Sustainability of Human Resource Management Processes through Employee Motivation and Job Satisfaction

Miloš Hitka[1], Jarmila Schmidtová[1], Silvia Lorincová[1*], Peter Štarchoň[2], Dagmar Weberová[3] , Rudolf Kampf[4]

[1]Technical University in Zvolen, Faculty of Wood Sciences and Technology, T. G. Masaryka 24, 96053 Zvolen, Slovakia, hitka@tuzvo.sk, jarmila.schmidtova@tuzvo.sk, silvia.lorincova@tuzvo.sk

[2]Comenius University in Bratislava, Faculty of Management, Odbojárov 10, P.O. BOX 95, 82005 Bratislava, Slovakia, peter.starchon@fm.uniba.sk

[3]Tomas Bata University in Zlín, Faculty of Multimedia Communications, nám. T. G. Masaryka 5555, 760 01 Zlín, Czech Republic, weberova@utb.cz

[4]The Institute of Technology and Business in Ceske Budejovice, Faculty of Corporate Strategy, 370 01 Ceske Budejovice, Czech Republic, kampf@mail.vstecb.cz

Abstract: Small and medium-sized enterprises form a significant part of the economy of each country with the greatest potential for growth and the impact on stabilizing the economy. Their success or failure depends not only on know-how, capital, or machinery, but also on human resources, one of the competitive advantages and a critical factor of success. In order to achieve success and ensure the sustainability of business processes, the focus is on employee motivation and employee satisfaction, with an emphasis on effective management as multicultural workers' groups are becoming the current trend in logistics companies. Using Tukey's HSD post-hoc test and ANOVA, differences in the perception of motivation and job satisfaction of employees are identified. As part of the post-hoc analysis, the observed dependencies of the mean values of importance and satisfaction with the effect of selected motivation factors are examined in more detail. Based on the results, the fact that employee motivation in logistics companies in Slovakia and the Czech Republic is different, can be concluded. In addition, it varies according to the size of the enterprise. These findings are important for the members of management because of the globalization of economies and multiculturalism of workers' teams in both logistics and also other enterprises. Finding a variety of preferences for motivational needs and job satisfaction does not make it possible to develop unified motivation programs. The needs of employees regarding the size of the enterprise and also the country of origin must be taken into account by the management of an enterprise.

Keywords: strategic human resource management; innovative and sustainable business practices; optimization of sustainable human resource management strategies; employee motivation; job satisfaction; employee satisfaction and productivity

1 Introduction and Literature Background

Small and medium-sized enterprises are considered the most flexible, efficient, most progressive and therefore the most important part of the economy in developed countries [1]. They offer a number of benefits that large businesses are not usually able to provide. Flexibility, fast response to changes in the environment, ease of decision-making, implementation of innovations, and high market focus belong to the most valuable features of small and medium-sized enterprises [2]. Many large businesses rely on small and medium-sized enterprises to provide their support services and products so that they can focus on their core business, and this is the reason that small and medium-sized businesses are highly valued for their creativity [3, 4].

Category of small and medium-sized enterprises is defined by the European Commission [5] as a set of enterprises employing less than 250 people and having either an annual turnover not exceeding EUR 50 million, or assets in an annual balance sheet not exceeding EUR 43 million. Micro-enterprises employ fewer than 10 people and their annual turnover and/or total annual balance sheet does not exceed EUR 2 million. Small businesses employ fewer than 50 people and their annual turnover and/or total annual balance sheet does not exceed EUR 10 million. Medium-sized enterprises are defined as enterprises employing fewer than 250 people and their annual turnover does not exceed EUR 50 million and/or their total annual balance sheet does not exceed EUR 43 million. Large enterprises employ more than 250 employees or their annual turnover exceeds EUR 50 million or their total annual balance sheet exceeds EUR 43 million [6].

There are more than 23 million businesses in the European Union. Total of 98.7% of them are represented entrepreneurs and small businesses with up to 49 employees. Moreover, the smallest enterprises up to ten employees (93%) dominate this group. Companies with 50 to 249 employees have a 1% share and, on average, only two out of a thousand companies (0.2%) are large companies with 250 and more employees. On average, small businesses generate every second job in the EU, further 17% are medium-sized enterprises and 33% are large enterprises with 250 and more employees [7]. According to the Eurostat, European Statistical Office survey, small and medium-sized enterprises (SMEs) account for half of the volume of trade within the EU. In total, this represents 51% of the total import volume and 45% of the volume of export within the EU. In Slovakia, small and medium-sized enterprises make up 99.9% of the total number of business entities. 96.9% of small and medium-sized enterprises are micro-

enterprises employing fewer than 10 employees [8]. Up to 56% of employees work in micro-enterprises. Medium-sized companies in Slovakia generate 16% of the jobs and the remaining 28% are generated by the largest enterprises [7]. In the year 2017, the share of small and medium-sized enterprises in the total number of active business entities was 99.8% in the Czech Republic. In 2017, the share of added value was 54.6%. The share of small and medium-sized enterprises in the total number of employees in the business sphere was 58.0% [9].

Enterprises make up a significant part of the economy of each country. Their success or failure does not depend only on know-how, capital, or machinery, but also on human resources, which are undoubtedly one of the competitive advantages and one of the critical factors of success of companies. Human resource management is the most important component of corporate governance in all businesses [10, 11]. It is particularly human resources that have a specific position within all strategic sources. Compared with others, they are able, based on their internal potential, to increase their level of performance, to ensure an increase in the level of other strategic resources, to adjust spontaneously their structure to changing external and internal conditions [12, 13].

As each company works primarily with people, their abilities and talents, the main objective of the whole human potential development system is to create the conditions to meet the enterprise business concept by maximizing the performance of each employee. The performance of employees, groups and the whole of the company as a total potential and as the overall summary of physiological and psychological abilities to deliver sustainable, desirable and appropriate performance should be cultivated and developed in a sophisticated way together with the motivation, which is the key and most dynamic attribute of each personality (individual and group). Employees and groups are supposed to be motivated systematically that can result in motivational processes leading to effective and thoughtful action [14, 15]. With regard to the size of the business, the manager's role is to manage the employees properly [16, 17]. The manager’s capabilities, knowledge and achieved experience result in motivation of subordinates to create a sense of personal benefit in accordance with the business management intentions and, in this respect, a sense of satisfaction [18, 19]. Motivation is a dynamic process driven by personal, socio-psychological, and context factors interacting with one another [20]. It is a process responsive to individual intensity, direction, and ongoing efforts to achieve the goal. It represents a permanent process of efficiency and effectiveness asking for constant and systematic attention [21]. A competitive advantage as well as the sustainability of business processes due to higher productivity can be achieved by an enterprise through employee motivation [22, 23].

The application of motivation to practice is implemented through the enterprise motivation program. It is a comprehensive set of measures in the field of human resources management, which, following the other management activities of management, aims to influence actively work performance and behavior.

Work satisfaction, as the subjective side of every person executing work in the enterprise is an inseparable part of motivation. It is a reflection of their work and its conditions in the context of individual standards, value orientation, aspirations and expectations related to the performed activities. The objective aspect of job satisfaction is expressed by such manifestations of human working behavior as performance, efficiency, quality of work results, etc., both (subjective and objective) sides are linked, but for example, the good quality of one side does not mean that the second side must also be favorable. It is not always true that a satisfied employee is automatically efficient because, for example they can be happy just because they are inefficient. Work satisfaction in the broad sense of the word is a positive or a positive emotional relationship based on performance and additionally, on the evaluation of the work. It is the attitude of a man to work. Previous research has confirmed that job satisfaction influences both the behavior of workers and the productivity of firms [27, 28].

As competitive environments globalize, a competitive advantage requires more than ownership of heavily replicated assets or resources. At present, it is just human resources, which are one of the competitive advantages and a critical factor determining the success of an enterprise. Because of increased rates of global migration, employees commonly have multicultural backgrounds [29]. In order to be effective in this context, incentive programs must be tailored to the choices and sizes of each work team and the capabilities and size of each enterprise [14]. The aim of this study is to identify the differences in the perception of the preferred level of motivation and job satisfaction in terms of enterprise size and within selected countries. It is assumed that levels of employee motivation (preferred level) and job satisfaction (current level) will vary regarding the enterprise size and the country.

2 Materials and Methods

Level of motivation and job satisfaction, in other words preferred level and current level, were analyzed in companies operating in the Slovak Republic and the Czech Republic in 2018. The analysis was conducted as a part of an extensive research. Research was carried out in the field of transportation as this sector represents the sector with the most significant growth of small and medium-sized enterprises [30].

A questionnaire was used to determine the level of motivation and job satisfaction, i.e. preferred and current level. The questionnaires were submitted to randomly selected employees of logistic companies in both the Slovak Republic and the Czech Republic in order to ensure variability and randomness of respondent selection necessary for relevant data acquisition. The selection of respondents was proportionately allocated across the Slovak Republic and the Czech Republic.

Therefore, all parts of Slovak Republic and the Czech Republic were covered by the research sampling unit.

The research data were collected from 4,885 employees working in logistic companies. 690 employees from small enterprises, 720 employees from medium-sized enterprises and 1,170 employees from large companies operating in Slovakia participated in the research. In the Czech Republic, 837 employees from small enterprises, 712 employees from medium-sized enterprises and 756 employees from large companies took part in the research.

Levels of motivation and job satisfaction were analyzed by 30 motivation factors in the following structure: 1. atmosphere in the workplace; 2. good work team; 3. fringe benefits; 4. physical effort at work; 5. job security; 6. communication in the workplace; 7. name of the company; 8. opportunity to apply one's own ability; 9. workload and type of work; 10. information about performance result; 11. working hours; 12. work environment; 13. job performance; 14. career advancement; 15. competences; 16. prestige; 17. supervisor's approach; 18. individual decision-making; 19. self-actualization; 20. social benefits; 21. fair appraisal system; 22. stress; 23. mental effort; 24. mission of the company; 25. region's development; 26. personal growth; 27. relation to the environment; 28. free time; 29. recognition; 30. basic salary.

All factors were measured on the Likert scale from 1 (the least important/satisfied) to 5 (the most important/satisfied). Except these ordinal variables, two nominal variables – the size of the company and the country of origin were used.

The aim of this study is to identify the differences in the perception of the preferred level of motivation and job satisfaction in terms of the size of enterprises and the selected countries. The following hypotheses were tested:

- Hypothesis 1: There are differences in the level of motivation and job satisfaction depending on the size of the enterprise.
- Hypothesis 2: There are differences in the level of motivation and job satisfaction depending on the country.

Within our research hypotheses, two-way ANOVA with interaction was applied. In the frame of inferential statistics, the ANOVA is an appropriate technique to consider the effect of the factor on the variable of interest. In post-hoc analysis, the Tukey's HSD test for unequal sample size was involved. Next, 0.95 confidence intervals for population means was calculated. Box plots were used for graphical interpretation of the results. For all estimates and hypothesis testing, basic descriptive statistics of our research sample was used. In hypothesis testing, 0.05 level of significance was used. All results were carried out with the statistical software STATISTICA 12.

3 Results and Discussion

The overview of the descriptive statistics results as well as the interval estimates of the mean values are presented in Table 1.

Table 1
Motivation factors – basic statistic characteristics

Motivation factor	Preferred level (motivation)				Current level (satisfaction)			
	Mean	St. deviation	Conf. interval 95%		Mean	St. deviation	Conf. interval 95%	
			lower limit	upper limit			lower limit	upper limit
30	4.54	1.03	4.51	4.57	2.99	1.13	2.96	3.02
2	4.49	0.70	4.47	4.51	3.51	1.01	3.48	3.54
1	4.46	0.75	4.44	4.48	3.37	1.02	3.34	3.40
21	4.39	0.81	4.37	4.41	3.13	1.08	3.10	3.16
17	4.37	0.81	4.35	4.40	3.33	1.16	3.30	3.37
5	4.35	0.83	4.32	4.37	3.45	1.05	3.42	3.48
3	4.29	0.81	4.27	4.31	3.00	1.06	2.97	3.03
6	4.25	0.82	4.22	4.27	3.26	1.02	3.23	3.29
11	4.14	0.90	4.12	4.17	3.38	1.07	3.35	3.41
29	4.12	0.87	4.10	4.15	3.03	1.01	3.01	3.06
12	4.11	0.84	4.08	4.13	3.35	1.03	3.32	3.37
22	4.10	0.90	4.07	4.12	3.34	1.07	3.31	3.37
9	4.06	0.83	4.04	4.08	3.40	0.96	3.37	3.42
28	4.03	0.94	4.01	4.06	3.13	1.04	3.10	3.16
20	4.02	0.92	4.00	4.05	3.07	1.05	3.05	3.10
26	4.00	0.91	3.98	4.03	3.08	1.02	3.05	3.11
8	4.00	0.86	3.97	4.02	3.22	1.02	3.19	3.25
13	4.00	0.84	3.98	4.02	3.44	0.90	3.42	3.47
23	3.95	0.92	3.93	3.98	3.07	1.00	3.04	3.09
19	3.91	0.90	3.89	3.94	3.11	1.00	3.08	3.14
18	3.90	0.89	3.88	3.93	3.22	0.97	3.19	3.24
10	3.90	0.90	3.87	3.92	3.21	0.96	3.18	3.23
14	3.89	0.87	3.87	3.92	3.20	0.92	3.17	3.22
7	3.79	1.03	3.76	3.82	3.40	0.98	3.37	3.43
15	3.78	0.92	3.76	3.81	3.02	0.96	2.99	3.05
27	3.75	1.04	3.72	3.78	3.20	1.02	3.17	3.23
24	3.71	1.00	3.68	3.74	3.21	0.95	3.18	3.24
16	3.71	0.97	3.68	3.73	3.11	0.93	3.09	3.14
4	3.60	0.99	3.58	3.63	3.21	1.03	3.18	3.24
25	3.55	1.03	3.52	3.58	2.95	0.94	2.92	2.98

Mean and standard deviation are used to define each factor for the entire sampling unit. Following the data, 95% confidence intervals were calculated for the mean values (preferred level) and satisfaction (current level) in the basic sampling unit. The data in Table 1 is ranked in descending order according to the mean value of the importance of the motivation factors at the preferred level.

