335	0.21144	0.07521	**0.09711**	0.06928	0.02053	0.00730
Total evaluation					0.21433	**0.51608**	0.26959
The order of suitability of the variants					3	**1**	2

The result of Saaty´s matrix are the weights of respective options for each assessed criterium (Tables 7 and 8). These weights of options under criteria are recalculated through the weights of criteria in the Table 7 and the sum of resulting values within respective options determines the order of their appropriateness. For women, the V2 option seems to be the most appropriate, while subsequently the V3 option, with a lower preference by 49.5%, is identified. In case of men (Table 8), the V2 option seems to be the most appropriate, while subsequently, the V3 option is preferred, losing by 47.8% compared to the previous one.

From the stated application of the AHP method to this specific case it's clear that for both groups of leading workers (marked as talents by enterprises), working in the transportation and logistics industry, the second option of motivation program, proposed by selected enterprise, is the most optimal one. An interesting aspects is the fact that despite the preference of base wage by men at the second top place, the second option is more appropriate, having its base wage at lower level in comparison with competitors while the total evaluation is based on another financial aspect of personal evaluation of performance for certain period of time. From the stated above it's clear that the option based on cooperation atmosphere, open communication and coaching approach by superiors, it forms appropriate motivation conditions for workers of both gender categories, despite a lower level of base wage. Also, the workers at managing positions in the transportation and logistics industry, considered as talents, have such wage remuneration that this hygienic factor is fulfilled and the relationship motivation factors are becoming more motivational. From the result of the use of the AHP method, we can confute the H2 work hypothesis for the benefit of the alternative one. For the group of workers in consideration, the most appropriate motivation program is the option that does not offer the highest level of base wage.

Vlacseková and Mura [44] [45] stress the fact that motivation is very individual and managers have a difficult role to motivate their employees. Research has confirmed a stronger level of motivation by internal factors more than external factors, which superiors should not overlook. Based on our results, it can be stated that women tend to assign greater importance to all factors in general compared to men. In the context of comparable research, this trend is also seen in women [46] [47] [48], regardless of nationality [49] [50] [51]. Hitka et al. [52] presents the results of research of motivational preferences of managers in woodworking companies in Slovakia. He determined 3 basic clusters, which differ in the preferences of motivational factors. Two clusters consider the basic salary to be the most important motivational factor and the third cluster to be primarily a fair evaluation system. The results of this research may differ for a number of reasons from ours, as respondents live under different national economic conditions, but it is also a different professional field of work and 2016, and the fact that they are not labeled as talents. On the contrary, a more recent study from 2019 by Lorincova at al. [53] about the motivational preferences for the senior management category correspond to our findings from the gender perspective.

Slovak senior management prefers the basic salary factor to a workplace atmosphere factor for both men and women. While for women, the second most important factor is a good work team and then a basic salary. Men have a sequence of two other factors opposite. Mikkelsen et al. [54] states that employee motivation requirements may change even if their regional needs are met. In view of this, it is advisable to continuously review the effectiveness of the current incentive program and to diversify it as needed. Greiner [55] draws attention to the fact that, for each enterprise, the incentive system is a complex and costly activity, but according to Kachaňáková and Urbancová [56], its effectiveness can significantly affect and promote the competitiveness of the company. Vetráková [5] [57] adds that the effectiveness of the motivation program is influenced by a precise analysis of employees and not neglecting this aspect can significantly strengthen the incentive program.

Conclusions

The aim of the paper is to identify the motivation preferences of Czech managers on critical management positions of transport and logistics companies and to determine the method for effective setting of motivational factors in order to keep them in the company. Correct definition and selection of a motivational program may depend on multiple factors. In this article, attention is focused on workers referred to as talents who work in the transport and logistics field. The most important thing for these workers is the atmosphere in the workplace and then the preferences diversify by gender. For men, the amount of basic salary is another powerful incentive. However, in general it can be said that, in the first place, relationship motivation factors such as workplace atmosphere, good workforce and workplace communication are at the forefront. This may be due to the fact that these workers have a relatively high financial reward and a clear career in the company. For this reason, the importance of financial valuation and career advancement is shifted to other aspects. This also explains the appropriateness of a determined motivational program for both gender groups. However, it is a matter of further research, as the motivation of the category of workers under investigation will evolve over time and also the impact of satisfying other motivational factors on the perception of their importance. Conclusions in this article may be helpful for the entrepreneurs not only in the area of transportation and logistics services to get a strong system for the purpose of keeping talents in the enterprise, but also for the formation of satisfaction and loyalty towards enterprise. Presented method of setup of motivation factors is universally utilizable for any industry and region.

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Novel Motion Planning Method for Mobile Robots Using Velocity Obstacle

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The main concept of this article is to introduce a cost function based algorithm for the reactive motion planning problem of mobile robots. With the usage of the cost function, different strategies can be combined. Next to speed and safety, several aspects can play a role in the motion. i.e. Traffic Regulation rules or lane-keeping. The different methods can be used separately as well, but the combination of methods provides an appropriate solution. The introduced reactive motion planning algorithm generates a collision-free solution for the agent in dynamic environment.

Keywords: motion planning; mobile robots; cost function; dynamic environment; obstacle avoidance

1 Introduction

Robot technology is one of the most important fields of modern technology. The robots are used in different fields of the world to perform tasks faster or more accurate than humans (e.g, [1]-[3]). The main task of mobile agents is to execute a collision-free motion to the target position from a start position. The agent has to fulfill several requirements during its motion. One of the most critical tasks is to reach the target quickly as possible. Another important goal of motion planning is to ensure the safety of the environment and the agent.

Using motion planning algorithms, the velocity and the path profile of the robot can be generated. These algorithms can be divided into subsets considering the knowledge of the environment. If every information is given as a priori information, then offline global motion planning methods (e.g.: *Rapidly-exploring random tree (RRT)* [4]-[5], *Hybrid A** [6], *Metaheuristic Global Path planning* [7]) can ensure a suitable solution. If there is only local information about the environment, online reactive motion planning algorithms should be applied. The main goal of local motion planning algorithms is to plan local obstacle-avoidance maneuvers.

At the *Artificial Potential Field (APF)* method, all of the obstacles appear as repulsive forces, and the target generates an attractive virtual force. The result of the summation of the presented forces should be calculated [8]-[12]. With this methodology, the actual direction and the magnitude of the velocity of the robot can be calculated. The method was defined for the static environment first; after that, it was extended for dynamic environment. For example, it was applied in robot soccer [12]. It can also be used for nonholonomic robots too. Sometimes this motion planning method finds only a local optimum. A novel optimization method was introduced for AMOEBA-I robot using the modified potential field method [13]. In that case, the robot has the opportunity to find a solution in divergent cases when the normal *APF* method fails (narrow spaces).

Introducing a time dimension, the *State time-space* method [14] can generate a solution in dynamic environment. The task is to find a time-optimal trajectory for the robot using a confined set of canonical trajectories. The algorithm was also used for car-like robots.

The main idea of the *Dynamic velocity space (DVS)* motion planning method is to map the obstacles (static and moving) and the robot from the workspace to the velocity space. Two components should be used to accomplish this mapping: times to escape from collision and times to collision. Several aspects can be taken into account during the motion, i.e.: shortest path, minimum time trajectories [15].

The *Dynamic window (DWA)* method was introduced as a velocity space-based local motion planning method [16]. The control commands are selected in the velocity space for the robot. The final trajectory can be defined as the series of straight line and circular arcs as it was introduced in [17]. The actual velocity vector can be calculated, considering the kinematic and dynamic constraints of the robot.

The set of *Inevitable collision states (ICS)* contains every state of the robot when the collision is inevitable between the agent and the obstacle in the future. The state of the robot is in *ICS* if no control would result in a collision-free motion for the robot [18]. In a collision-free guaranteed motion, the robotic system never finds itself in an ICS situation. The algorithm was also extended for the dense and dynamic environment [19].

The *Directive circle (DC)* method is an extension of the *Velocity Obstacles (VO)* method [20]-[21]. At this method, the velocity of the agent will be selected from *DC*. That is drawn using the maximum velocity of the robot for the radius of the *DC*. Ensuring the kinematic constraints of the robot, the best solution is selected from the DC that is in the optimal direction to the target position. The DC method prevents the robot from staying in a local minima situation.

The *Evolutionary Algorithm* can also be used to generate an optimal path for the agent [22]-[23]. A novel concept was introduced using Gravitational Search Algorithm [24]. In that case, the optimal path can be generated in a partially

known environment. First, an optimal path is constructed offline, and later on, the agent follows this optimal path until a new obstacle blocks the path. At that time, using the sensor data, the robot can determine the positions of the other obstacles, and it is able to plan a collision-free path. The implemented algorithm was successfully used in robotic system. The evolutionary algorithm can be used with Artificial Neural Networks for optimization problems [25].