In the study, the occurrence of significant differences in the perception of importance of motivation factors by employees in enterprises of varying size in two different countries and at the same time is discussed. The first four motivation factors in Table 1 were selected for a more detailed analysis. These motivation factors were marked by respondents with the highest values of importance at the preferred level. With the exception of the basic salary – factor No. 30, employees attach the greatest importance to the relationship motivation factors. These are motivation factors No. 2 – good work team, No. 1 – atmosphere in the workplace and No. 21 – fair appraisal system.

Selected motivation factors were subjected to two-dimensional scattering analysis, where two variables act as factors affecting the level of values. Country of origin with two levels – Slovakia and the Czech Republic and size of the enterprise with three levels – small, medium and large enterprise. Variables No. 30, 2, 1 and 21 were analyzed in both at preferred and current level which makes it possible to assess the situation how employees in logistics companies would like to be motivated (importance) and are really motivated (satisfaction).

Table 2

Results of two-way ANOVA: df-degree of freedom, SS-sum of square, MS- mean square, F-value of F-test[1]

Motivation factor		Preferred level					Current level				
		df	SS	MS	F	p-level	df	SS	MS	F	p-level
30	Country of origin	1	0.71	0.71	0.67	0.414	1	**121.32**	**121.32**	**97.90**	**0.000**
	Size of company	2	0.46	0.23	0.22	0.804	2	**33.99**	**16.99**	**13.71**	**0.000**
	Interaction	2	**8.89**	**4.44**	**4.17**	**0.016**	2	**24.65**	**12.32**	**9.95**	**0.000**
	Error	4,879	5,201.27	1.07			4,879	6,045.85	1.24		
1	Country of origin	1	**44.31**	**44.31**	**92.6**	**0.000**	1	**7.59**	**7.59**	**7.70**	**0.006**
	Size of company	2	**12.14**	**6.07**	**12.7**	**0.000**	2	**128.12**	**64.06**	**65.00**	**0.000**
	Interaction	2	**14.60**	**7.30**	**15.3**	**0.000**	2	**37.96**	**18.98**	**19.26**	**0.000**
	Error	4,879	2,333.67	0.48			4,879	4,808.44	0.99		
2	Country of origin	1	**90.83**	**90.83**	**167.7**	**0.000**	1	**12.58**	**12.58**	**12.56**	**0.000**
	Size of company	2	**23.63**	**11.82**	**21.8**	**0.000**	2	**110.68**	**55.34**	**55.26**	**0.000**
	Interaction	2	**9.18**	**4.59**	**8.5**	**0.000**	2	**38.37**	**19.19**	**19.16**	**0.000**
	Error	4,879	2,641.68	0.54			4,879	4,885.48	1.00		

[1] note: statistically significant differences are highlighted in bold

21	Country of origin	1	**4.56**	**4.56**	**7.0**	**0.008**	1	**41.91**	**41.91**	**37.02**	**0.000**
	Size of company	2	**48.84**	**24.42**	**37.7**	**0.000**	2	**55.04**	**27.52**	**24.31**	**0.000**
	Interaction	2	**11.87**	**5.93**	**9.2**	**0.000**	2	**80.37**	**40.18**	**35.50**	**0.000**
	Error	4,879	3,163.47	0.65			4,879	5,522.79	1.13		

Table 2 summarizes the results of the F-test, which is the essence of the scattering analysis. On the basis of p-levels, it can be said that significant differences in the mean values of importance and satisfaction with the motivation factors observed are the results of interaction between the two observed factors. With the exception of the basic salary at the preferred level, there are also significant differences in the mean values of importance from the point of view of the individual factors alone. Both factors significantly affect the values of importance of motivation basic salary (No. 30), however, only in interaction.

Following the results of the scattering analysis, the fact that the motivation of employees working in logistics companies is different in Slovakia and in the Czech Republic and motivation varies also depending on the fact whether employees work in small, medium or large enterprises can be concluded. As part of the post-hoc analysis, the observed dependencies of the mean values of importance and satisfaction of two factors were examined in more detail. The results are presented separately by individual factors. A focus will be put on a deeper analysis of the issue as required because of a priority to know what way employees need to be motivated. Paired test results are presented in box plots representing confidence intervals of 95% for the average values of the given motivation factors in both at the preferred and current level.

3.1 Motivation Factor No. 30 – Basic Salary

The Tukey's HSD post-hoc test results are shown in Table 3. In a pairwise comparison, it can be observed that, at the preferred level, all employees perceive the basic salary as a strong motivating factor, whether in Slovakia or in the Czech Republic, in companies of varying sizes.

Table 3

Basic salary: pairwise comparison, p-levels of Tukey's HSD test[2]

	Preferred level – above the diagonal					
	SVK-small	SVK-medium	SVK-large	CZ-small	CZ-medium	CZ-large
SVK-small	–	0.160	0.685	0.581	1.000	0.964
SVK-medium	1.000	–	0.935	0.971	0.179	0.596
SVK-large	**0.000**	**0.000**	–	1.000	0.726	0.984
CZ-small	**0.000**	**0.000**	**0.002**	–	0.623	0.959

[2] note: statistically significant differences are highlighted in bold

CZ-medium	**0.000**	**0.000**	0.996	**0.030**	–	0.977
CZ-large	**0.000**	**0.000**	0.083	0.932	0.292	–
	Current level – below the diagonal					

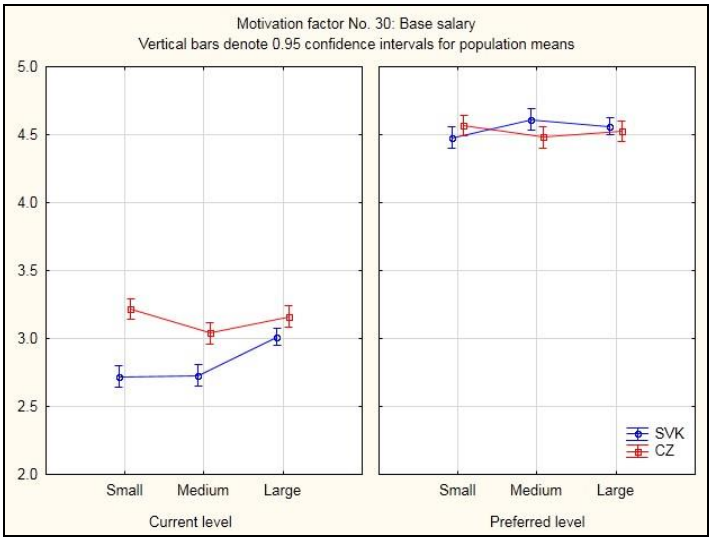


Figure 1
Box plot – Basic salary

In perceiving the real level of motivation, employees in small and medium-sized enterprises in the Czech Republic are more satisfied with salaries than employees working in companies of a given size in Slovakia. Opinions of employees working in large Slovak and Czech enterprises are not different in satisfaction with the basic salary at the level of significance α=0.05.

Figure 1 presents 95% confidence intervals for the mean values of the importance of the motivation factor – basic salary in both at the preferred and current level. It is clear that employees working in logistics companies, irrespective of their country and enterprise size, evaluate their actual motivation by a basic salary in a neutral way, i. e. the mean value of importance is around 3 (Figure 1 on the left). Figure 1 on the right shows the priority of basic salary for the employees (mean values around 4.5 and above).

3.2 Motivation Factor No. 2 – Good Work Team

The pairwise comparison results are presented in Table 4 showing the significant differences in mean values of importance at the preferred level. The greatest importance is attributed to the good work team by employees in large Czech enterprises. There is the statistically significant difference in their views from the

rest of the groups. An equal level of importance is attributed to a good work team by employees working in Czech small and medium-sized enterprises. The same level of values of importance is attributed by employees working in Slovak medium-sized enterprises. Opinions of employees working in small and large Slovak enterprises differ from other groups surveyed, but not from each other. In general, respondents attribute the lowest value of importance to a good work team.

Job satisfaction is presented in Table 4 and Figure 2 on the left.

Table 4

Good work team: pairwise comparison, p-levels of Tukey's HSD test[3]

	Preferred level – above the diagonal					
	SVK-small	SVK-medium	SVK-large	CZ-small	CZ-medium	CZ-large
SVK-small	–	**0.000**	0.085	**0.000**	**0.000**	**0.000**
SVK-medium	0.063	–	**0.009**	0.873	0.941	**0.000**
SVK-large	**0.000**	**0.000**	–	**0.000**	**0.000**	**0.000**
CZ-small	**0.008**	**0.000**	**0.000**	–	1.000	**0.011**
CZ-medium	0.742	**0.000**	**0.000**	0.301	–	**0.008**
CZ-large	**0.000**	**0.000**	**0.017**	0.560	**0.003**	–
	Current level – below the diagonal					

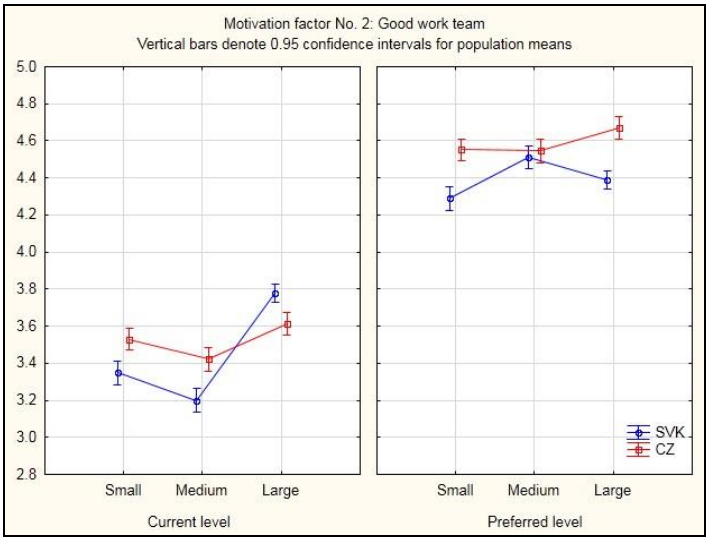


Figure 2

Box plot – Good work team

[3] note: statistically significant differences are highlighted in bold

Employees of large Slovak companies are the most satisfied with their work team. The results are significantly different from the remaining groups. Employees working in medium-sized and small Slovak enterprises rated their work teams with lower marks of satisfaction than the Czech respondents.

Figure 2 presents 95% confidence intervals for the mean values of the importance of the motivation factor – good work team. The difference in the mean values between preferred and current level is observed, i. e. between employee satisfaction with a given factor in their real working conditions and their need to be motivated by a good work team.

3.3 Motivation Factor No. 1 – Atmosphere in the Workplace

The results of post-hoc testing are presented in Table 5. Employees of all Czech enterprises, irrespective of size, rate the atmosphere in the workplace equally important. On a scale of importance, they assess this factor with higher average values than employees working in Slovak logistics companies. In Slovak enterprises, the views of employees working in small enterprises differ from those of employees working in medium-sized and large enterprises. Respondents attribute to the atmosphere in the workplace the lowest average value of all groups. Employees of middle-sized and large enterprises, regardless of their country, are equally satisfied with the atmosphere in the workplace. The opinions of employees working in small Slovak and small Czech enterprises differ significantly.

Table 5
Atmosphere in the workplace: pair-wise comparison, p-levels of Tukey's HSD test[4]

	Preferred level – above the diagonal					
	SVK-small	SVK-medium	SVK-large	CZ-small	CZ-medium	CZ-large
SVK-small	–	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
SVK-medium	0.972	–	0.734	**0.012**	**0.000**	**0.000**
SVK-large	**0.000**	**0.000**	–	**0.000**	**0.000**	**0.000**
CZ-small	**0.000**	**0.000**	0.481	–	0.856	0.262
CZ-medium	0.980	0.659	**0.000**	**0.000**	–	0.940
CZ-large	**0.000**	**0.000**	0.374	1.000	**0.000**	–
	Current level – below the diagonal					

Figure 3 presents 95% confidence intervals for the average values of the importance of the motivation factor – atmosphere in the workplace. A clear discrepancy between employee assessment of the atmosphere in their workplace (Figure 3 on the left) and how much importance they attribute to this factor in their work motivation (Figure 3 on the right) is observed.