At the *Bug* algorithm, the robot moves in the direction of the target if the path is free. If the agent reaches an obstacle, then it has a tangential motion on the boundary of the obstacle. After that, the agent continues the motion to the target position [26].

There are even more mobile robots that have been appeared in the technology using automatization. In the future, they may have to use similar traffic rules and lanes in the factories as the cars on the roads. The main novelty of our work is that the introduced reactive motion planning methods can consider these new ideas (such as lane-keeping or traffic rules) during the motion planning of the mobile robots next to the obstacle avoidance strategy considering dynamic environment. Our main motivation was to combine and develop our previously introduced motion planning algorithms [27]- [29] using an extension of the lane keeping algorithm.

The article is constructed in the following order: Section 1.1 presents the *Velocity Obstacles* method that is the basic of our introduced motion planning methods. Section 2 presents the *Traffic Regulation Velocity Obstacles (TRVO)* method that can handle the traffic rules during the motion planning. After that, different aspects and strategies of the motion planning algorithms are introduced in Section 3 (using cost function based methods). Later, the simulation results will be presented in Section 4. At the end of the paper, conclusions are given.

1.1 Velocity Obstacles Method

The *Velocity Obstacles* (*VO*) method is a reactive motion planning method that uses the velocities and the positions of the agent and the obstacles [30]-[34]. The *VO* method was first developed for omnidirectional robots. So in this paper, an omnidirectional robot is used too, considering that at a velocity selection step, it can change its velocity vector immediately. The limitation of this usage is that most of the autonomous vehicles are nonholonomic like differential-driven mobile robots or cars. There were also attempts to use the *VO* for differential-drive mobile robots [31]. To increase the maneuverability, an *Effective center* and *Effective radius* were defined [35]. The kinematic constraints were fulfilled for this new center-point of the agent.

As an assumption, the obstacles B_i ($i = 1 \ldots n$ where n denotes the number of obstacles) and the robot A are presented as disk-shaped objects and their radii are known. In the motion planning algorithms, the robot is usually presented as a

point by decreasing its radius to zero and increasing the radii of obstacles. $\mathbf{p}_A$ is the position of the robot, $\mathbf{p}_{Bi}$ is the position of the obstacle B_i. $\mathbf{v}_A(0)$ represents the initial velocity vector of the agent, and $\mathbf{v}_{Bi}$ is the velocity vector of B_i. Both the position and velocity vectors are two-dimensional vectors in the workspace.

The VO_i is a cone that consists of every velocity of the agent ($\mathbf{v}_A$) that would result in a collision with B_i in the future if $\mathbf{p}_A$, $\mathbf{p}_{Bi}$ and $\mathbf{v}_{Bi}$ are given. The cone of VO_i can be defined as:

$$VO_i = \{ \ \mathbf{v}_A \mid \exists t: \mathbf{p}_A + \mathbf{v}_A t \cap \ \mathbf{p}_{Bi} + \mathbf{v}_{Bi} t \neq 0\} \tag{1}$$

It is assumed in (1) that the velocities of the robot and also the obstacles will not change until t. Every velocity vector of the robot is always represented with the endpoint of the velocity vector and the starting point is always the position of the robot.

If there are more obstacles in the workspace, the whole *VO* set can be defined by the union of the different VO_i cones:

$$VO = \cup_{i=1}^{n} VO_i \tag{2}$$

Figure 1 shows an example of the workspace of the robot with a moving obstacle (with position $\mathbf{p}_{B1}$ and velocity $\mathbf{v}_{B1}$) and a static obstacle (with position $\mathbf{p}_{B2}$). The grey cones mean the *VO*.

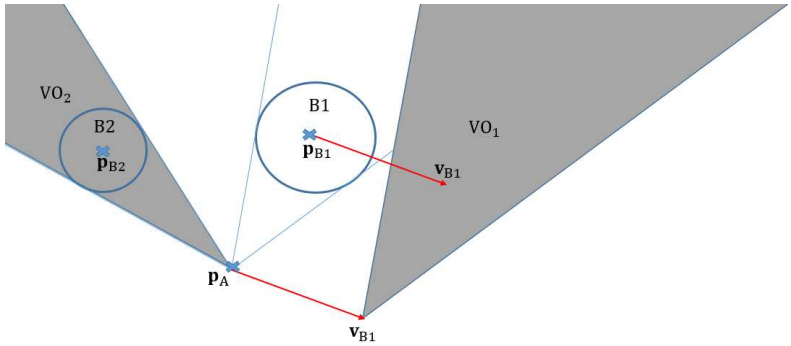

Figure 1
Example for Velocity Obstacles

Using the kinematic and dynamic constraints of the robot, the *Reachable Velocities* (*RV*) can be calculated that consists of every $\mathbf{v}_A$ velocity vector of the robot that is reachable from $\mathbf{v}_A(0)$ in the next sampling time. By subtracting the *VO* from the *RV*, the *Reachable Avoidance Velocities (RAV)* can be calculated. The velocity selection from the *RAV* area is presented in Figure 2, where the yellow area presents the *RAV*, R means the the robot, O is the obstacle, the grey area represents the *VO* set, the selected velocity vector is presented with a blue circle, and the G shows the goal. Usually, a heuristic method is used to choose a velocity vector from *RAV*. For example, the robot can select such a velocity vector that will cause the nearest motion to the target position.

Using the *Velocity Obstacle method*, it is also possible that the robot selects a velocity from the boundary of the *VO* and *RAV* to ensure the fastest target reaching. In that case, the robot will move tangentially to the obstacle during its motion. If information about the obstacles ($\mathbf{p}_{Bi}, \mathbf{v}_{Bi}$) are not accurate, this type of motion could cause a collision between the agent and the obstacle. To ensure a collision-free motion, different aspects can be taken into account.

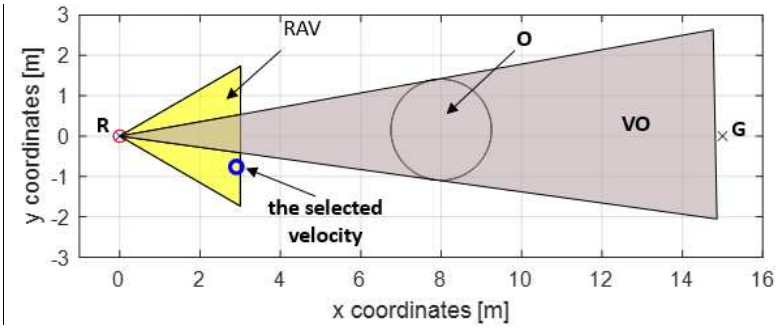

Figure 2
Selecting a velocity vector from RAV

2 Traffic Regulation Velocity Obstacles (TRVO) Method

The basic of the *Traffic Regulation Velocity Obstacles (TRVO)* method was first introduced by us in [27]. In this paper, a developed version of the *TRVO* method is introduced with lower calculating cost. The main idea of this method is to choose a velocity for the agent that will satisfy the basic rules of the Traffic Regulation. This method was inspired by [36]-[37], where *COLREGS (International Regulations for Preventing Collisions at Sea)* were used for *Unmanned Surface Vehicles (USV).*

The *TRVO* method considers four rules for motion planning:

- Crossing from the left, Crossing from the right
- Overtaking, Head-on

The main concept of this method is to select the velocity areas from the *RAV* that will ensure compliance with the rules. These areas can be denoted for every obstacle by S_r, S_f, and S_d. Using a velocity vector for the agent from these areas will result in different maneuvers for the robot during its motion. The r has a meaning of rear maneuver, d is the divergent, and f is the front maneuver in consideration of the obstacle and the robot. For a given $\mathbf{v}_A$, if it is not parallel to $\mathbf{v}_{Bi}$ the intersection point of the paths of A and B_i can be determined as:

$$\mathbf{p}_A + \mathbf{v}_A t_A = \mathbf{p}_{Bi} + \mathbf{v}_{Bi} t_{Bi} = \mathbf{p}_x \tag{3}$$

where $\mathbf{p}_x$ is a point in the workspace where the obstacle and the robot would intersect their path during their motion in the future or the past.

The different subsets of *RAV* can be defined using the value of t_A and t_{Bi} as:

$$0 < t_A < t_{Bi} \Rightarrow \mathbf{v}_A \in S_f \tag{4}$$

$$0 < t_{Bi} < t_A \Rightarrow \mathbf{v}_A \in S_r \tag{5}$$

$$\min(t_A, \ t_{Bi}) \ < 0 \Rightarrow \mathbf{v}_A \in S_d \tag{6}$$

$$t_A = t_{Bi} \ and \ \ min(t_A, t_{Bi}) > 0 \Rightarrow collision \tag{7}$$

Figure 3 shows a situation where the velocities can be divided into three subsets. The red-colored subset represents the velocity vectors of the agent that would result in a front maneuver to the obstacles. The green area consists the velocities resulting in a rear maneuver. The blue area means the divergent velocity vectors of the agent.