[4] note: statistically significant differences are highlighted in bold

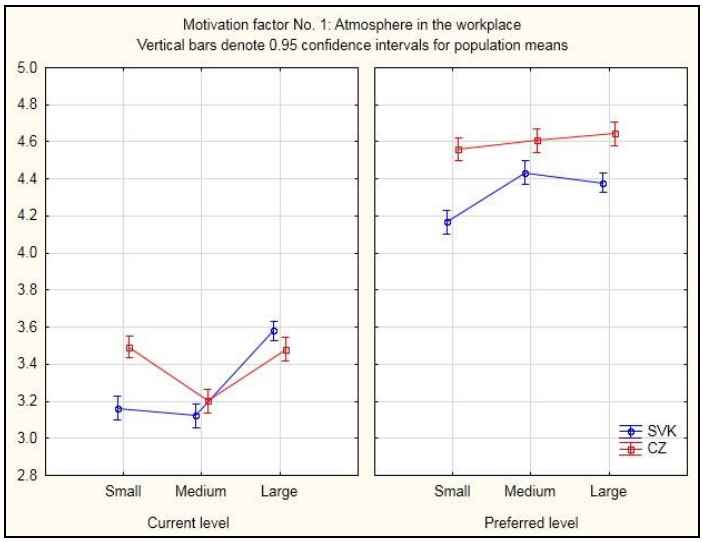


Figure 3
Box plot – Atmosphere in the workplace

3.4 Motivation Factor No. 21 - Fair Appraisal System

Table 6 presents Tukey's HSD test results.

Table 6
Fair appraisal system: pairwise comparison, p-levels of Tukey's HSD test[5]

	Preferred level – above the diagonal					
	SVK-small	SVK-medium	SVK-large	CZ-small	CZ-medium	CZ-large
SVK-small	–	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
SVK-medium	**0.000**	–	0.997	**0.032**	0.692	0.952
SVK-large	**0.000**	**0.001**	–	0.068	0.919	0.742
CZ-small	**0.000**	**0.000**	0.537	–	0.646	**0.001**
CZ-medium	**0.000**	1.000	**0.000**	**0.000**	–	0.182
CZ-large	**0.000**	**0.000**	0.999	0.821	**0.000**	–
	Current level – below the diagonal					

When examining the preferred level, the opinions of employees working in small Slovak enterprises are significantly different from other respondents. Compared to other groups of enterprises, respondents perceive fair appraisal of employees as

[5] note: statistically significant differences are highlighted in bold

the lowest mean value of importance. Employees working in medium and large enterprises, regardless of country, perceive the motivation factor in the same way.

Respondents in small Slovak enterprises attribute the lowest mean value to work satisfaction. These results are significantly different from the rest of the groups surveyed.

Figure 4 shows 95% confidence intervals for the mean values of the importance of the motivation factor – fair appraisal system. Fair appraisal of employees is considered a factor of great importance by employees in logistics companies in their work motivation (Figure 4 on the right). However, the real situation in fair appraisal system is perceived in a different way. Mean values of job satisfaction are at a neutral level in the rating scale (Figure 4 on the left) with a more pronounced difference between small enterprises in Slovakia and the Czech Republic.

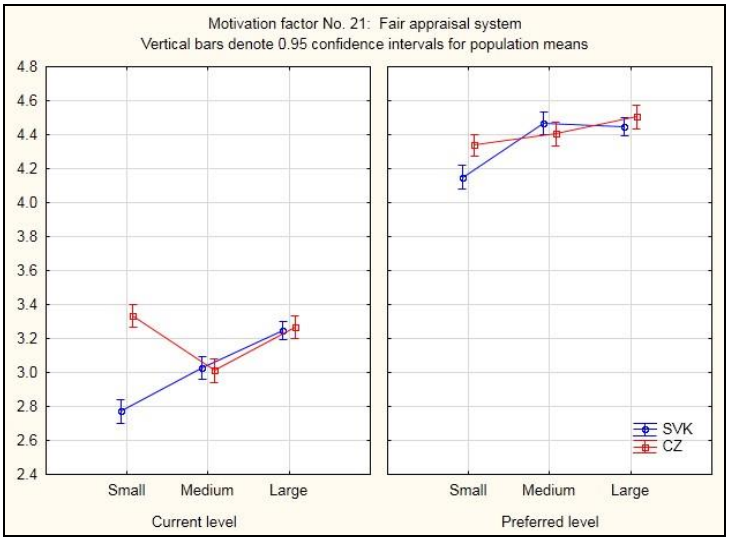


Figure 4
Box plot – Fair appraisal system

Small and medium-sized enterprises constitute a major part of the economy of each country with the greatest potential for growth and the impact on economic stabilization and balanced development of the regions [31]. They are one of the biggest drivers of regional development as they are important in creating jobs and creating an entrepreneurial spirit [32, 33]. Considering the growing economy that is creating new opportunities, no business entity (small, medium or large) is able to satisfy the customer by delivering the right product, in the right quality, in the right amount, in the right place, at the right time, at the right price, and reasonable costs in a tough competitive environment [34, 35].

At present, logistics is becoming the center of attention more and more frequently. This is an area that is affected by the globalization of world trade, the explosion of information and communication technologies, the growing importance of system approach, the concept of total costs and the orientation of the enterprise to top quality as well as high-level of customer service [36, 37]. The progressive growth of the economy in this sector brings a rapid progress in the field of innovations, in which sustainable innovation management has its irreplaceable place. Thanks to the fact that logistics in the Slovak Republic and the Czech Republic has become part of European and global trade, logistics providers are involved in transnational production and distribution chains and in the application of modern procedures. In this context, the lack of qualified workers is the biggest challenge for Slovak and Czech small, medium-sized and large enterprises. Nearly three quarters (71%) of the respondents agree to this in the study published by Casey [38]. For logistics companies, this situation presents the challenge and the necessity not only to acquire but also to maintain good human resources. Therefore, business strategies are geared towards achieving sustainable processes. Employer branding is becoming an important part of a business strategy [39, 40]. This approach includes progressive HR activities so that the employers proactively differentiates themselves from their competitors and maintains and attracts as many new high-quality employees as possible [41, 42]. Employer branding uses a variety of original employee-oriented tools [43, 44]. In order to succeed, to ensure sustainability, to build a reputation for business and a strong brand, companies meet their employees' needs by providing good working conditions [45, 46]. An interest in the level of employee motivation and employee satisfaction is becoming of vital importance [20, 22]. In this context, the role of managers is to respect the principles of sustainability while taking into account the size of the enterprise, because according to the results of previous research, job satisfaction levels are lower in large enterprises and management-employee relationships are less satisfactory in large enterprises than in small enterprises [19, 21]. The findings by Artz [28] indicate that net performance pay increases job satisfaction in larger enterprises. Improving management-employee relations in large enterprises will increase employee satisfaction in many respects as well as increase productivity and reduce turnover [19].

Multicultural teams of workers are becoming current trends in logistics companies [47]. Thanks to the global nature of logistics, they have become a reality in logistics companies. Organizations with competitors increasingly global, require managers who excel in managing culturally diverse, very complex and rapidly changing conditions [29, 48]. Intercultural (global) competencies and the emphasis on effective management from an intercultural point of view, which means an increased tolerance to cultural differences, while taking into account different values, priorities and therefore different motivational elements, are indispensable for managers working in intercultural teams. Research results by Blašková and Hitka [14], Daud [22], Nastacă [49], Nikulin and Szymczak [50], Seilerová [51], Extremera et al. [52], Kim and Choi [53], Sanchez-Sellero et al.

[54], Žuľová et al. [55], Malá et al. [56], and Kamdron [57] confirm that adequate managing of intercultural aspects results in increased satisfaction, motivation and improved work performance of employees.

Conclusions

The aim of this study was to identify differences in the perception of motivation and job satisfaction of employees in selected countries. Based on the research results, the fact that motivation of employees in the logistics industry is different in Slovakia and in the Czech Republic can be concluded. At the same time, motivation varies in terms of the size of enterprise. As part of the post-hoc analysis, the observed dependencies of the mean values of motivation and satisfaction with the effects of the selected motivation factors were examined in more detail. These findings are important for the members of management because of the globalization of economies and multiculturalism of teams, in (but not only) logistics companies. Finding a variety of preferences for motivational needs and job satisfaction does not make it possible to develop unified motivation programs. Finally, the fact that the company management has to take into account the needs of its employees with regard to the size of an enterprise as well as the country of origin can be stated.

Acknowledgement

This research was supported by projects KEGA 005TU Z-4/2020 “Economics, Management and Enterprising in Wood Industry Companies – university textbook with visualization support in virtual space”.

References

[1] M. Wosiek: Rural–Urban Divide in Human Capital in Poland after 1988. Oeconomia Copernicana, Vol. 11, 2020, No. 1, pp. 183-201

[2] P. Sánchez-Sellero, M. C. Sánchez-Sellero, F. J. Sánchez-Sellero, M. M. Cruz-González: Innovation and Manufacturing Productivity. Journal of Technology Management and Innovation, Vol. 9, 2014, No. 3, pp. 135-145

[3] J. Horecký, M. Blažek: Dependent Work and Internship. Central European Journal of Labour Law and Personnel Management, Vol. 2, 2019, No. 2, pp. 7-20

[4] E. Nedeliaková, M. Panak: Methodology for Quality Assessment within Transportation Chain. Proceedings of CITPM, Czestochawa (Poland), 2016, pp. 309-214

[5] The European Commission. User Guide to the SME Defiinition, Publications Office of the European Union, Luxemburg, 2015

[6] Definice velkého podniku. (In English – Definition of a Large Enterprise.) Availbale online: http://www.50001.cz/definice-velkeho-podniku/ (accessed on 27 November 2018)

[7] Malé podniky zamestnávajú na Slovensku viac než polovicu ľudí, je to piaty najvyšší podiel v EÚ (In English – Small Businesses Employ More Than Half of the People in Slovakia, the Fifth Highest Share in the EU.) Available online: https://touchit.sk/male-podniky-zamestnavaju-na-slovensku-viac-nez-polovicu-ludi-je-to-piaty-najvyssi-podiel-v-eu/180486 (accessed on 27 November 2018)

[8] SBA. Malé a stredné podnikanie v číslach v roku 2017 (In English – Small and Medium Business in Numbers in 2017) Available online: https://www.npc.sk/file?uuid=b40742be-ac93-4fd0-ae60-b52467626139 (accessed on 27 November 2018)

[9] Zpráva o vývoji malého a středního podnikání a jeho podpoře v roce 2017 (In English – Report on the Development of Small and Medium-Sized Enterprises and their Support in 2017) Availbale online: https://www.mpo.cz/assets/cz/podnikani/male-a-stredni-podnikani/studie-a-strategicke-dokumenty/2018/10/Zprava_MSP_2017.pdf (accessed on 30 November 2018)

[10] J. Kubaľa, M. Vetráková: Reasons of the Employees' Stabilization in Hotels in Slovakia. Acta Oeconomica Universitatis Selye, Vol. 6, 2018, No. 2, 90-100

[11] M. Nosková, T. Peráček: Termination of Employment in the Slovak Republic as a Key Issue of HR Management. Central European Journal of Labour Law and Personnel Management, Vol. 2, 2019, No. 2, pp. 44-59, doi: 10.33382/cejllpm.2019.03.04

[12] M. Vokoun, Z. Caha, J. Straková, F. Stellner, J. Váchal: The Strategic Importance of Human Resources Management and the Roles of Human Capital Investment and Education. SCIPAP, Vol. 25, 2018, No. 42, pp. 258-268

[13] D. Gottwald, L. Svadlenka, P. Lejskova, H. Pavlisova: Human Capital as a Tool for Predicting Development of Transport and Communications Sector: The Czech Republic Perspective. Communications - Scientific Letters of the University of Zilina, Vol. 19, 2017, No. 4, pp. 50-56

[14] M. Blašková, M. Hitka: Model Riadenia Pracovnej Motivácie v Priemyselných Podnikoch (In English - Work Motivation Management Model in Industrial Enterprises) Technical University in Zvolen, Zvolen, Slovakia, 2011

[15] A. Aydin, S. Tiryaki: Impact of Performance Appraisal on Employee Motivation and Productivity in Turkish Forest Products Industry. Drvna Industrija, Vol. 69, 2018, No. 2, pp. 101-111

[16] A. Tansel, S. Gazioglu: Management-Employee Relations, Firm Size and Job Satisfaction. International Journal of Manpower, Vol. 35, 2012, pp. 1260-1275

[17] A. Al Mamun, M. D. Ibrahim, M. N. H. B. Yusoff, S. A. Fazal: Entrepreneurial Leadership, Performance, and Sustainability of Micro-enterprises in Malaysia. Sustainability, Vol. 10, 2018

[18] L. Mura, B. Gontkovicova, E. Dulova Spisakova, Z. Hajduova: Position of Employee Benefits in Remuneration Structure. Transformations in Business & Economics, Vol. 18, 2019, No. 2, pp. 156-173

[19] S. Cantele, A. Zardini: Is Sustainability a Competitive Advantage for Small Businesses? Journal of Cleaner Production, Vol. 182, 2018, pp. 166-176

[20] R. Kanfer, G. Chen, R. D. Pritchard: Work Motivation: Past, Present and Future. Routledge, New York, NY, USA, 2012

[21] B. Roxas, N. Ashill, D. Chadee: Effects of Entrepreneurial and Environmental Sustainability Orientations on Firm Performance. Journal of Small Business Management, Vol. 55, 2017, No. S1, pp. 163-178

[22] N. Daud: Determinants of Job Satisfaction. In Proceedings of BSS, Kuala Lumpur, Malaysia, 2015

[23] D. Jelačić, T. Grladinović, A. Pirc, L. Oblak: Motivation Factors Analysis in Industrial Plants. Strojarstvo, Vol. 52, 2010, No. 3, pp. 349-361

[24] L. Mura, D. Vlacseková: Motivation of Public Employees: Case Study of Slovak Teaching and Professional Staff. Administratie si Management Public, Vol. 31, 2018, pp. 67-80

[25] J. Jeong, M. Choi: The Expected Job Satisfaction Affecting Entrepreneurial Intention as Career Choice in the Cultural and Artistic Industry. Sustainability, Vol. 9, 2017

[26] J. Rosak-Szyrocka: Empoyees Motivation at Hospital as a Factor of the Organizational Success. Human resources Management & Ergonomics, Vol. 8, 2014, No. 2, pp. 102-111

[27] Z. Stacho, H. Urbancová, K. Stachová: Organisational Arrangement of Human Resources Management in Organisations Operating in Slovakia and Czech Republic. Acta Universitatis Agriculturaeet Silviculturae Mendelianae Brunensis, Vol. 61, 2013, No. 7, pp. 2787-2799

[28] B. Artz: The Role of Firm Size and Performance Pay in Determining Employee Job Satisfaction. Labour, Vol. 22, 2008, No. 2, pp. 315-343

[29] M. Szymanski, S. R. Fitzsimmons, W. M. Danis: Multicultural Managers and Competitive Advantage. International Business Review, Vol. 28, 2018, No. 2, pp. 305-315

[30] E. Duľová Spišáková, L. Mura, B. Gontkovičová, Z. Hajduová: R&D in the Context of Europe 2020 in Selected Countries. Economic Computation and Economic Cybernetics Studies and Research, Vol. 51, 2017, No. 4, pp. 243-261

[31] A. Kucharčíková, M. Mičiak: Human Capital Management in Transport Enterprises with the Acceptance of Sustainable Development in the Slovak Republic. Sustainability, Vol. 10, 2018

[32] M. Němec, Ľ. Krišťák, P. Hockicko, Z. Danihelová, K. Velmovská: Application of Innovative P&E Method at Technical Universities in Slovakia. Eurasia Journal of Mathematics Science and Technology Education, Vol. 13, 2017, No. 6, pp. 2329-2349

[33] B. Antonová, J. Chocholáč, I. Drahotský: The Analysis of the Dependence of the Road Transport Infrastructure and Transport Performances in the Relation with GDP of the Czech Republic. SCIPAP, Vol. 36, 2016, No. 1, pp. 5-16

[34] B. Sarkan, O. Stopka, C. Li: The Issues of Measuring the Exterior and Interior Noise of Road Vehicles. Communications, Vol. 19, 2017, No. 2, pp. 50-55

[35] Ľ. Bajzíkova, D. Novackova, D. Saxunova: Globalization in the Case of Automobile Industry in Slovakia. In Proceedings of IBIMA, Madrid, Spain, 2017

[36] E. Tokarčíková, A. Kucharčíková, M. Ďurišová: Corporate Social Responsibility Managers and their Decision Making. Turkish Online Journal of Educational Technology, 2017, pp. 654-664

[37] M. Gejdos, M. Lieskovsky, M. Slancik, M. Němec, Z. Danihelová: Storage and Fuel Quality of Coniferous Wood Chips. BioResources, Vol. 10, 2015, No. 3, pp. 5544-5553

[38] S. Casey: Global Business Monitor 2017, Bibby Financial Services

[39] A. M. Sivertzen, E. R. Nilsen, A. H. Olafsen: Employer branding. Journal of Product & Brand Management, Vol. 22, 2013, pp. 473-483

[40] D. Kucherov, E. Zavyalova: HRD Practices and Talent Management in the Companies with the Employer Brand. European Journal of Training and Development, Vol. 36, 2012, No. 1, pp. 86-104

[41] A. Raziq, R. Maulabakhsh: Impact of Working Environment on Job Satisfaction. Procedia Economics and Finance, Vol. 23, 2015, pp. 717-725

[42] E. Loučanová, M. Olšiaková, M. Dzian: Suitability of Innovative Marketing Communication Forms in the Furniture Industry. Acta Facultatis Xylologiae Zvolen, Vol. 60, 2018, No. 1, pp. 159-171

[43] M. Sedliačiková, Z. Stroková, J. Klementová, A. Šatanová, M. Moresová: Impacts of Behavioral Aspects on Financial Decision-Making of Owners of Woodworking and Furniture Manufacturing and Trading Enterprises. Acta Facultatis Xylologiae Zvolen, Vol. 62, 2020, No. 1, pp. 165-176

[44] M. Sedliačiková, Z. Stroková, J. Drábek, D. Malá.: Controlling Implementation: What are the Benefits and Barries for Employees of Wood Processing Enterprises? Acta Facultatis Xylologiae Zvolen, Vol. 61, 2019, No. 2, pp. 163-173

[45] H. Palus, J. Parobek, M. Dzian, S. Šimo-Svrček, M. Krahulcová: How Companies in the Wood Supply Chain Perceive the Forest Certification. Acta Facultatis Xylologiae Zvolen, Vol. 61, 2019, No. 1, pp. 155-165

[46] J. Dirisu, R. Worlu, A. Osibanjo, O. Salau, T. Borishade, S. Meninwa, T. Atolagbe: An Integrated Dataset on Organisational Culture, Job Satisfaction and Performance in the Hospitality Industry. Data in Brief, Vol. 19, 2018, pp. 317-321

[47] T. Johánek: Nedostatek lidí v obchodech a dopravě zboží tlačí nejen na vyšší mzdy (In English – The Lack of People in Shops and the Transport of Goods is not Only Pushing for Higher Wages) Available online: http://www.dnoviny.cz/spedice-logistika/nedostatek-lidi-v-obchodech-a-doprave-zbozi-tlaci-nejen-na-vyssi-mzdy (accessed on 11 December 2018)

[48] N. Mikušová, M. Timák, G. Fedorko, V. Molnár: Design of New Effective Train Traffic Diagram for a Railway Line. In Proceedings of MATEC, 2018

[49] C. C. Nastacă: Leadership and Resilience in Romanian Public Administration from County Level. Administratie si Management Public, Vol. 34, 2020, pp. 78-96

[50] D. Nikulin, S. Szymczak: Effect of the Integration into Global Value Chains on the Employment Contract in Central and Eastern European countries. Equilibrium. Quarterly Journal of Economics and Economic Policy, Vol. 15, 2020, No. 2, pp. 275-294

[51] M. Seilerová: The Consequences of Psychosocial Risks in the Workplace in Legal Context. Central European Journal of Labour Law and Personnel Management, Vol. 2, 2019, No. 1, pp. 47-60

[52] N. Extremera, S. Mérida-López, N. Sánchez-Álvarez, C. Quintana-Orts: How does Emotional Intelligence Make One Feel Better at Work? International Journal of Environmental Research and Public Health, Vol. 15, 2018, No. 9

[53] S. J. Kim, S. O. Choi: The Effects of Job Mismatch on Pay, Job Satisfaction, and Performance. Journal of Open Innovation, Vol. 4, 2018

[54] M. C. Sanchez-Sellero, P. Sanchez-Sellero, M. M. Cruz-Gonzalez, F. J. Sanchez-Sellero: Determinants of Job Satisfaction in the Spanish Wood and Paper Industries. Drvna Industrija, Vol. 69, 2018, No. 1, pp. 71-80

[55] J. Žuľová, M. Švec, A. Madleňák: Personality Aspects of the Employee and their Exploration from the GDPR Perspective. Central European Journal of Labour Law and Personnel Management, Vol. 1, 2018, No. 1, pp. 68-77

[56] D. Malá, M. Sedliačiková, M. Dušak, A. Kaščáková, Z. Musová, J. Klementová: Green Logistics in the Context of Sustainable Development in Small and Medium Enterprises. Drvna Industrija, Vol. 68, 2017, pp. 69-79

[57] T. Kamdron: Work Motivation and Job Satisfaction of Estonian Higher Officials. International Journal of Public Administration, Vol. 28, 2005, No. 13-14

Towards Fast and Understandable Computations: Which "And"- and "Or"-Operations Can Be Represented by the Fastest (i.e., 1-Layer) Neural Networks? Which Activations Functions Allow Such Representations?

Kevin Alvarez[1], Julio C. Urenda[1,2], Orsolya Csiszár[3,4], Gábor Csiszár[6], József Dombi[7], György Eigner[5], and Vladik Kreinovich[1]

Departments of [1]Computer Science and [2]Mathematical Sciences
University of Texas at El Paso, El Paso, TX 79968, USA
kalvarez9@miners.utep.edu, jcurenda@utep.edu, vladik@utep.edu
[3]Faculty of Basic Sciences, University of Applied Sciences Esslingen
Esslingen, Germany
[4]Institute of Applied Mathematics, Óbuda University
[5]Institute of Biomatics and Applied Artificial Intelligence, Óbuda University
Budapest, Hungary,
orsolya.csiszar@nik.uni-obuda.hu
eigner.gyorgy@nik.uni-obuda.hu
[6]Institute of Materials Physics, University of Stuttgart
Stuttgart, Germany
gabor.csiszar@mp.imw.uni-stuttgart.de
[7]Institute of Informatics, University of Szeged
Szeged, Hungary, dombi@inf.u-szeged.hu

Abstract: We want computations to be fast, and we want them to be understandable. As we show, the need for computations to be fast naturally leads to neural networks, with 1-layer networks being the fastest, and the need to be understandable naturally leads to fuzzy logic and to the corresponding "and"- and "or"-operations. Since we want our computations to be both fast and understandable, a natural question is: which "and"- and "or"-operations of fuzzy logic can be represented by the fastest (i.e., 1-layer) neural network? And a related question is: which activation functions allow such a representation? In this paper, we provide an answer to both questions: the only "and"- and "or"-operations that can be thus represented are $\max(0, a+b-1)$ *and* $\min(a+b, 1)$*, and the only activations functions allowing such a representation are equivalent to the rectified linear function – the one used in deep learning. This result provides an additional explanation of why rectified linear neurons are so successful. With also show that with full 2-layer networks, we can compute practically any*

"and"- and "or"-operation.

Keywords: neural networks, fuzzy logic, "and"- and "or"-operations, rectified linear neurons, explainable AI

1 Formulation of the Problem

1.1 What we plan to do in this section

In this section, we not only explain our problem – we also explain *why* this problem is, in our opinion, very important.

We do not just want to formulate a technical problem listed in the title of this paper – we want to explain, from scratch, why we use neural networks and fuzzy techniques, and why it is important to relate these techniques.

We hope that these explanations will motivate the readers to continue research in this direction – in particular, to solve open problems that we listed at the end of this paper.

1.2 Computations are needed

In many application areas, we need to process data. Because of this need, computers are ubiquitous. What do we want from the computation results? First of all, we want them to be correct:

- if we are predicting weather, we want these predictions to be mostly successful,
- if we are deciding whether to give a loan to a bank's customer, we want to be sure that customers who get the loans have a high chance of repaying them, and that most customers to whom the program decided not to give the loan will not become very successful – and thus will not present our missed opportunities.

Coming up with such an algorithm is not easy, this is the main challenge. But once we have this algorithm, there are two other important challenges.

1.3 Two important challenges: computation speed and understandability

First, in most practical problems, we need to process a large amount of data – and we need to make a decision reasonably fast:

- if we predict weather, we need to take into account all the results of today's measurements of temperature, wind speed and direction, etc., in a given geographic areas, satellite images, historical data – and get the prediction of tomorrow's weather the same day: otherwise, our prediction will be useless;

- if we decide whether to give a person a loan, we need to take into account this person's financial history, financial history of similar customers, general economic situation in the region, etc. – and get the result fast, otherwise the customer may lose the business opportunity for which he/she is seeking this loan.

So, we need all the computations to be as fast as possible.

We also ideally want the computations to be understandable.

- When a weatherperson on the TV predict's tomorrow's weather, it is much more convincing if this person explains why we should expect strong winds, or, vice versa, perfect weather. These explanations may not be quantitative, usually, qualitative explanations are good enough.
- When we explain, to the person, why he/she is not getting a loan while his/her friends are, we need to have some reasonable explanations – at least to avoid lawsuits claiming gender-based, age-based, or race-based bias.

How can we achieve these two goals?

1.4 Need for fast computations leads to neural networks

A natural way to speed up computations is to perform them in parallel. In the past, only high-performance super-computers had several processors working in parallel, but nowadays, parallelism is ubiquitous: even the cheapest computers have up to four processors working in parallel. In parallel computations, all that matters is how fast computations can be performed on one of the processors – since computations on other processors are performed at the same time.

Which computations are fast? In general, computers process numbers, so, in general, any computation takes numerical inputs $x_1, \ldots, x_n$ – e.g., measurement results – and converts them into one or more numerical values y. In mathematics, a situation when to each input $x = (x_1, \ldots, x_n)$ there corresponds the result is known as a *function*, so we can say that each processor computes some function $y = f(x_1, \ldots, x_n)$.

Which functions are the easier to compute? Functions can be linear or non-linear. In general, linear functions, i.e., functions of the type

$$f(x_1, \ldots, x_n) = w_0 + w_1 \cdot x_1 + \ldots + w_n \cdot x_n \tag{1}$$

are the easiest to compute, so let us keep them in our list of easiest-to-compute functions. However, we cannot just limit ourselves to linear functions, because otherwise, if we only apply linear transformations, you will only get linear functions, but in real life, many dependencies are nonlinear. So, we need some nonlinear functions as well.