In every sampling time, these subsets must be constructed. With the knowledge of the measured position and velocities of the agent and the obstacles, the actual rule can be constructed. At *Crossing from the right* situation, the velocity can be chosen from the union of S_r and S_d. At *Crossing from the left* situation, the velocity can be chosen from the union of S_r, S_f. and S_d, so form the *RAV*. At *Head-on* situation, every velocity vector can be chosen that will result in a right maneuver to the corresponding obstacle. At the *Overtaking* situation, those velocities can be selected that will contribute a left maneuver to the corresponding obstacle. (The algorithm is applied in right-hand traffic situation).

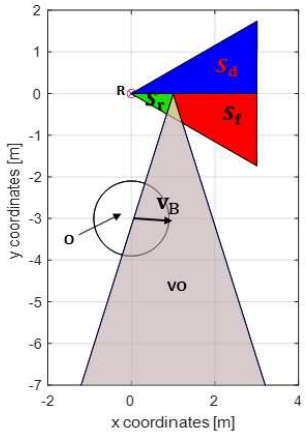

Figure 3
3 subsets of the RAV

3 Strategies for Velocity Selection of the Mobile Robot

In this section, different methods will be presented that can be used for selecting velocities of the robot considering the introduced *TRVO* method.

During motion planning, not every obstacle will play a role at every sampling time. Only those obstacles have an impact on the motion, whose distance to the robot is inside of a limit [27]. For every obstacle B_i, the time $t_{min_{A,\mathrm{Bi}}}$ can be defined as:

$$t_{min_{A,\mathrm{Bi}}} = \frac{-(\mathbf{p}_A - \mathbf{p}_{Bi})\cdot(\mathbf{v}_A - \mathbf{v}_{Bi})}{||\mathbf{v}_A - \mathbf{v}_{Bi}||} \tag{8}$$

where $t_{min_{A,\mathrm{Bi}}}$ is the time when the obstacle is at the nearest to the agent if $\mathbf{v}_A$ and $\mathbf{v}_{Bi}$ remain constant. The notation $||.||$ means the secondary norm, so the Euclidean distance of the presented vectors.

The minimal distance at the calculated $t_{min_{A,Bi}}$ is:

$$d_{min_i} = ||(\mathbf{p}_A + \mathbf{v}_A t_{min_{A,Bi}}) - (\mathbf{p}_{Bi} + \mathbf{v}_{Bi} t_{min_{A,Bi}})|| \tag{9}$$

At a given time moment, only those obstacles will be considered that satisfy the following relation:

$$0 < t_{min_{A,Bi}} < t_{max} \quad and \quad d_{min_i} < d_{max} \tag{10}$$

where t_{max} is a specified time limit, and d_{max} is a specified maximal limit of the distance between the agent and the obstacle. This equatuion can be calculated using precheck algorithm that is presented in Figure 4.

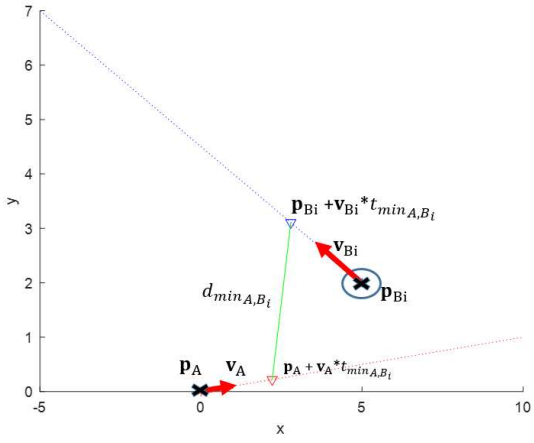

Figure 4
Precheck algorithm

3.1 Safety Velocity Obstacles (SVO) Method

Safety Velocity Obstacles (SVO) was first introduced by us in [28]. The main goal of the *SVO* method is to find the velocity vector for the agent that will result in the safest motion. For the solution, the furthest vector from *RAV* must be selected in consideration of the nearest VO cone. To ensure this solution, the minimal 2-norm must be calculated between the VO cone and the given velocity vector as it is presented in (11). $\mathbf{p}_{VO}$ is the point of the nearest VO cone and $D_S(\mathbf{v}_A)$ means the minimal distance:

$$D_S(\mathbf{v}_A) = \min\{\min_{\mathbf{p}_{VO} \in VO} ||\mathbf{v}_A - \mathbf{p}_{VO}||, D_{max}\} \tag{11}$$

where D_{max} represents the maximum distance that is considered.

$D_S(\mathbf{v}_A)$ can be transformed into [0,1] by dividing $D_S(\mathbf{v}_A)$ by D_{max}.

$$C_S(\mathbf{v}_A) = 1 - \frac{D_S(\mathbf{v}_A)}{D_{max}} \tag{12}$$

The safest motion will be resulted by selecting the velocity vector for the robot that has the minimum value of $C_S(\mathbf{v}_A)$.

Using only the above-presented algorithm, it can be resulted that selecting the safest velocity will not ensure the target reaching during the motion.

3.1.1 Extended Cost Function of SVO Method

Using an extended cost function at the *SVO* method, the safety of the robot and the environment, and also the target reaching will influence the motion planning algorithm. The value of the cost function can be calculated as:

$$Cost(\mathbf{v}_A) = \alpha\, C_S(\mathbf{v}_A) + \beta\, C_G(\mathbf{v}_A) \tag{13}$$

In (13), always the minimal value of $Cost(\mathbf{v}_A)$ must be found. $C_G(\mathbf{v}_A)$ represents the cost value of the fastest target reaching:

$$C_G(\mathbf{v}_A) = \frac{||\mathbf{p}_A + \mathbf{v}_A T_s - \mathbf{p}_{goal}||}{||\mathbf{p}_A(0) - \mathbf{p}_{goal}||} \tag{14}$$

where T_s means the sampling time, $\mathbf{p}_{goal}$ means the position of the goal, $\mathbf{p}_A(0)$ is the start position of the robot. So $C_G(\mathbf{v}_A)$ means the distance between the robot and the desired position using the investigated velocity vector, and it is normalized with the distance of the target and start position.

In the cost function, the motion planning is influenced by the $\alpha \geq 0$ and $\beta \geq 0$ parameters. If $\beta = 0$ and $\alpha \neq 0$, then the safest, if $\alpha = 0$ and $\beta \neq 0$, then the fastest solution will be generated. In other cases, safety and speed will play a different role during the algorithm.

3.2 Lane Keeping Velocity Obstacles (LKVO) Method

The *Velocity Obstacles* method and the *Safety Velocity Obstacles* method can be used even if there is no lane inside of the workspace of the agent. However, if there is a lane, then the *Lane Keeping Velocity Obstacles (LKVO)* method can ensure an appropriate solution. The basic of this motion planning method was introduced in our previous work for straight lanes [29]. In this work, as an extension, the structure of the lanes are constructed in a more general way using Bezier splines [38].

3.2.1 The Basic of Bezier Splines

For creating the lanes, splines can be used as an adequate solution opportunity. Different types of splines are usable, e.g.: Bezier [39], B-splines [40], Catmull-Rom [41]. The spline can be divided into segments, and each segment is an n degree polynomial. The Bezier spline was chosen for constructing the lane. The lane is fixed during the motion, and as an assumption, the control points of the spline are known at the beginning of the motion planning. The Bezier splines can be created as:

$$\mathbf{Bez}(\boldsymbol{t}) = \sum_{i=0}^{n} \; b_{i,n}(t)\, \mathbf{P}_i \tag{15}$$

where $t = 0\ldots1$, $\mathbf{P}_i$ is a two-dimensional control point of a segment, there are *n+1* control points in each segment and $\mathbf{Bez}(t)\colon [0..1] \subset \mathbb{R} \rightarrow \mathbb{R}^2$. The Bernstein polynomial can be calculated as:

$$b_{i,n}(t) = \binom{n}{i} \quad t^i \quad (1-t)^{n-i} \tag{16}$$

where $i = 0\ldots n$ and

$$\binom{n}{i} = \frac{n!}{i! \;\; (n-i)!} \tag{17}$$

3.2.2 Structure of the Lanes

The borders of the lanes are calculated using second-degree Bezier splines. First, one side of the borders shall be calculated. The other border can be defined by using an offset for the spline. For a second degree, Bezier spline three control points have to be used in every segment ($\mathbf{P}_0,\ \mathbf{P}_1, \mathbf{P}_2$). Every control point has two coordinates (x, y). The second-degree Bezier spline is represented in (18), by using (15) with $n = 2$ substitution:

$$\mathbf{Bez}(\boldsymbol{t}) = \mathbf{P}_0\,(1-t)^2 + 2\,\mathbf{P}_1 t\,(1-t) + \mathbf{P}_2\,t^2 \tag{18}$$

As an expectation, the border has to ensure the zero and first-order continuity. For the zero-order continuity, the first control point of the next segment must be the same as the last control point of the previous segment. If $\mathbf{Bez_1}$ means the Bezier curves to the first segment (with control points $\mathbf{P}_0, \mathbf{P}_1$, and $\mathbf{P}_2$) and $\mathbf{Bez_2}$ means

the Bezier curves to the second segment (with control points $\mathbf{P}_2$, $\mathbf{P}_3$ and $\mathbf{P}_4$), then for the first order continuity, the next equations must be fulfilled:

$$\mathbf{Bez_1}'(1) = \mathbf{Bez_2}'(0) \tag{19}$$

Where $\mathbf{Bez_1'}(1)$ means the time-derivation of the $\mathbf{Bez_1(t)}$ and substituted the value of 1 into the derivated equation.