Which nonlinear functions are the easiest to compute? In general, the more inputs the function has, the longer it takes to process all these inputs. Thus, the easiest to compute are functions of one variable $y = s(z)$.

So, we arrive at the following computation scheme:

- first, each processor applies the fastest – linear – transformation to the data, i.e., computes the value $z = w_0 + w_1 \cdot x_1 + \ldots + w_n \cdot x_n$;
- if this is not enough, we apply the fastest non-linear transformation and compute $y = s(z)$; as a result, we get the value

$$y = s(w_0 + w_1 \cdot x_1 + \ldots + w_n \cdot x_n); \tag{2}$$

- then, if needed, we apply another linear transformation, then another nonlinear one, etc.

As a result, we get a layered computation scheme in which on each layer, each pair of processors computes the values (2), and then the results from these pairs become inputs to another layer, etc.

This scheme is what is usually known as a *neural network*; readers interested in more details can see, e.g., [6, 11, 23]. A two-part component computing the expression (2) is known as a *neuron*, and the non-linear function $s(z)$ is known as the *activation function*. So, the need for fast computations has indeed led us to neural networks. The fewer layers, the faster computations: 1-layer networks are the fastest, 2-layer networks are second fastest. This is especially important if we implement neural networks in hardware; see, e.g., [1].

Of course, to make sure that neural networks are useful, we need to check that neural networks can indeed describe any possible continuous dependence with any desired accuracy, i.e., in precise terms, that for every continuous function $y = f(x_1, \ldots, x_n)$ on a bounded domain and for every desired accuracy $\varepsilon > 0$, there exists a function which is ε-close to $f(x_1, \ldots, x_n)$ and which can be represented by a neural network. Such *universal approximation* results are indeed known for many different activation functions; see, e.g., [6, 7, 19, 26].

Neural networks have been very successful in practical applications. Which activation function should we use? Traditionally, the most widely used neural networks used *sigmoid* activation functions $s(z) = 1/(1 + \exp(-z))$. Lately, it turned out that even more successful are *deep* neural networks [11] that use *rectified linear* functions $s(z) = \max(0, z)$.

Comments.

- Deep neural networks not only use a different activation function, they also use a large number of layers. This makes the computations somewhat slower that for traditional "shallow" (few-layers) neural networks, but this slowing down is needed to provide a better approximation accuracy; see, e.g., [4, 21, 23, 22] for a detailed explanation of this need.
- Another case when sacrificing speed can improve accuracy is recurrent neural networks that work iteratively: Hopfield networks [13], Elman networks [10], Kohonen's self organizing maps [16], fuzzy cognitive maps (see, e.g., [27, 49]), and other similar schemes (see, e.g., [9]).

- How many neurons do we need to get a good approximation? The space of all continuous function is infinite-dimensional. This means, crudely speaking, that to precisely describe a generic function, we need to use infinitely many parameters. The more parameters we use, the more accurately we can approximate each function. For neural networks, this means that the more neurons we allow, the more accurate is the resulting approximation.
- How can we prove universal approximation results? Many of these proofs use Stone's generalization [46] of the classical Weierstrass's Theorem [52] according to which each continuous function can be approximated, with any given accuracy, by a polynomial.
- Interestingly, by using appropriate activation functions, we can get not only an ε-*approximation* to the desired function $f(x_1,\ldots,x_n)$, but also the *exact* representation of this function. This possibility follows from the unexpected Kolmogorov's solution [17] to the 13th Hilbert problem [12], one of the 23 problems that 19 century mathematicians left to the 20th century to solve. According to Kolmogorov's theorem, every continuous function on a bounded domain can be represented as a composition of addition and functions of one variable; see, e.g., [30, 31]. This result – as well as its improvements and generalizations such as [36, 45] – underlies the theorems about exact representation of functions by neural networks; see, e.g., [28].

  It is worth mentioning that the corresponding activation functions cannot be smooth. This fact relates these functions to another Weiestrass's result – that there exist continuous functions which are nowhere differentiable [51]. Weierstrass's functions are actually historically the first examples of what is now called a *fractal*; see, e.g., [33].
- It is also worth mentioning that the universal approximation result for neural networks has applications beyond neural networks themselves: e.g., it can explain complexity of collective decision making [48] and – on the qualitative level – the existence and properties of quarks [20].

1.5 Need for understandability leads to fuzzy techniques

Neural networks can compute any dependence – and we can train them to fit any given data, but the problem is that the resulting recommendations come with no justification. As we have mentioned, it is desirable to make our recommendations understandable – i.e., justified, explainable by words from natural language.

Understandability means that we should be able to describe the computations by using words from natural language. One of the main challenges in coming up with such a description is that natural language is imprecise (fuzzy), so it is difficult to find the relation between imprecise words from natural language and precise algorithms. In solving this challenge, it is natural to use the experience of researchers who came up with such a relationship from the other side of it: by trying to translate natural-language knowledge into precise terms.

This experience led to the design on fuzzy logic by Lotfi Zadeh; readers interested in

more details can see, e.g., [5, 15, 34, 42, 43, 55]. Lotfi Zadeh, a specialist in control and an author of a successful textbook on control, noticed, in the early 1960s, a puzzling phenomenon: that human-led control often leads to much better results than even the optimal automatic control. The answer to this puzzle was clear: humans use additional knowledge which was not taken into account when the automatic controllers were designed. The reason why this additional knowledge was not taken into account is that this knowledge is not described in precise terms, it is described by using imprecise words from natural language. For example, an operator may say: if the pressure drops a little bit, increase a little bit the flow of the chemical into the chamber; here, "a little bit" does not have a precise meaning. Zadeh invented a methodology for translating this "fuzzy" knowledge into precise terms, a methodology that he called *fuzzy logic*, or, more generally, *fuzzy techniques*.

His main point is that in contrast to exact statements like "pressure is below 1.2 atmospheres" – which is always either true or false – about the statements that include natural-language words – like "the drop from 1.3 to 1.2 means that the pressure dropped a little bit" – experts are not sure. The smaller the drop, the larger the expert's degree of confidence that this statement is true. For each value of the corresponding quantity (e.g., pressure), we can gauge the expert's degree of confidence in the corresponding statement by asking the expert to mark it on a scale, e.g., from 0 to 10. The resulting mark depends on what scale we use: from 0 to 5 or from 0 to 10 or form 0 to any other number. To make these estimates uniform, a reasonable idea is to divide the mark by the largest number on the scale, so that, e.g., 7 on a scale from 0 to 10 becomes $7/10 = 0.7$. In this new scale, 1 means that the expert is absolutely confident that this statement is true, 0 means that the expert is absolutely confident that the statement is false, and values between 0 and 1 correspond to intermediate degrees of confidence.

The reason why this methodology is called fuzzy *logic* is that in addition to simple statements – like the ones above – expert knowledge often contains statements that include *logical connectives* like "and" and "or". For example, an expert can recommend a certain action if the pressure dropped a little bit *and* the temperature increased somewhat. How can we gauge our degree of certainty in such composite statements? It would be great if we could similarly ask the expert to estimate his/her degree of confidence for all possible pairs of values (pressure, temperature). If we have a composite statement combining three or four different statements, we would need to consider all possible triples or quadruples. Even if we consider a reasonable number 20-30 of possible values of each quantity, it makes sense to ask the expert about all 30 values, but asking about all $30^4 = 810000$ possible quadruples is not realistic. Since we cannot directly elicit the degree of confidence in all such composite statements directly from the expert, we need to be able to estimate this degree based on whatever information we can elicit – i.e., based on the expert's degrees of confidence in the component statements.

In precise terms, we need a procedure that would take, as input, the degrees of confidence a and b in two statements A and B and return an estimate for the expert's degree of confidence in a composite statement $A\,\&\,B$. We will denote this estimate by $f_{\&}(a,b)$. The corresponding function $f_{\&}$ is known as an *"and"-operation*, or,

for historical reason, a *t-norm*.

Since the statements "A and B" and "B and A" mean the same thing, it is reasonable to require that for these two statements, we have the same degree of confidence, i.e., that $f_{\&}(a,b) = f_{\&}(b,a)$. In other words, an "and"-operation must be commutative.

When A is false, clearly $A\,\&\,B$ is false too, so we must have $f_{\&}(0,b) = 0$ for all b. When A is true, our degree of confidence in $A\,\&\,B$ is the same as our degree of confidence in B, i.e., we must have $f_{\&}(1,b) = b$.

Similarly, we need a procedure that would take, as input, the degrees of confidence a and b in two statements A and B and return an estimate for the expert's degree of confidence in a composite statement $A \vee B$. We will denote this estimate by $f_{\vee}(a,b)$. The corresponding function $f_{\vee}$ is known as an *"or"-operation*, or, for historical reason, a *t-conorm*.

Since the statements "A or B" and "B or A" mean the same thing, it is reasonable to require that for these two statements, we have the same degree of confidence, i.e., that $f_{\vee}(a,b) = f_{\vee}(b,a)$. In other words, an "or"-operation must be commutative.

When A is true, clearly $A \vee B$ is true too, so we must have $f_{\vee}(1,b) = 1$ for all b. When A is false, our degree of confidence in $A \vee B$ is the same as our degree of confidence in B, i.e., we must have $f_{\vee}(0,b) = b$.

Fuzzy logic can help translate expert rules of the type "if $A_i(x)$ then $B_i(u)$" related the input x with the control value u – rules that are formulated by using natural-language terms $A_i(x)$ and $B_i(u)$ (such as "x is small") – into precise recommendations. Indeed, for any given input x, the value u is a reasonable control if one of the rules is applicable, i.e., if either $A_1(x)$ is true and $B_1(u)$ holds, or $A_2(x)$ is true and $B_2(u)$ holds, etc.:

$$(A_1(x)\,\&\,B_1(u)) \vee (A_2(x)\,\&\,B_2(u)) \vee \ldots$$

We can elicit, from the expert, degrees to which the statements $A_i(x)$ and $B_i(u)$ hold for different values x and u – the resulting functions are known as *membership functions.* After that, we can use appropriate "and"- and "or"-operations to come up with a degree to which, for given input x, the control u is reasonable. Then, if needed, we can combine these degrees into a single recommendation $\bar{u}(x_1,\ldots,x_n)$ corresponding to the given input $(x_1,\ldots,x_n)$.

It is know that functions $\bar{u}(x_1,\ldots,x_n)$ corresponding to different rules and different membership functions are also universal approximators; see, e.g., [2, 3, 8, 18, 24, 25, 37, 40, 44, 50, 53, 54].

Comments.

- Similarly to the case of neural networks, the more rules we allow, the more accurate is the approximation: if we fix the number of rules, we can only achieve a limited approximation accuracy; see, e.g., [14, 35, 47].
- Similar universal approximation results are known for fuzzy neural networks that combine fuzzy and neural techniques; see, e.g., [29, 32].

- Also similarly to the neural network case, it is possible not only to *approximate* any continuous function by an appropriate system, but also to represent any function *exactly* – by using non-smooth ("fractal") membership functions motivated by the above-mentioned Kolmogorov's theorem; see, e.g., [38, 39].

1.6 Natural questions

As we have mentioned earlier, we want our computations to be both fast and understandable. Understandable means that we have to use some "and"- and "or"-operations. We thus want these operations to be fast. The fastest possible computations are computations on a 1-layer neural network, in which thus "and"-operation is computed by a single neuron, and in which the "or"-operation can also be computed by a single neuron. So, natural questions are:

- which "and"- and "or"-operations can be computed by a 1-layer neural network, and
- what activation functions allow computing "and"- and "or"-operations by such neural networks.

1.7 What we do in this paper

In this paper, we provide answers to both questions, namely:

- we show that the only "and"- and "or"-operations which can be computed by a 1-layer neural network are $\max(0, a+b-1)$ and $\min(a+b, 1)$, and
- we show that the only activation function allowing such fast computations are equivalent to *rectified linear neurons* – which probably provides some explanations for the current success of such activation functions.

We also show that if we allow linear pre-processing after a single neuron, then we also represent $\min(a,b)$ and $\max(a,b)$. If we allow several neurons in a 2-layer network, then, in effect, we can compute any "and"- and "or"-operations.

2 Definitions and the Main Results

Definition 1. *By an* "and"-operation*, we mean a function*

$$f_{\&} : [0,1] \times [0,1] \to [0,1] \tag{3}$$

for which the following properties are satisfied:

- $f_{\&}(a,b) = f_{\&}(b,a)$ *for all a and b,*
- $f_{\&}(0,b) = 0$ *and* $f_{\&}(1,b) = b$ *for all b.*

Definition 2. *By an* "or"-operation*, we mean a function*

$$f_{\vee} : [0,1] \times [0,1] \to [0,1] \tag{4}$$

for which the following properties are satisfied:

- $f_\vee(a,b) = f_\vee(b,a)$ *for all* a *and* b,
- $f_\vee(0,b) = b$ *and* $f_\vee(1,b) = 1$ *for all* b.

Comment. Usually, for both "and"- and "or"-operations, other properties are required as well – namely, continuity, monotonicity, and associativity – but for our main results, we do not need these additional properties.

Definition 3. *We say that a function* $f(x_1,\ldots,x_n)$ *can be represented by a 1-layer neural network if this function can be represented in the form*

$$f(x_1,\ldots,x_n) = s(w_0 + w_1 \cdot x_1 + \ldots + w_n \cdot x_n) \tag{5}$$

for some function $s(z)$ *and for some values* w_i. *The corresponding function* $s(z)$ *is called an* activation function.