After the substitution, the result is:

$$\mathbf{P}_3 = -\mathbf{P}_1 + 2\,\mathbf{P}_2 \tag{20}$$

If all the points are known that the spline has to contain, then the Bezier spline can be already calculated using (18) and (20).

Figure 5 illustrates a Bezier spline with two segments. The second control point of the second segment ($\mathbf{P}_3$) is calculated using (20), ensuring the first-order continuity. If the Bezier spline has more than two segments, the control points of the segments can be calculated with the same algorithm.

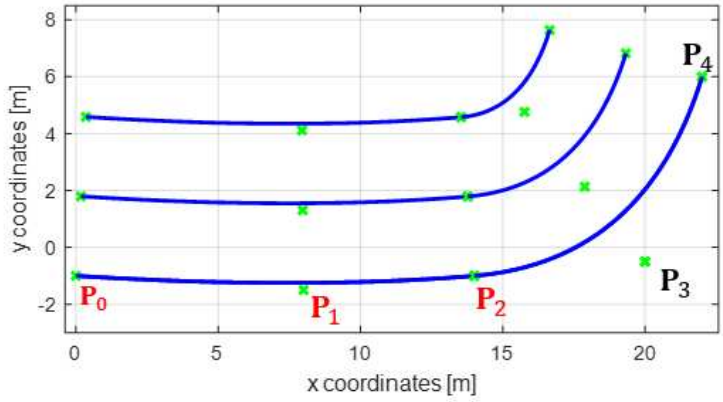

Figure 5
Lanes with the control points

After all of the control points of all segments have been defined, the whole Bezier spline can be established. To get the other side of the corridor, another Bezier spline is needed that always has the same distance from the previous spline. The resulted Bezier splines that generate the lanes are presented in Figure 5. The control points are marked with green shaped x-s, and the borders of the lanes are shown with blue color.

3.2.3 Steps of LKVO

The main concept of the $LKVO$ method is to select a velocity vector for the robot with that the agent will stay inside of the lane if it is possible or reach the boundary of the lane in the furthest time.

To detect, when the robot would reach the boundary of the lane, the intersection of the line of the velocity and second-order Bezier spline has to be calculated. Suppose the line has the (normal vector) equation.

$$ax + by = c \tag{21}$$

In vector form:

$$\mathbf{A}^{\mathrm{T}} \cdot \mathbf{X} = c \tag{22}$$

Now $\mathbf{A}^T = (a, b)$, $\mathbf{X}(t) = \mathbf{Bez}(t)$ from (18) because for the border of the lanes, second-order Bezier spline is used. After the substitution of (18) into (22), the result is:

$$(1-t)^2(\mathbf{A}^{\mathrm{T}} \cdot \mathbf{P}_0) + 2\,t(1-t)\,(\mathbf{A}^{\mathrm{T}} \cdot \mathbf{P}_1) + t^2(\mathbf{A}^{\mathrm{T}} \cdot \mathbf{P}_2) - c = 0 \tag{23}$$

Using (23) for every investigated velocity vector from the corresponding subset that satisfies the *TRVO* algorithm, every intersection point can be defined. It is possible that for a selected velocity of the robot, there are more intersection points on the Bezier spline. In that case, the algorithm has to choose the closest intersection point to the position of the robot with the right orientation. For every velocity $\mathbf{v}_A$, it has to be calculated when the robot would reach the right $(t_R(\mathbf{v}_A))$ and the left boundary $(t_L(\mathbf{v}_A))$ of the lane and use the minimum from them.

The cost value of the $LKVO$ method can be defined after a normalization:

$$C_{LK}(\mathbf{v}_A) = 1 - \frac{\min(t_R(\mathbf{v}_A),\ t_L(\mathbf{v}_A))}{t_H} \tag{24}$$

where t_H is a given time horizon, the cost value is even smaller if the robot will reach the boundary of the lane in a further time. If both of $t_R(\mathbf{v}_A)$ and $t_L(\mathbf{v}_A)$ are infinite numbers, then the robot will never reach the boundary, it will move in the lane. In that case, t_H must be used in the cost function instead of $\min(t_R(\mathbf{v}_A),\ t_L(\mathbf{v}_A))$. (24) should be used if the robot is inside of the lane. A new logical variable can be introduced ($inLane$) that has a value of 1 if the robot is inside of the lane. The value of the variable is 0 if the agent is outside of the lane. As an assumption, the robot leaves the lane on the left side. So the extended cost value for this method can be defined as:

$$C_{LK}(\mathbf{v}_A) = inLane\left(1 - \frac{\min(t_R(\mathbf{v}_A),\ t_L(\mathbf{v}_A))}{t_H}\right) + (1 - inLane)\ \frac{t_R(\mathbf{v}_A)}{t_H} \tag{25}$$

because if the robot is outside of the lane, it has to select a velocity vector that will result in the lane entering back to the right as fast as it is possible (if $t_R(\mathbf{v}_A)$ exists). If there is no opportunity to select a velocity vector resulting lane reaching, the same strategy must be used as in the case when the robot is inside of the lane.

As in Section 3.1, at this algorithm, it is also a weakness that using only the $LKVO$ method, the agent has a slow motion inside of the lane because the main goal is to keep the lane if it is possible. The target position reaching has in this algorithm no effect.

So an appropriate solution idea is using a similar cost function as it was used in Section 3.1.1:

$$Cost(\mathbf{v}_A) = \gamma\, C_{LK}(\mathbf{v}_A) + \beta\, C_G(\mathbf{v}_A) \tag{26}$$

where $\gamma \geq 0$. In that case, the motion planning can be influenced by the target reaching and the lane-keeping at the same time.

3.3 Combination of the Different Methods

A cost function can be constructed that contains every above-presented strategy:

$$Cost_{total}(\mathbf{v}_A) = \alpha\, C_S(\mathbf{v}_A) + \beta\, C_G(\mathbf{v}_A) + \gamma\, C_{LK}(\mathbf{v}_A) \tag{27}$$

where every part of the cost function is the same as it was introduced in Section 3.1.1 and Section 3.2.3. The α, β, and γ parameters will influence which strategy will play a higher role during the motion planning at a specific sampling time. These parameters are given at the beginning of the motion planning algorithm, and they have the same value during the whole motion. The exact values of the parameters can be specified considering the expected solution strategy using the empirical parameter tuning methodology with the experimental results.

A cost value can be calculated for the velocity vectors of the appropriate subsets of the *RAV* (see Section 2). The best option can be selected using an optimization method (e.g., genetic algorithm [22]-[24]).

4 Simulation Results

In this section, several simulation results are presented.

Because of the low calculation cost, a grid-based solution is introduced. In our scenario, a 5*5 velocity grid is used in *RAV*. The $Cost_{total}(\mathbf{v}_A)$ value is calculated in every grid point. The optimal solution can be generated selecting the velocity vector from the grid that has the minimal cost value hence ensures a collision-free motion for the robot using the traffic rules and the lane-keeping algorithm.

So the steps of the motion planning algorithm are:

- Calculate the *VO* sets for every obstacle (Section 1.1).
- Calculate the subsets that satisfy the Traffic Regulation rules (Section 2).
- Make a grid from the investigated velocity vectors.
- Calculate the cost value for every grid point in the *RAV* set (after calculating every part of the cost function described in Section 3).
- Select the velocity vector that has minimal cost value.

There are two obstacles in the workspace of the agent: the first obstacle is a moving obstacle that approaches to the agent in the opposite lane; the second

obstacle is a static obstacle located in front of the robot in the same lane where the agent is (at the start). The parameters of the robot model are: radius: 0.3 m, maximum velocity: 3 m/s (the absolute value of the velocity vector can be in the interval of 0-3 m/s). The parameters of the obstacles are: radii: 0.6, 0.7 m, the velocity of the first obstacle is changing during the motion considering the curvature of the lane, d_{max} = 5 m, D_{max} = 3m, t_H = 1 s. The parameters have been calculated using empirical results. These examples show the differences between the introduced strategies and the result of the strategy where every part plays a role in the cost function.

In every example, (27) is used with different parameter values considering the desired strategy. As an assumption, the *TRVO* method, which was introduced in Section 2, is used in every example.

4.1 The Fastest Solution

To get the fastest solution for the target reaching the parameters must be set as:

- $\alpha = 0, \beta = 1, \gamma = 0$

In this case, the agent will select a velocity vector that causes the fastest motion, as it is represented in Figure 6, where the grid is represented using the little red x-s, the black line shows the previous path of the robot and the other notations are the same as in Figure 2. It can be recognized that the robot has a tangential situation with the static obstacle during the motion. The robot executed the overtaking maneuver before the moving obstacle crosses the path of the robot, ensuring the target reaching as fast as it is possible. The soft-landing algorithm is used during the method. In that case, the closer the robot is to the goal the smaller velocity vector will be selected.

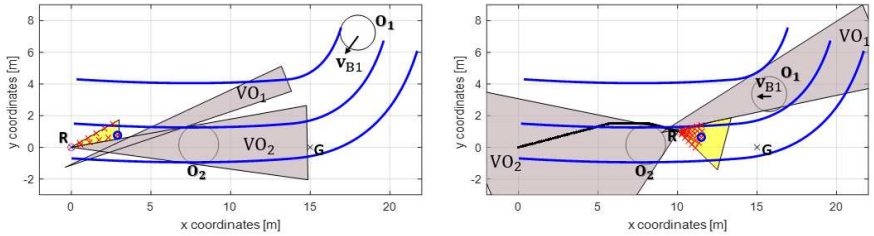

Figure 6
Selecting the velocity vector for the robot using the fastest solution

4.2 Lane-Keeping Algorithm

To execute the lane-keeping algorithm, the parameters must be set as:

- $\alpha = 0, \beta = 0, \gamma = 1$

In that case, the robot will select a velocity vector that will result to stay inside of the lane for the longest time. The result of this method is presented in Figure 7. As it is shown, the moving obstacle has already gone before the agent would have started the overtaking maneuver.

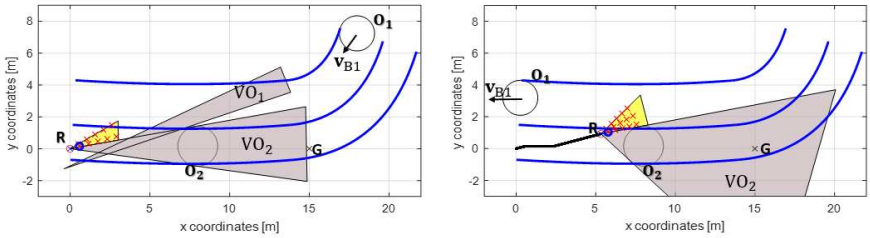

Figure 7

Selecting the velocity vector for the robot using LKVO

On the left side of Figure 8, the lane-keeping algorithm is presented in the situation when the robot is outside of the lane. In that case, if the robot has the opportunity, then a velocity vector is selected that results in the lane entering in the next time interval.

On the right side of Figure 8, the final path of the motion is presented. If the robot is outside of the lane, then the domination of the lane-entering maneuver is remarkable. **S** means the start position of the robot.

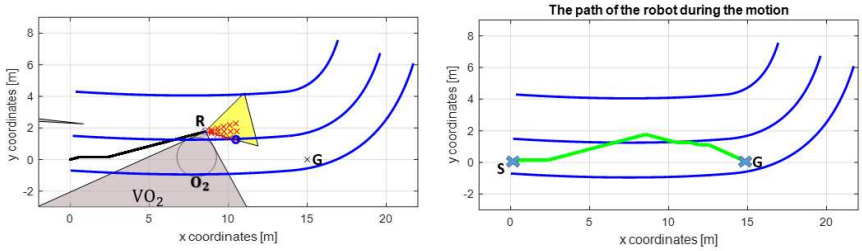

Figure 8

Selecting the velocity vector for the robot using LKVO outside of the lane and path

4.3 Combination of Every Method

To use all of the introduced methods together, the parameters must be set as:

- $\alpha = 1, \beta = 1, \gamma = 1$

At the beginning of the motion, the *LKVO* method plays a higher role. The velocity vector with the minimal cost value ensures the lane-keeping as it is presented in Figure 9 (t = 1s).

As the agent nears to the static obstacle, it has a small velocity until the moving obstacles execute its motion in the next lane. After that, the agent starts the overtaking maneuver. Velocity is selected, resulting in a safe motion for the robot because the static obstacle is close to the robot. So at this moment, the *SVO* method has a higher impact on the cost (t = 8 s). If the robot is out of the lane and it has the chance to come back, then it will execute this maneuver immediately.

After the robot passed the static obstacle, it reaches the target position as fast as it is possible (t = 10 s and t = 12 s). This example illustrated if the combined cost function is used with all components presented in Section 3, how the location of the obstacles and their velocities influence which component of the cost function will dominate at the velocity selection.

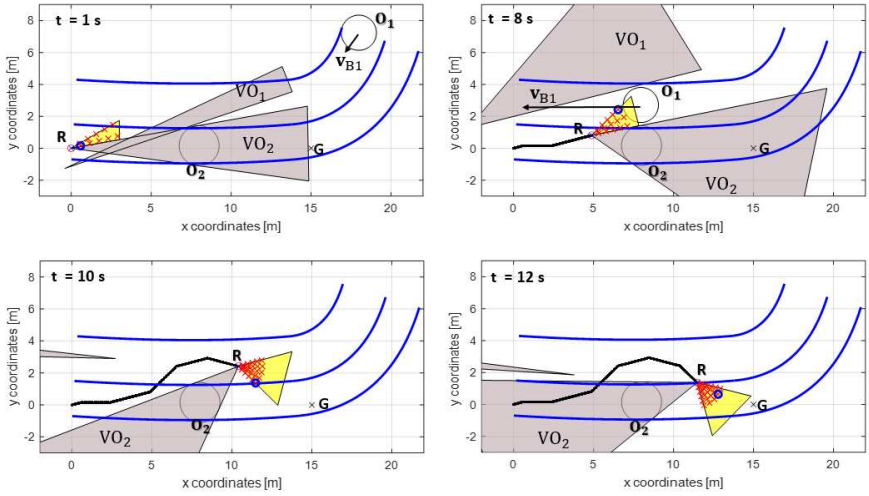

Figure 9
The result of the motion planning using the combined cost

4.4 Simulation in V-REP

V-REP [42] provides an appropriate solution opportunity to test mobile and non-mobile robots using motion planning algorithms. Several types of robots can be used for test cases.

The result of the defined algorithm was also tested in V-REP simulation environment. The motion planning algorithm was implemented in MATLAB, and there is the opportunity to connect the V-REP simulation environment with the MATLAB.

At the aspect of the mobile robot selection, an omnidirectional robot was used (blue colored). In that case, the direction of the movement can be changed in every sampling time if it is necessary. In the first example, there is a static

obstacle (presented with a grey colored cylinder) between the robot and the target point. The goal will be reached using the fastest solution without the *TRVO* method. The video of the solution in V-REP can be checked in [43].

In the second example, the *TRVO* algorithm is also considered. The workspace of the robot is presented in Figure 10. There are a static (O_1 presented with grey colored cylinder), and two moving obstacles (O_2, O_3 – presented with grey colored differential driven robots) in the environment of the robot. In consideration of the O_3, an overtaking maneuver is presented, ensuring an evasive maneuver. O_2 is crossing from the left, so the agent can execute its motion to the goal position without giving priority to the obstacle. The video of the motion is presented in [44].

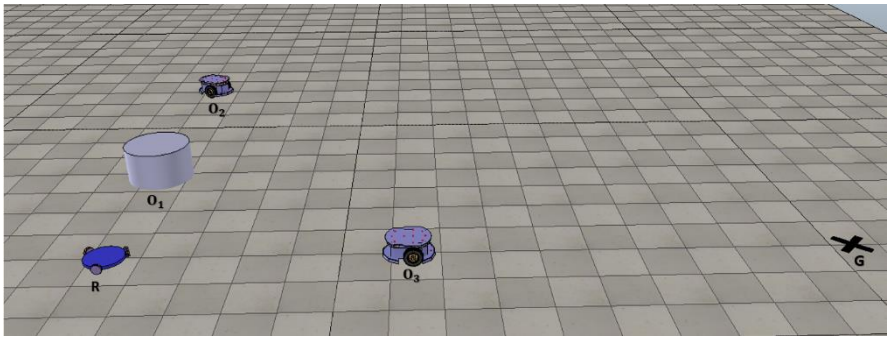

Figure 10
V-REP simulation

Conclusions

In this work, a reactive motion planning algorithm was presented with a cost function. The cost can be determined according to the requirements of safety, speed, and lane-keeping. An appropriate solution can be provided by using the combined cost function with all of these components. Some Traffic Regulation rules can also be considered during motion planning. The motion planning algorithm was also simulated in V-REP simulation environment and generated an appropriate solution using only the kinematic constraints of the robot. The main novelty of our approach was to use these different aspects of the motion planning problem at the same time, generating an optimal collision-free target reaching solution for the mobile robot.