Definition 4. *By a* rectified linear *function, we mean a function*

$$s_0(z) = \max(0,z). \tag{6}$$

Definition 5. *We say that two activation functions* $s_1(z)$ *and* $s_2(z)$ *are* equivalent *if for some constants* a_{ij} *and* b_{ij}, *we have*

$$s_1(z) = a_{10} + a_{12} \cdot s_2(b_{10} + b_{11} \cdot z) + a_{1z} \cdot z \tag{7}$$

and

$$s_2(z) = a_{20} + a_{21} \cdot s_1(b_{20} + b_{21} \cdot z) + a_{2z} \cdot z \tag{8}$$

for all z.

Comment. This way, the corresponding multi-layer neural networks represent, in effect, the same class of functions, since each non-linear layer is equivalent to adding extra linear transformations before and after the non-linear layer representing another activation function.

Theorem 1. *The only "and"-operation that can be represented by a 1-layer neural network is* $\max(0,a+b-1)$, *and all activation functions allowing such a representation are equivalent to the rectified linear function.*

Theorem 2. *The only "or"-operation that can be represented by a 1-layer neural network is* $\min(a+b,1)$, *and all activation functions allowing such a representation are equivalent to the rectified linear function.*

Comment. These results provide another explanation for why rectified linear activation functions are so successful in deep neural networks.

2.1 Proof of Theorem 1

Let us consider an "and"-operation $f_{\&}(a,b)$ which can be represented by a 1-layer neural network. By definition of such a representation, this means that $f_{\&}(a,b) = s(w_0 + w_a \cdot a + w_b \cdot b)$ for some function $s(z)$ and for some coefficients w_i.

By definition of an "and"-operation, we have $f_{\&}(a,b) = f_{\&}(b,a)$ for all a and b. Thus, the expression $s(w_0 + w_a \cdot a + w_b \cdot b)$ should not change if we swap a and b: $s(w_0 + w_a \cdot a + w_b \cdot b) = s(w_0 + w_a \cdot b + w_b \cdot a)$. Therefore, we must have $w_a = w_b$, i.e., $f_{\&}(a,b) = s(w_0 + w_a \cdot a + w_a \cdot b)$, and thus,

$$f_{\&}(a,b) = s(w_0 + w_a \cdot (a+b)). \tag{9}$$

Let us introduce an auxiliary function $t(z) \stackrel{\text{def}}{=} s(w_0 + w_a \cdot z)$. This function is, by the definition of equivalence, equivalent to $s(z)$. In terms of this auxiliary function, the formula (9) takes the following simplified form:

$$f_{\&}(a,b) = t(a+b). \tag{10}$$

For $a = 0$, by definition of an "and"-operation, we have $f_{\&}(0,b) = 0$ for all $b \in [0,1]$, thus $t(z) = 0$ for all $z \in [0,1]$.

For $a = 1$, by definition of an "and"-operation, we have $f_{\&}(1,b) = b$ for all $b \in [0,1]$, thus $t(1+b) = b$ for all $b \in [0,1]$. For $z = 1+b$, we have $z \in [1,2]$ and $b = z-1$, thus $t(z) = z-1$ for all $z \in [1,2]$. So, we have:

- $t(z) = 0$ for $z \in [0,1]$, and
- $t(z) = z-1$ for $z \in [1,2]$.

These two cases can be combined into a single formula

$$t(z) = \max(0, z-1). \tag{11}$$

Substituting this expression for $t(z)$ into the formula (10), we conclude that $f_{\&}(a,b) = \max(0, a+b-1)$. So, this "and"-operation is indeed the only one that can be represented by a 1-layer neural network.

Which activation functions can be used for this representation? From the formula (11), we can see that $t(z)$ is indeed equivalent to the rectified linear activation function. Since the original function $s(z)$ is equivalent to $t(z)$, we can conclude that $s(z)$ is also equivalent to the rectified linear activation function. Thus, the 1-layer representation of an "and"-operation is only possible if we use rectified linear neurons.

The theorem is proven.

2.2 Proof of Theorem 2

Let us now consider an "or"-operation $f_{\vee}(a,b)$ which can be represented by a 1-layer neural network. By definition of such a representation, this means that $f_{\vee}(a,b) = s(w_0 + w_a \cdot a + w_b \cdot b)$ for some function $s(z)$ and for some coefficients w_i.

By definition of an "or"-operation, we have $f_\vee(a,b) = f_\vee(b,a)$ for all a and b. Thus, the expression $s(w_0 + w_a \cdot a + w_b \cdot b)$ should not change if we swap a and b: $s(w_0 + w_a \cdot a + w_b \cdot b) = s(w_0 + w_a \cdot b + w_b \cdot a)$. Therefore, we must have $w_a = w_b$, i.e., $f_\vee(a,b) = s(w_0 + w_a \cdot a + w_a \cdot b)$, and thus,

$$f_\vee(a,b) = s(w_0 + w_a \cdot (a+b)). \tag{12}$$

Similar to the proof of Theorem 1, let us introduce an auxiliary function $t(z) \stackrel{\text{def}}{=} s(w_0 + w_a \cdot z)$. This function is, by the definition of equivalence, equivalent to $s(z)$. In terms of this auxiliary function, the formula (12) takes the following simplified form:

$$f_\vee(a,b) = t(a+b). \tag{13}$$

For $a = 0$, by definition of an "or"-operation, we have $f_\vee(0,b) = b$ for all $b \in [0,1]$, thus $t(z) = z$ for all $z \in [0,1]$.

For $a = 1$, by definition of an "or"-operation, we have $f_\&(1,b) = 1$ for all $b \in [0,1]$, thus $t(1+b) = 1$ for all $b \in [0,1]$. For $z = 1+b$, we have $z \in [1,2]$ and $b = z-1$, thus $t(z) = 1$ for all $z \in [1,2]$. So, we have:

- $t(z) = z$ for $z \in [0,1]$, and
- $t(z) = 1$ for $z \in [1,2]$.

These two cases can be combined into a single formula

$$t(z) = \min(z,1). \tag{14}$$

Substituting this expression for $t(z)$ into the formula (13), we conclude that $f_\vee(a,b) = \min(1, a+b)$. So, this "or"-operation is indeed the only one that can be represented by a 1-layer neural network.

Which activation functions can be used for this representation? One can easily see that the expression (14) can be represented in an equivalent form

$$t(z) = 1 - \max(1-z, 0), \tag{15}$$

so $t(z)$ is indeed equivalent to the rectified linear activation function. Since the original function $s(z)$ is equivalent to $t(z)$, we can conclude that $s(z)$ is also equivalent to the rectified linear activation function. Thus, the 1-layer representation of an "or"-operation is only possible if we use rectified linear neurons.

The theorem is proven.

3 Two-Layer Networks and the Auxiliary Result

3.1 What about other "and"- and "or"-operations?

In this paper, we have shown that only the operations $f_\&(a,b) = \max(0, a+b-1)$ and $f_\vee(a,b) = \min(a+b, 1)$ can be represented by 1-layer neural networks. How many layers do we need to represent general "and"- and "or"-operations?

It is known – see, e.g., [41] – that for every continuous "and"- (or "or"-) operation $f(a,b)$ and for every $\varepsilon > 0$, then exists a function $F(z)$ for which an "and"- (or, respectively, "or"-) operation

$$g(a,b) = F^{-1}(F(a) + F(b)) \tag{16}$$

satisfies the property $|f(a,b) - g(a,b)| \le \varepsilon$ for all a and b. (Of course, for this result to be true, it is not sufficient to have the above simplified definitions of "and"- and "or"-operations: we also need to assume associativity and monotonicity.)

For very small ε, the operations $f(a,b)$ and $g(a,b)$ are practically indistinguishable. So, from practical viewpoint, every "and"-operation and every "or"-operation can be represented in the form (16). Every function of this form can be computed by a 2-layer neural network:

- in the first layer, we use the inputs a and b to compute the values $a' = F(a)$ and $b' = F(b)$;
- then, in the second layer, we compute the value $F^{-1}(a' + b')$, which is exactly the desired value $F^{-1}(F(a) + F(b))$.

So, from the practical viewpoint, every "and"-operation and every "or"-operation can be computed by a 2-layer neural network.

For example, a widely used "and"-operation $f_{\&}(a,b) = a \cdot b$ can be computed as $\exp(\ln(a) + \ln(b))$, with $F(z) = \ln(z)$ and the inverse function $F^{-1}(z) = \exp(z)$. Similarly, a widely used "or"-operation $f_{\vee}(a,b) = a + b - a \cdot b$ can be computed in the form (16) with $F(z) = \ln(1-z)$ and $F^{-1}(z) = 1 - \exp(z)$.

3.2 When is it sufficient to have a single neuron with linear post-processing?

We have shown that, from the practical viewpoint, all "and"- and "or"-operations can be represented by a 2-layer neural network. Interestingly, some "and"- and "or"-operations $f(a,b)$ can be represented by a single neuron if we allow an additional linear post-processing. For example, one can easily see that $\min(a,b) = b - \max(0, b-a)$ and $\max(a,b) = a + \max(0, b-a)$.

It turns out that these are the only "and"- and "or"-operations which can be thus represented.

Definition 6. *We say that a continuous monotonic associative "and"-operation* $f_{\&}(a,b)$ can be computed by a single neuron with linear post-processing *if we have*

$$f_{\&}(a,b) = c_0 + c_a \cdot a + c_b \cdot b + s(w_0 + w_a \cdot a + w_b \cdot b). \tag{17}$$

Definition 7. *We say that a continuous monotonic associative "or"-operation* $f_{\vee}(a,b)$ can be computed by a single neuron with linear post-processing *if we have*

$$f_{\vee}(a,b) = c_0 + c_a \cdot a + c_b \cdot b + s(w_0 + w_a \cdot a + w_b \cdot b). \tag{18}$$

Theorem 3. *The only "and"-operations that can be computed by a single neuron with linear post-processing are* $\max(0, a+b-1)$ *and* $\min(a,b)$. *All activation functions allowing such a computation are equivalent to the rectified linear function.*

Theorem 4. *The only "or"-operations that can be computed by a single neuron with linear post-processing are* $\min(a+b,1)$ *and* $\max(a,b)$. *All activation functions allowing such a computation are equivalent to the rectified linear function.*

3.3 Proof of Theorems 3 and 4

First of all, let us somewhat simplify the expressions (17) and (18) for the corresponding operation $f(a,b)$.

We cannot have $w_a = w_b = 0$ because then, the function $f(a,b)$ would be linear, and it is easy to show that no linear function can satisfy all the requirements of an "and"-operation or of an "or"-operation. Thus, either $w_a \neq 0$ or $w_b \neq 0$ (or both).

If $w_a = 0$, then, due to commutativity of $f(a,b)$, we can swap a and b and get an expression with $w_a \neq 0$. Thus, without losing generality, we can assume that $w_a \neq 0$.

We can thus introduce an auxiliary function $t(z) = c_0 + s(w_0 + w_a \cdot z)$. In terms of this auxiliary function, formulas (17) and (18) take the form

$$f(a,b) = c_a \cdot a + c_b \cdot b + t(a + k \cdot b), \tag{19}$$

where $k \stackrel{\text{def}}{=} w_b / w_a$.

If $k = 1$, then the expression $t(a+k\cdot b)$ is symmetric with respect to a and b. Since for both types of operations, the function $f(a,b)$ is commutative, we thus conclude that the difference

$$c_a \cdot a + c_b \cdot b = f(a,b) - t(a+b) \tag{20}$$

is also commutative. Therefore, $c_a = c_b$, hence the whole expression (19) depends only on the sum $a+b$, i.e., has the form $F(a+b)$ for some function $F(z)$. This means that each such function is computable by a 1-layer neural network, and all "and"- and "or"-operations which can be thus represented have been described in Theorems 1 and 2.

To complete the proof, it is therefore necessary to consider the case when $k \neq 1$, i.e., when the lines $a + k \cdot b = \text{const}$ are not parallel to the diagonal $a = b$ of the square $[0,1] \times [0,1]$. Each line $a + k \cdot b = \text{const}$ intersects the borderline of the square at two points. On the borderline – i.e., when one of the values a and b is equal to 0 or to 1 – the value of an "and"- or "or"-operation is uniquely determined by the corresponding Definition (Definition 1 or Definition 2). Since the function $f(a,b)$ is linear on this line, its values for all the points from this line are uniquely determined by the values at these two borderline points. Thus, for each k, we uniquely determine all the values $f(a,b)$ for all the pairs (a,b).

One can check that the only case when the resulting function is commutative and associative is the case $k = -1$, in which case we indeed get $\min(a,b)$ and $\max(a,b)$. We can also easily check that in both case, the activation function $t(z)$ is indeed equivalent to the rectified linear function. The theorems are proven.

3.4 Remaining open problems

It is known (see, e.g., [6]) that functions represented as linear combinations of the results of 1-neuron layer are universal approximators – i.e., for each continuous function on a bounded domain and for each accuracy $\varepsilon > 0$, we can find a neural network which computes the given function with the desired accuracy. In general, the more accuracy we require, the more neurons we need. So, to achieve perfect accuracy – i.e., exact computations – we will need *potentially infinite* number of neurons.