As a future plan, the algorithm will be implemented on a real robotic system. The parameters of the cost function could also be changed in real-time during the motion considering the uncertainty of the sensor measurement data. The cost function could also be extended with new aspects of motion planning.

The algorithm could also be extended for autonomous vehicles, not only for holonomic mobile robots.

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Study of Algorithmic Problem-Solving and Executive Function

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Abstract: Many processes make up cognitive-communication, such as orientation, attention, memory, problem-solving and executive function. Executive functions are necessary for the cognitive control of behavior and refer to some basic cognitive processes such as attentional control, working memory and cognitive flexibility. In this paper, a study is presented, which examines the relationship between algorithmic problem-solving and executive function. Executive functions are examined using Hanoi-tower test and algorithm problem-solving is investigated using a flowchart-based debugging test. The results indicate that a relationship can be found between problem-solving requiring algorithmic thinking and the executive function. The results received may have a positive impact on the efficiency of education of programming through the dedicated development of executive functions.

Keywords: executive functions; problem-solving; programming; Hanoi-tower test

1 Introduction

Many processes make up cognitive-communication, such as orientation, attention, memory, problem solving, and executive function. Executive functions are a set of cognitive processes that are necessary for the cognitive control of behavior, a higher-level of cognitive skills to control and coordinate other cognitive abilities [1]. These functions refer to some basic cognitive processes, such as, attentional control, cognitive inhibition, working memory and cognitive flexibility.

The executive function has high significance from the aspect of human behavior organization, however, there is no uniform definition on it [2], nor any agreement what exact partial operations make up executive functions. According to [3], we consider executive function as a set of abilities, which enables us to represent a target to be achieved, to establish a behavior plan to achieve such target so, that meanwhile, we are monitoring both the environment and our actions, and if necessary, flexibly adjusting the plan worked-out to achieve the particular target.

However, not every behavior requires control implemented by executive functions, such as reflex (e.g. muscle contraction upon pain stimuli) in very simple, routine actions (e.g. touching a glass on the table).

executive functions are always necessary if the target cannot be achieved by direct action. It is important, however, that this behavior control is implemented through the complex control of cognitive and other psychological processes (emotions, passions) being the basis the behavior [3]. Executive functions play a major role in all complex cognitive tasks, such as problem-solving, working memory function, lingual processing and communication. Executive function has therefore principal significance from the aspect of organizing adaptive, problem-solving human behaviors and psychological processes. The disorder of different components of executive functions may seriously limit both learning and adaptive abilities [4].

The behavior process described thus also fits well to solving a problem designated as a target, where the steps of the solution or the evaluation of the steps of the solution in the problem era requires the continuous re-thinking of solution options. During computer software development, the determination of steps leading to the solution of the task designated as the target, then it's coding into a series of instructions workable for the computer are the result of a similar process. In the analysis of this field, modern methods provided by cognitive info-communications [5][6] may be well utilized, that enable the examination of several aspects of cognitive processes [7]-[10].

There is a strong correlation between executive function and problem-solving controlled by conscious processes. The purpose of this paper is to create an analysis aimed at executive function and algorithmic thinking among students learning programming, which may provide grounds to determine further research directions.

2 Test of Executive Function

The measuring of executive functions is a quite complex methodology problem [3]. It makes another difficulty, that there is no clear boundary between routine, known and new tasks. The more routine-like is the actual task, the fewer executive functions are necessary for implementation [3]. The routine-novelty is, therefore, a very important dimension of measuring executive functions.

2.1 Wisconsin Card Sorting Test (WCST)

In the often used Wisconsin card sorting test, cards indicating simple figures must be grouped so (Figure 1), that the actual aspect of grouping must be figured out by the examination manager using the ‘correct/incorrect’ feedbacks on the testing subject’s attempts [11]. For instance, the cards must be grouped based on the

shape, color or number of the figures presented on them. The examination manager, however, varies the aspects of grouping in fixed periods, without notifying about it, and this time, the testing subject has to give up his strategy although correctly figured out earlier, now being incorrect as soon as possible, and find the applicable new aspect. The test is primarily used to measure behavior/cognitive flexibility.

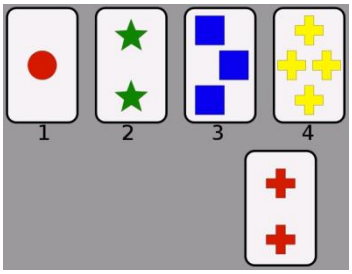

Figure 1
Wisconsin Card Sorting Test

2.2 Stroop Task

Stroop task processes are used to measure inhibition functions, thus, prepotent response inhibition. In classic Stroop-tasks, the subject has to answer which color was used when printing the particular color name [12]. The task is not trivial and considered as an executive function test, because – as we know from the failures – to correctly name the color of the ink, the response arising from the automatic reading of the word (as a prepotent response) must be inhibited when the color of the ink and the color indicated by the word do not match. Using the number/ratio of failures, the inhibition component of executive functions may be measured. The task has several variants.

2.2 Go/No-go Task

In this task type, a (usually simple) motoric response must be provided on every appearance of the warning stimulus, but the motoric response must be avoided when another warning stimulus appears [13]. Using the incidence of the two types of failures (motoric response when it should not be given; or the lack of response where it should be given), inhibition and flexibility aspects can be measured. Very versatile variants are used.

2.2 Tower of Hanoi and its Variants

Tower of Hanoi and its variants are procedures primarily used to measure planning, problem-solving [14]. In the classic Hanoi-tower task (Figure 2), there

are three pegs and three/five discs of various sizes, where the discs are strung on either peg, in sizes decreasing to the top. The task is to reproduce this shape on either another peg so, that only one disc may be moved at the same time, and bigger disc must not be placed onto the smaller one. This variant is not easy, several 'divergent', i.e. steps apparently to bring us farther from the solution must be executed systematically to achieve the goal. Using the number and ratio of correct/incorrect steps, as well as the time required to solve the task, planning and quick problem-solving function can be measured. Its simplified variant is the London-tower.

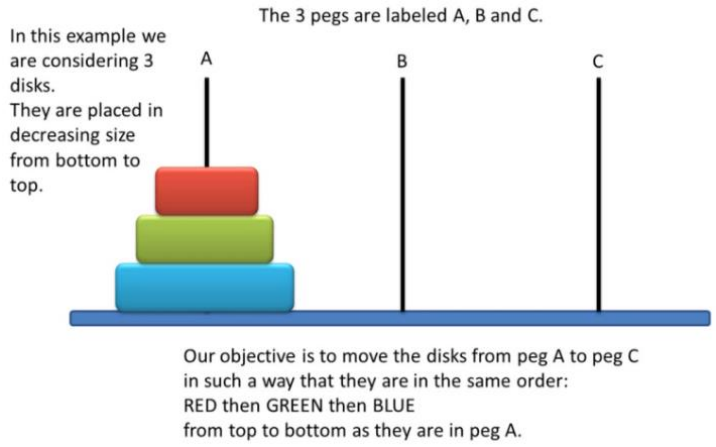

Figure 2
Tower of Hanoi using 3 discs

Tower of Hanoi is a mathematical game, where according to the game's rules, the discs must be relocated from the first peg to the last one so, that one disc may be relocated in each step, the bigger disc must not be placed onto smaller ones, and there are only three pegs available. The game was invented by Édouard Lucas, French mathematician in 1883 [15].

The solution of the puzzle requires concentration, quick planning, problem-recognizing & solving abilities, where the solution must be divided into appropriate steps, similar to a program algorithm.

1.1.1 The Mathematical Solution of the Tower of Hanoi

Let's make the lowest number of required steps: t_n. If there are n+1 discs, the bottom disc cannot be moved, as long as all discs above it are not yet relocated to the middle peg, which can be performed exactly in t_n steps. Then only the bottom (and biggest) disc may be moved onto the third peg, which may be performed in a single step. This is the tn+1 step. Then the n number of discs on the second peg may be relocated to the third peg, which can be achieved in additional t_n steps. Then the following correlation may be drawn up as to the number of steps:

$$t_{n+1} = t_n + 1 + t_n = 2t_n + 1 \quad (1)$$

$$\Delta t_n = t_n + 1 \quad (2)$$

As learned in the solution of first-grade linear inhomogeneous equations:

$$t_n = c \cdot 2^n - 1 \quad (3)$$

$$t_1 = 1;\ 1 = t_1 = c \cdot 2^1 - 1 = 2 \cdot c - 1 \rightarrow c = 1 \quad (4)$$

$$t_n = 2 \cdot n - 1 \quad (5)$$

1.1.2 PEBL Test of Tower of Hanoi

The Psychology Experiment Building Language (PEBL) is a free cross-platform system for designing and running computer-based experiments and tests. It is free to use, there are no licenses to maintain [16]. PEBL distributes a set of standard and novel test in the form of the Test Battery. The Tower of Hanoi is implemented in PEBL and uses a random problem generator (Figure 3).

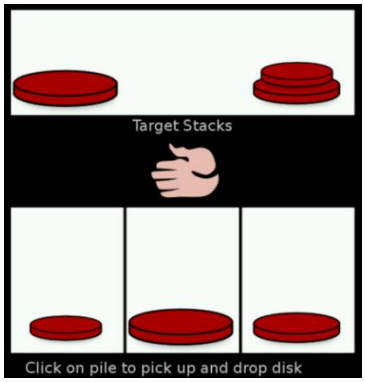

Figure 3
PEBL based Tower of Hanoi

Table 1
Summary test results of PEBL based Tower of Hanoi

sub	trial	size	shortest	startlab	endlab	startconf	endconf	success	steps	time[ms]
3	1	3	6	221	332	221	332	1	10	12456

To evaluate the individual differences, these parameters are important:

- The mean time to complete the task (time)
- The number of steps needed to complete the task (steps)
- The number of 'extra' steps needed (steps-shortest, where the fourth column is the shortest)

3 Executive Function and Algorithm Problem Solving

Programmers, following writing a program, can memorize only a small part of the program code, since human working memory is very limited [17]. Writing is already a very complex thinking process, and the same refers to writing a code [18]. However, coding must be always preceded by the creation of the algorithm leading towards the solution. This process is the algorithmic thinking, which is closely related to problem-solving since in both cases, we have to split up the route towards the solution of a problem into a series of subsequent steps. The conscious activity driven by the executive function affects the use of working memory. Due to the limited capacity of working memory, the programmer is unable to keep too complicated or code parts in their mind, as long as he interprets them as separate data. Once one learns how to organize these ideas and algorithms into samples, and create mental models on them, then one becomes able to solve more complicated tasks [19]. Executive function and problem-solving driven by conscious processes are therefore closely related to each other.

A preliminary study is introduced below, which aims to analyze the relationship between executive function and algorithmic problem-solving [20]. The executive function is examined using the Hanoi-tower test, whilst algorithmic problem-solving using debugging in an algorithm provided on a flowchart.

4 Study and Procedure

The evaluation of the relationship between executive function and algorithmic problem-solving is performed through the Hanoi-tower test, the successful debugging of the two errors in the algorithm described by a flowchart, and the comparison of mathematical and algorithmic abilities related to problem-solving.

The purpose of the test was primarily to determine how the interpretation of the algorithm according to the flowchart and finding the errors are related to the test results received regarding the Hanoi-tower task measuring the executive function. Also, how students' mathematical, algorithmic and foreign language skills are related to the test results of the Hanoi-tower task measuring the executive function.

In the test, 23 people, IT-Engineer students of 19-22 years, participated (M=20.78±1.28). There were 11 females and 12 males among the testing subjects. Testing subjects were volunteers.

As a first step to prevent the prior knowledge play a role in the interpretation of the flowchart, a test analyzing the previous knowledge of the basic elements of the flowchart was performed. The test consisted of 9 questions, aimed at the flowchart basic elements and their functions. Two test questions are indicated in Figure 4. In

the case of those students, where the certain knowledge of the flowchart elements was inappropriate, the information related to the failed questions were discussed.

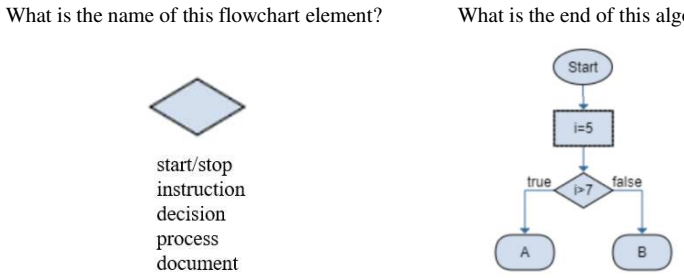

Figure 4
Sample test questions for flowcharts

In the second step of the investigation, the flowchart indicated in Figure 5 had to be observed by the students for 2 minutes. The students were aware that two errors were hidden in the flowchart, which they had to say when the time expired. The flowchart's elements were numbered, making the error easier to determine. In the flowchart, one of the two errors was the arrow marked with No. 23, which connects to an inappropriate place, and the other one was in the process marked with No. 13, where the c[k]=a[i] index variants were mixed up.

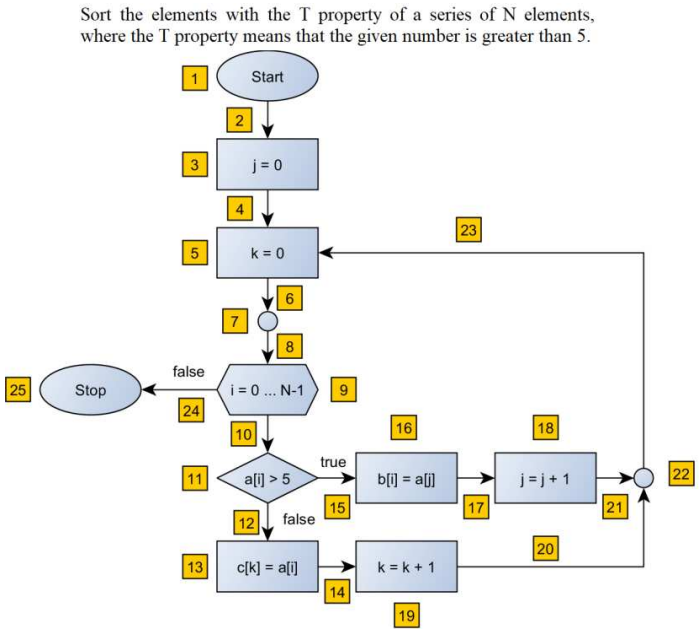

Figure 5
Flowchart test

In the third phase of the test, the students were practicing the Hanoi-tower test implemented into PEBL system three times, to learn what was the test about and how to execute it. Following the initial practicing, in the fourth phase of the test, they solved the Hanoi-tower task ten times in a row. The parameters, results related to the solution were saved by the PEBLS system into a file, which may be thus post-processed.

In the last phase of the investigation, the students answered an additional five questions using a questionnaire. The five questions were as follows:

1. How would You rate your mathematical skills? (1-5 on Likert scale)
2. How would You rate your algorithmic skills? (1-5 on Likert scale)
3. How would You rate your foreign language skills? (1-5 on Likert scale)
4. How long have You been dealing with programming?
5. How many types of programming languages have You learnt so far?

5 Results

The students' knowledge related to flowchart interpretation proved to be appropriate, some of them completed the test consisting of 9 questions flawlessly, whilst some with only 1-2 mistakes. The results are summarized in Table 2.

Table 2
Results of flowchart basic pre-knowledge test

Number of good answers (9 questions)	Number of test subjects
9	16
8	6
7	1

Following discussing the mistakes made regarding the questions, the test was continued with the second phase, the debugging on the flowchart. Table 3 and Figure 6 indicates how many of the testing subjects managed to find 0, 1 or both of the 2 errors on the flowchart.

Table 3
Results of flowchart debugging test

Number of errors found	Number of test subjects
0	5
1	13
2	5

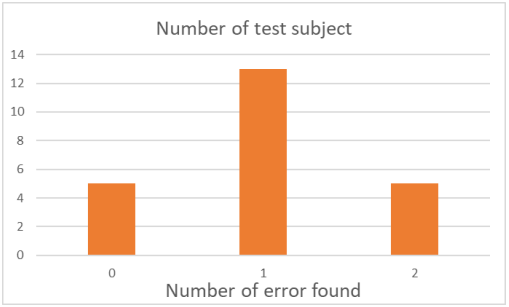

Figure 6
Results of flowchart debugging test

Based on the results, we can see that among the testing subjects, 13 persons could find only one error, 5 were able to find both of them, and the number of those who did not manage to find any was 5. Testing subjects were unable to find the index mixing-up error in most cases.