Interestingly, for some "and"- and "or"-operations, we can have perfect accuracy with a *limited number* of neurons: e.g., the operation $a \cdot b$ can be computed by a 2-neuron network, as

$$a \cdot b = \frac{1}{4} \cdot (a+b)^2 - \frac{1}{4} \cdot (a-b)^2. \tag{21}$$

The operation $a + b - a \cdot b$ can be computed by a 3-neuron network:

$$a + b - a \cdot b = (a+b) - \frac{1}{4} \cdot (a+b)^2 - \frac{1}{4} \cdot (a-b)^2. \tag{22}$$

It would be interesting to describe all such "and"- and "or"-operations. Maybe $a \cdot b$ and $a + b - a \cdot b$ are the only such operations?

4 Conclusions

We would like our computations to be fast and understandable. As we show in this paper, the need for the computations to be fast naturally leads to neural networks, and the need for the computations to be understandable – i.e., describable by words from natural language – naturally invokes techniques relating imprecise natural-language words with numerical recommendations – techniques of fuzzy logic. The need to use both neural and fuzzy techniques necessitates analyzing when fuzzy "and"- and "or"-operations – the main building blocks of fuzzy techniques – can be implemented by the fastest possible (1-layer) neural network, and which activation functions can be used for such an implementation.

Interestingly, the answer is that we need to use min, max, and related fuzzy operations $\min(a+b,1)$ and $\max(a+b-1,0)$ – which are indeed among the most successfully used fuzzy techniques, and the corresponding activation function is the rectified linear function – the activation function which is successfully used in deep learning. These result provide a possible explanation of why neural networks that use rectified linear activation function are so successful.

Acknowledgements

This work was supported in part by the grant TUDFO/47138-1/2019-ITM from the Ministry of Technology and Innovation, Hungary, and by the US National Science Foundation grants 1623190 (A Model of Change for Preparing a New Generation for Professional Practice in Computer Science) and HRD-1242122 (Cyber-ShARE Center of Excellence).

The authors are greatly thankful to the anonymous referees for their thorough reading and valuable suggestions.

References

[1] N. Ádám, A. Baláž, E. Pietriková, E. Chovancová, and P. Fecil′ak: The impact of data representations on hardware based MLP network implementation, Acta Polytechnica Hungarica, 2018, Vol. 15, No. 2, pp. 69–88.

[2] M. M. Afravi and V. Kreinovich: From fuzzy universal approximation to fuzzy universal representation: it all depends on the continuum hypothesis, Proceedings of the Joint 17th Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems IFSA-SCIS'2017, Otsu, Japan, June 27–30, 2017.

[3] M. Afravi and V. Kreinovich: Fuzzy systems are universal approximators for random dependencies: a simplified proof, In: M. Ceberio and V. Kreinovich (eds.): Decision Making under Constraints, Springer Verlag, Cham, Switzerland, 2020, pp. 1–5.

[4] C. Baral, O. Fuentes, and V. Kreinovich: Why deep neural networks: a possible theoretical explanation, In: M. Ceberio and V. Kreinovich (eds.): Constraint Programming and Decision Making: Theory and Applications, Springer Verlag, Berlin, Heidelberg, 2018, pp. 1–6.

[5] R. Belohlavek, J. W. Dauben, and G. J. Klir: Fuzzy Logic and Mathematics: A Historical Perspective, Oxford University Press, New York, 2017.

[6] C. M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006.

[7] E. K. Blum and L. K. Li: Approximation theory and feedforward networks, Neural Networks, 1991, Vol. 4, No. 4, pp. 511–515.

[8] J. L. Castro: Fuzzy logic controllers are universal approximators, IEEE Transactions on Systems, Man, and Cybernetics, 1995, Vol. 25, pp. 629–635.

[9] Chiu-Hsiung Chen, Chang-Chih Chung, Fei Chao, Chih-Min Lin, and I. J. Rudas: Intelligent robust control for uncertain nonlinear multivariable systems using recurrent cerebellar model neural networks, Acta Polytechnica Hungarica, 2015, Vol. 12, No. 5, pp. 7–33.

[10] J. L. Elman: Finding structure in time, Cognitive Science, 1990, Vol. 14, pp. 179-211.

[11] I. Goodfellow, Y. Bengio, and A. Courville: Deep Leaning, MIT Press, Cambridge, Massachusetts, 2016.

[12] D. Hilbert: Mathematical Problems, Bulletin of the American Mathematical Society, 1902, Vol. 8, No. 10, pp. 437–479.

[13] J. J. Hopfield: Neural networks and physical systems with emergent collective computational abilities, Proceedings of the National Academy of Sciences of the USA, 1992, Vol. 79, No. 8, pp. 2554–2558.

[14] E. P. Klement, L.T. Kóczy, and B. Moser: Are fuzzy systems universal approximators?, International Journal of General Systems, 1999, Vol. 28, No. 2–3, pp. 259–282.

[15] G. Klir and B. Yuan: Fuzzy Sets and Fuzzy Logic, Prentice Hall, Upper Saddle River, New Jersey, 1995.

[16] T. Kohonen: Self-organized formation of topologically correct feature maps, Biological Cybernetics, 1982, Vol. 43, No. 1, pp. 59–69.

[17] A. N. Kolmogorov: On the representation of continuous functions of many variables by superposition of continuous functions of one variable and addition, Dokl. Akad. Nauk. SSSR, 1957, Vol. 114, pp. 953–956 (in Russian).

[18] B. Kosko: Fuzzy systems as universal approximators, In: Proceedings of the IEEE International Conference on Fuzzy Systems FUZZ-IEEE'92, San Diego, California, 1992, pp. 1153–1162.

[19] V. Kreinovich: Arbitrary nonlinearity is sufficient to represent all functions by neural networks: a theorem, Neural Networks, 1991, Vol. 4, 381–383.

[20] V. Kreinovich, Fundamental properties of pair-wise interactions naturally lead to quarks and quark confinement: a theorem motivated by neural universal approximation results, In: M. Ceberio and V. Kreinovich (eds.): How Uncertainty-Related Ideas Can Provide Theoretical Explanation for Empirical Dependencies, Springer, Cham, Switzerland, to appear.

[21] V. Kreinovich: From traditional neural networks to deep learning: towards mathematical foundations of empirical successes, In: S. N. Shahbazova, J. Kacprzyk, V. E. Balas, and V. Kreinovich (eds.): Proceedings of the World Conference on Soft Computing, Baku, Azerbaijan, May 29–31, 2018.

[22] V. Kreinovich and O. Kosheleva: Optimization under uncertainty explains empirical success of deep learning heuristics", In: P. Pardalos, V. Rasskazova, and M. N. Vrahatis (eds.): Black Box Optimization, Machine Learning and No-Free Lunch Theorems, Springer, Cham, Switzerland, to appear.

[23] V. Kreinovich and O. Kosheleva: Deep learning (partly) demystified, Proceedings of the 4th International Conference on Intelligent Systems, Metaheuristics & Swarm Intelligence ISMSI'2020, Thimpu, Bhutan, April 18–19, 2020.

[24] V. Kreinovich, G. C. Mouzouris, and H. T. Nguyen: Fuzzy rule based modeling as a universal approximation tool, In: H. T. Nguyen and M. Sugeno (eds.): Fuzzy Systems: Modeling and Control, Kluwer, Boston, MA, 1998, pp. 135–195.

[25] V. Kreinovich, H. T. Nguyen, and Y. Yam: Fuzzy systems are universal approximators for a smooth function and its derivatives, International Journal of Intelligent Systems, 2000, Vol. 15, No. 6, pp. 565–574.

[26] V. Kreinovich and O. Sirisaengtaksin: 3-layer neural networks are universal approximators for functionals and for control strategies, Neural, Parallel, and Scientific Computations, 1993, Vol. 1, pp. 325–346.

[27] V. Kreinovich and C. Stylios: Why Fuzzy Cognitive Maps are efficient, International Journal of Computers, Communications, & Control, 2015, Vol. 10, No. 6, pp. 825–833.

[28] V. Kůrková, Kolmogorov's theorem and multilayer neural networks, Neural Networks, 1992, Vol. 5, pp. 501-506.

[29] A. Lemos, V. Kreinovich, W. Caminhas, and F. Gomide: Universal approximation with uninorm-based fuzzy neural networks, Proceedings of the 30th Annual Conference of the North American Fuzzy Information Processing Society NAFIPS'2011, El Paso, Texas, March 18–20, 2011.

[30] G. G. Lorentz: Approximation of Functions, Holt, Reinhard and Winston, New York, 1965.

[31] G. G. Lorentz: The 13th problem of Hilbert, In: F. Browder (ed.): Mathematical Developments Arising from Hilbert's Problems, American Mathematical Society, Providence, Rhode Island, 1976, Vol. 2, pp. 419-430.

[32] R. Lovassy, L. T. Kóczy, and L. Gál: Function approximation performance of fuzzy neural networks, Acta Polytechnica Hungarica, 2010, Vol. 7, No. 4, pp. 25–38.

[33] B. B. Mandelbrot: The Fractal Geometry of Nature, Henry Holt and Company, New York, 1983.

[34] J. M. Mendel: Uncertain Rule-Based Fuzzy Systems: Introduction and New Directions, Springer, Cham, Switzerland, 2017.

[35] B. Moser: Sugeno controllers with a bounded number of rules are nowhere dense, International Journal of General Systems, 1999, Vol. 28, No. 3, pp. 269–277.

[36] M. Nakamura, R. Mines, and V. Kreinovich: Guaranteed intervals for Kolmogorov's theorem (and their possible relation to neural networks), Interval Computations, 1993, No. 3, pp. 183–199.

[37] H. T. Nguyen and V. Kreinovich: On approximations of controls by fuzzy systems, Proceedings of the Fifth International Fuzzy Systems Association World Congress IFSA'93, Seoul, Korea, July 1993, pp. 1414–1417.

[38] H. T. Nguyen and V. Kreinovich: Kolmogorov's Theorem and its impact on soft computing, In: R. R. Yager and J. Kacprzyk (eds.), The Ordered Weighted Averaging Operators: Theory and Applications, Kluwer, Boston, MA, 1997, pp. 3–17.

[39] H. T. Nguyen, V. Kreinovich, and D. Sprecher: Normal forms for fuzzy logic – an application of Kolmogorov's theorem, International Journal on Uncertainty, Fuzziness, and Knowledge-Based Systems, 1996, Vol. 4, No. 4, pp. 331–349.

[40] H. T. Nguyen, V. Kreinovich, and O. Sirisaengtaksin: Fuzzy control as a universal control tool, Fuzzy Sets and Systems, 1996, Vol. 80, No. 1, pp. 71–86.

[41] H. T. Nguyen, V. Kreinovich, and P. Wojciechowski: Strict Archimedean t-norms and t-conorms as universal approximators, International Journal of Approximate Reasoning, 1998, Vol. 18, Nos. 3–4, pp. 239–249.

[42] H. T. Nguyen, C. L. Walker, and E. A. Walker: A First Course in Fuzzy Logic, Chapman and Hall/CRC, Boca Raton, Florida, 2019.

[43] V. Novák, I. Perfilieva, and J. Močkoř: Mathematical Principles of Fuzzy Logic, Kluwer, Boston, Dordrecht, 1999.

[44] I. Perfilieva and V. Kreinovich: A new universal approximation result for fuzzy systems, which reflects CNF–DNF duality, International Journal of Intelligent Systems, 2002, Vol. 17. No. 12, pp. 1121–1130.

[45] D. A. Sprecher: On the structure of continuous functions of several variables, Transactions of the American Mathematical Society, 1965, Vol. 115, pp. 340–355.

[46] M. H. Stone: A generalized Weierstrass approximation theorem, Mathematics Magazine, 1948, Vol. 21, pp. 167–184 and 237–254.

[47] D. Tikk: On nowhere denseness of certain fuzzy controllers containing prerestricted number of rules, Tatra Mountains Mathematical Publications, 1999, Vol. 16, pp. 369–377.

[48] R. Trejo and V. Kreinovich: Complexity of collective decision making explained by neural network universal approximation theorem, In: G. Alefeld and R. A. Trejo (eds.), Interval Computations and its Applications to Reasoning Under Uncertainty, Knowledge Representation, and Control Theory. Proceedings of MEXICON'98, Workshop on Interval Computations, 4th World Congress on Expert Systems, México City, México, 1998.

[49] J. Vaščák and L. Madarász: Function approximation performance of fuzzy neural networks, Acta Polytechnica Hungarica, 2010, Vol. 7, No. 3, pp. 109–122.

[50] L.-X. Wang and J. M. Mendel: Fuzzy basis functions, universal approximation and orthogonal least squares learning, IEEE Transactions on Neural Networks, 1992, Vol. 3, pp. 807–814.

[51] K. Weierstraß: Über continuirliche Functionen eines reellen Arguments,die für keinen Werth des letzeren einen bestimmten Differentialquotienten besitzen (On continuous functions of a real argument which possess a definite derivative for no value of the argument), Königlich Preussichen Akademie der Wissenschaften, 1872; reprinted in: Mathematische Werke von Karl Weierstrass, Mayer & Mueller, Berlin, Germany, 1895, Vol. 2, pp. 71–74.

[52] K. Weierstraß, Über die analytische Darstellbarkeit sogenannter willkürlicher Functionen einer reellen Veränderlichen, Sitzungsberichte der Akademie zu Berlin, 1885, pp. 633–639 and 789–805.

[53] R. R. Yager and V. Kreinovich: Universal approximation theorem for uninorm-based fuzzy systems modeling, Fuzzy Sets and Systems, 2003, Vol. 140, No. 2, pp. 331–339.