In the third phase of the investigation, testing subjects performed the Hanoi-tower test. The parameters of the Hanoi-tower specified in the PEBL test were supplemented with an additional two calculated parameters:

1) Compared to the lowest number of steps leading to the solution, the relative number of extra steps:

   rel_extrasteps=(steps-shortest)/shortest=extrasteps/shortest [%]

2) The average time between the steps during the solution:

   steps_time=time/steps [ms]

The first parameter indicates that the particular testing subject attempted to solve the task in how a considered manner, with as few mistakes as possible, whilst the second indicated how quick each subject decided on the next step. The averages and standard deviations of each parameter are indicated in Table 4.

Table 4
Results of Hanoi-tower

	Shortest	**steps**	**extrasteps**	**rel_extrasteps**	**time [ms]**	**steps_time [ms]**
MEAN	40.3913	56.5217	16.1304	37.99%	102 041	1819.9
SD	5.72665	15.6347	11.0836	24.02%	29 335,2	270.56

The results indicate that during solving the Hanoi-tower task, the 10 tests performed could be solved in average the least 40.4 (SD=5.7) steps, whilst testing subjects managed to solve this in average 56.5 (SD=15.6) steps. The number of extra steps is thus average 16.1 (SD=11), which is relative compared to the

shortest step number 38% (SD=24%). The total time to solve the 10 tests is average 102 s (SD=29.3 s), whilst the time passed between each steps was 1.82s (SD=0.27s).

However, to perform the evaluation specified as the purpose of the test, the results of the Hanoi-Tower tests must be compared with the flowchart debugging results. The comparison may be made based on the number of errors found, rendering the Hanoi-tower test results to the number of errors found. The results are summarized in Table 5.

Table 5
Results of Flowchart error - Hanoi-tower

Flowchart	**Hanoi-tower**			
Number of error found		**extrasteps**	**rel_extrasteps**	**steps_time [ms]**
0	**MEAN**	19.2	46.1%	1 772.0
	SD	13.6	30.9%	307.6
1	**MEAN**	17.4	40.3%	1 816.4
	SD	10.1	20.6%	301.9
2	**MEAN**	9.8	24.0%	1 877.0
	SD	11.0	24.6%	165.7

It can be seen from the results, that in case of the testing subject identifying 0 and 1 errors in the flowchart test, the extrasteps was similar, a bit higher, average 19.2 (SD=13.6) to the 0 and average 17.4 (SD=10.1) steps related to those of identifying 1 error. However, testing subjects finding both errors were able to solve the Hanoi-tower test on average less 9.8 (SD=11) extra steps. The relative number of extra steps was similar, in case of testing subjects identifying 0 error 46.1% (SD=30.9%), whilst at testing subjects identifying 1 error 40.3% (SD=20.6%). The number of extra steps was also much lower in case of those testing subjects, who managed to find both errors, 24% (SD=24.6%).

During solving the Hanoi-tower test, the mean time between the test was similar in case of testing subjects finding 0, 1 and 2 errors on the flowchart. We can learn from the results, that the mean time between the steps increased, in case of the group identifying 0 error 1.77 s (SD=0.31 s), at testing subjects finding 1 error 1.82 s (SD=0.3 s), whilst in case of testing subjects identifying both errors on the flowchart 1.88 s (SD=0.16 s).

The illustration of the results on the bar graph is indicated by Figures 7-9.

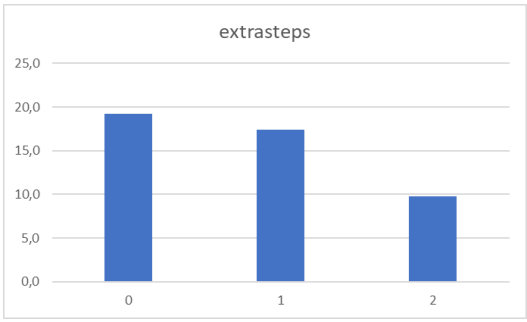

Figure 7
Identified errors in flowchart vs Hanoi-tower test extrasteps

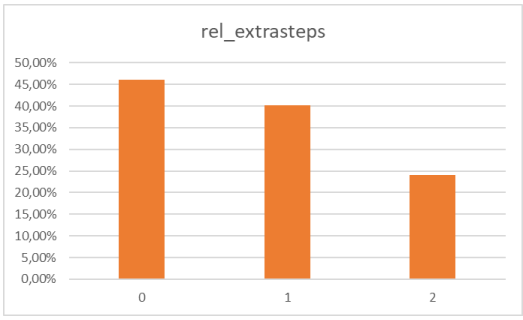

Figure 8
Identified errors in flowchart vs Hanoi-tower test relative extrasteps

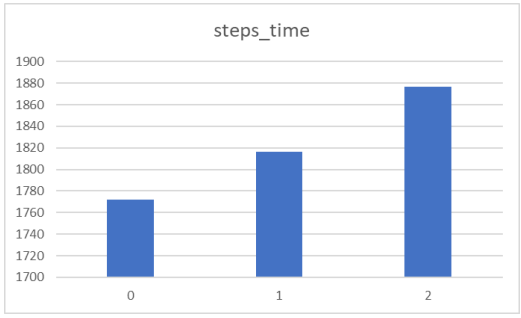

Figure 9
Identified errors in flowchart vs Hanoi-tower test step time

We can see from the results, that depending on the number of errors identified on the flowchart, if we create groups, then in case of these groups, differences can be indicated in the Hanoi-tower test results. In case of those testing subjects, who were more successful in the interpretation of the flowchart, thinking through the algorithm and as a result, identifying both errors, were able to complete the Hanoi-tower test with a better result, i.e. with less extra steps. However, it can be also

learnt, that the meant time between each step was the longest in their case. The background of the results might be that these testing subjects were thinking about the steps leading to the solution more thoroughly, thus spending more time for thinking on each step, however, they are more successful in the end, since they manage to solve the task with less extra steps. In other words, those are more successful in the end, who attempt to solve the task not by testing, rather thinking through the problem, applying a scheme on it.

Testing subjects also answered on additional questions regarding their mathematical knowledge, algorithmic abilities and language skills (1-5 Likert scale, taking the grades received in the particular subject into consideration) and regarding their previous programming knowledge, whose average results are indicated in Figures 10-12.

Figure 10
Level of math and algorithmic skills

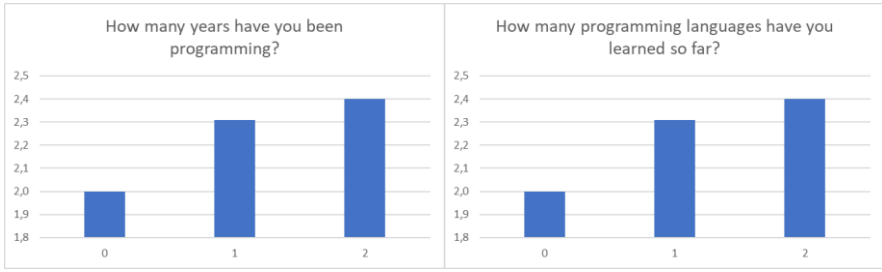

Figure 11
Prior programming experience

Figure 12
Foreign language skills

The results indicate that mathematical and algorithmic skills are in positive correlation with the success of the flowchart debug task solution. Similarly, prior programming experiences also provided a better result in solving the flowchart debug task. Interestingly, foreign language skill and programming abilities indicate a negative correlation.

Conclusions

Cognitive communication, such as, orientation, attention, memory, problem-solving and executive function, is the basis of several higher-level of cognitive skills. Executive functions control and coordinate other cognitive abilities and behavior. However, not every behavior requires control implemented by executive function, such as, reflex or other very simple, routine actions. However, if the target cannot be achieved by direct action, some kind of new behavior pattern must be established, executive functions are always necessary. The executive function, thus, plays a major role in all complex cognitive tasks, for example, problem-solving. Executive function and problem-solving driven by conscious processes are closely related to each other. Computer-based assessment of problem-solving skills and the cognitive processes it involves, is an intensively studied topic [21]-[22].

During computer software development, the determination of steps leading to the solution of the task designated as the target are developed and then coded into a series of instructions workable for the computer. In the analysis of this field, opportunities provided by cognitive info-communications [23]-[29] can be well utilized, which are applied to analyze cognitive processes in more fields [30]-[32]. The purpose of this paper was to perform tests aimed at the Executive Function and Algorithmic Thinking and to report the correlation between the two. The results indicate, that based on the tests introduced and performed in this paper, a positive correlation is indicated between the level of Executive Functions and Algorithmic Problem-solving. Better Algorithmic Problem-solving is coupled with more precise execution of Executive Functions. Results can also play an important role in increasing the efficiency of learning, through educational methods and ICT opportunities [33]-[36].

Acknowledgement

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