[54] Y. Yam, H. T. Nguyen, and V. Kreinovich, Multi-resolution techniques in the rules-based intelligent control systems: a universal approximation result, Proceedings of the 14th IEEE International Symposium on Intelligent Control/Intelligent Systems and Semiotics ISIC/ISAS'99, Cambridge, Massachusetts, September 15–17, 1999, pp. 213–218.

[55] L. A. Zadeh: Fuzzy sets, Information and Control, 1965, Vol. 8, pp. 338–353.

The Development of Economic and Social Indicators in V4 Countries

Pavol Schwarcz, Marián Kováčik, Maroš Valach

Department of European Policies, Faculty of European studies and Regional Development, Slovak University of Agriculture in Nitra
Tr. A. Hlinku 2, 949 76 Nitra, Slovakia
pavol.schwarcz@uniag.sk, marian.kovacik@uniag.sk, maros.valach@uniag.sk

Abstract: After the transition from a centrally planned economy to a market-based economy, and following EU membership, there were significant changes in particular branches of national economies in new member states, thereby reducing the self-sufficiency of these economies. In particular, we focused on central European countries. The aim of the paper was to assess the development of economic and social indicators in particular branches of national economies. To study the situation in these branches we focused on the following social and economic indicators, e.g. employment rate, unemployment rate by branches, people at risk of poverty, salaries in selected branches, gross fixed capital formation, share on GDP, the balance of payments and foreign direct investments. Furthermore, we studied the development of particular indicators in transition period followed by assessing their correlation to each other using appropriate statistical methods. In general, we assumed a positive correlation between the majority of social and economic indicators. In the end, these results were compared in chosen central European countries.

Keywords: gross domestic product; foreign trade; poverty risk; sectoral unemployment; gross fixed capital formation

1 Theoretical Framework

European countries endured many positive and negative experiences during the 20th Century. Among the most affecting can be counted two world wars which led to chaos and insecurity of inhabitants. After World War II the major participants in war decided to prevent further conflicts and ensure peace in Europe. Thus, began the path of creation of the European Economic Community, which could be seen as the beginning of an economic union which was aimed at strengthening the economic cooperation among its member states. This cooperation led to the creation of the European Union.

Not only western European countries had to undergo turbulent periods. In central European countries there was the communist arrangement which did not affect only personal rights but also the national economy as a whole. This was mainly due to the centrally planned economy which stated plans for production. Due to this arrangement, the western countries labelled these countries as a "commercial black hole". This period can also be characterized by lower consumer prices in comparison to the world market, inefficient production and distribution system, excessive demand after foreign products which led to rationing and queuing. In general, the poorer the country the higher the income disparities on a regional level (Nagy, 2016). After the collapse, the situation got worse because there was a sudden decline in production which led to decrease of GDP per capita and was accompanied by inflationary pressure as the central bank attempted to mitigate this decline to save state enterprises. Further disadvantages were high public debt, low productivity and lastly fear of political, economic and social changes accompanying the transformation process and sectoral changes. The post-soviet countries, in general, went through several currency crises during 1998 – 1999 and 2008 – 2009 periods followed by latest in 2014 – 2016 period questioning their macroeconomic stability and social assistance system. (Healey, 1994; FAO, 1995; Dabrowski, 2016; Androniceanu, Tvaronavičienė, 2019; Jašková, 2019).

Negative impacts can be reduced by foreign direct investments (FDI). In a study carried out by Gnangnon (2018), there is a correlation between multilateral trade policy (MTP) and FDI and structural economic vulnerability (SEV) and FDI. His study shows us that MTP encourages the outward FDI and the SEV is discouraging it. These results show us that with lowering the countries development level the MTP impact on FDI is rising and SEV impact is decreasing. Economic growth also depends on economic freedom in a country which can be measured by the Index of Economic Freedom. Various authors study this index and its relation to indicators characterising the source of the economic system. In a study carried out by Mura et al. (2017) the results showed us that Index of Economic Freedom has an important impact on the identification of the mutual relationship between the Index of Economic Freedom and indicators characterizing source sufficiency, public sector, autonomy and the economic stability.

As a result, these changes also affected the sectoral employment. The transition period is associated with the reallocation of the labour force. This shift could be observed from the public sphere to the private sphere as well as between the different industries. This shift had an impact on two important indicators. Firstly, there was a change in the level of education due to the necessity to acquire new knowledge and skills and, secondly, there was a change in regional employment structure (Rutkowski, 2006). The Czech Republic and Slovakia went through major societal changes after 1989 which resulted in the desire of employees for corporate culture (Hitka, et al., 2018). During this period the labour market had undergone many changes, while in the 1990s it was due to extensive growth later

on, from 2000 it was due to new opportunities arisen from the membership in EU. The employment rate in V4 countries was higher than in the old member states. The V4 countries had shown similarities in decreasing employment in the agricultural sector and increase in the sector of services. This growth was the result of a competitive effect of membership (Bielik, Rajčániová, 2008). When considering educational level, the higher career degree means higher financial incentives, but it does not contribute to a higher motivation level. Employees with higher motivation levels are more satisfied with their work (Mura, Vlacseková, 2018).

One of the present competitive advantages of Slovakia, and other later EU member states, was a low-cost based economy to attract more foreign investors (Civelek et al., 2019). Among these advantages, we can count low wages and relatively low taxes compared to other European countries. Unfortunately in the global economy, these factors can no longer be seen as sustainable and therefore the countries need to focus more on advantages connected to resources, especially human resources. The potential can be seen in intellectual capital and innovative enterprises. Innovative leaders in the EU can be seen in the business sector, mainly in small and medium enterprises. Unfortunately for Slovakia, it is the least innovative economy among the V4 countries and EU member states focusing more on maintain partnerships and supply chain optimization (Volná, Papula, 2013; Čepel, 2019). Creation of EMU may seem like an attempt of creation of optimal currency area. Despite some disputes, officially this term was firstly mentioned by Robert A. Mundell in 1961. His theory states that maintaining national currencies needs not be the most efficient arrangement. Creation of common currency may allow deeper integration of countries and markets. On the other hand, the countries need to give up the options for influencing fiscal and monetary policies. Furthermore, he states that creation and functioning of OCA require the following four criteria: labour mobility, capital mobility (including prices and wages), similar business cycle and currency risk-sharing system. The latter was not fully implemented in EMU and the results were seen during the financial crisis which some authors refer to as “European Sovereign Debt Crisis” (Kräussl, Lehnert and Stefanova, 2016; Floyd, 2016). Some claim that the labour market in the European Union compared to other global labour markets, e.g. North America, is less flexible and therefore the unemployment rate is higher. These differences can be seen job vacancies, national or international mobility of labour force, level of education and other skills and even gender differences. In the case of Slovakia, there do not exist any differences in the assessment of corporate culture based on gender (Nickell, 1997; Pavlíková, Siničáková, 2012). Furthermore, the unfavourable conditions in the labour market combined with the impacts of the global financial crisis during the 2007 – 2008 period led to insecurity in various areas like employment, taxes and public revenues and public sector. Among younger people, there are problems with acquiring their own homes. Lennartz and his colleagues undertook a study which resulted in confirmation of decreasing home-ownership among young people up to 34 years

but also a very slight rise in renting. Their results show us that there is a transformation process going towards co-residence of people with their parents (Lennartz, Arundel, Ronald, 2015; Androniceanu et al., 2019; Okanazu, 2019). The impact of economic crisis can be divided into two basic groups, macroeconomic and microeconomic. Indicators which help us measure macroeconomic impacts are GDP, inflation, loan repayment and unemployment. Microeconomic impacts can be measured by the level of previously mentioned indicators in four target groups – individuals, companies, regions and industries (EEIP, 2010).

Entering the EU meant for all new member states change in foreign trade. These changes were connected to the adoption of several principles like free movement of goods and services, common tariffs as well as the removal of certain physical and non-physical barriers to trade inside the Community market (Czaja, Wach, 2009). Before the outburst of crisis, the export was slightly higher than the imports, however, this situation changed at the end of 2008. The previous growth of export was the result of transnational companies and high demand in developing countries, particularly in investments projects focused on electronic services. After the global financial crisis hit the economies of several states there occurred negative trade balances around the world. When considering our studied countries Poland was one of the luckiest countries which did not fall into recession. While the GDP of EU-28 was decreased by 4.5% the GDP of Poland was increased by almost 2%. However, also in Poland, there was a decrease in the export of intermediate products and raw materials. (Bloomberg, 2009; PWC 2010; Mitrega-Niestroj, 2011). This situation was achieved due to several factors, like strong internal market combined with a business-friendly political environment. The public debt was about 50% of GDP which was a result of strict financial regulation which also helped keep private debts low. Also, in comparison of other European countries, Poland did not fully implement saving policies but focused on domestic demand via tax cuts and foreign assistance (Drozdowicz-Bieć, 2013). Despite the loss of złoty value Poland did not get to be threatened by financial turmoil like in any other countries. The weaker currency helped the exporters to deal with the rapid decline of foreign demand (PWC, 2010). It may seem that Poland was the least affected country which maintained positive GDP growth even during the financial crisis. This could be the result of high investments and growth before the crisis outburst. It is also necessary to point out that this situation did not last long due to interaction and mutual economic dependence with its neighbours. From a social point of view, there also was an increase in unemployment like in other countries (Reichardt, 2011; Miłek, 2018). The global financial crisis is connected to smaller job creation and higher job destruction which further threatens regional stability. Growth of employment rate in Poland was almost 4% lower during the 2009-2010 period. Location of regions also plays an important role in the quality of life and employment, especially those located in central and north-western Europe (Chocholatá, Furková, 2018; Nowak, 2018; Chehabeddine, 2020). But on the other hand, the study conducted by Hagemejer

and Tyrowicz (2017) shows us that the rate of job creation is higher than job destruction. The overall employment growth is dependent on the position of the sector in the production chain. In manufacturing, faster employment growth occurred further away from the final demand. This effect is mostly due to the difference in job creation rates along the production chain as is for the job destruction. Considering the labour markets in new member states indicates that social cohesion was a bigger problem than it appears on simple studies based on Gini coefficients (Tomkiewicz, J., 2018).

After entering the EU, the Czech Republic had one of the best economies in central Europe. This situation was gained through economic openness when foreign investors controlled more than 95% of large financial and 70% of non-financial companies in the country, which meant that Czech became highly dependent on a decision made abroad. The growth of real GDP was 5% on average and GDP per capita from 73% to 80% of the EU average during the 2003-2008 period. This performance was gained due to effective macroeconomic and structural policies applied. But due to the export-oriented trade policy, the economy was slowed down when exports and industrial production fell by 18%. This led to strict conditions and decrease of FDI by 7.4% in the first half of 2009 following the rising unemployment rate with decreasing number of job vacancies. The government reacted by several measures like cuts is social security contributions, increased public investments business and employment support. Unlike other countries, the Czech Republic does not have to face several threats of internal imbalance due to the debt crisis. The Czech Republic maintained its high credibility and, strong banking sector and moderate foreign debt. (EC, 2009; PWC, 2010; Tvrdoň, 2010; EEIP, 2013). However, from a political point of view, the crisis resulted in the collapse of government which affected also the market. The higher impact could be felt on the currency market when the Czech crown fell to 27.3 to EUR from 26.91. Compared to other central and eastern European and Baltic countries this political instability was not so threatening because the financial crisis was mainly the result of decreased external demand for their production (Ram, 2009). Relative growth of demand is highly influencing factor on the positive trade balance, especially in manufacturing, in the Czech Republic as well as in Poland. This connection is mainly due to entering the EU and gaining European and global access to markets. The positive impact can also be achieved by expenditure on R&D. This positive development in the trade balance is also strongly connected to labour productivity. However, the positive trade balance can be jeopardized by government policies because these raise the minimum wage faster than average labour productivity (Duľová, et al., 2017; Olczyk, Kordalska, 2018).

In Hungary, the situation was different from the beginning because its economy has been weaker since before the global financial crisis. Labour productivity was decreasing and indebtedness was increasing. The general government deficit was 9.3% of GDP in 2006 whereas the GDP growth was only by 4%. The political

measures helped to decrease the budget deficit to 3.8% by 2008 but were not focused on important structural reforms. Therefore, the GDP growth was lower in comparison to other neighbour countries. Similar to the Czech Republic also Hungary is an export-oriented economy, mainly to Germany, which was unfavourable due to decreasing external demand. (EC, 2009; PWC, 2010). After the crisis outbreak, the Hungarian forint weakened by 17% compared to EURO. This decrease led to household's insolvency and credit crisis. It also led to a decrease in loans and mortgages. Based on the survey conducted by Egedy, people see the biggest crisis impacts in the cities in the area of employment and job opportunities, problems in real estate markets, business environment and financial shortages and funding problems (Egedy, 2012). Main problems of the national economy were low performance, low international competitiveness, and low amount of natural resources, small domestic market, unfavourable demographic trends and quantitative and structural problems of the labour force (Békesi, 2011). One of the most important lessons to be learnt from international examinations is that active labour market programmes are effective if they can ensure well-rounded complex solutions while concentrating on a special problem. In the case of Hungary, these programmes do not serve as long-term solutions and did not result in decreasing long-term unemployment (Cseh Papp et al., 2018).

Before the global financial crisis, Slovakia, with GDP growth of 7%, was considered as one of the best performing member states of the EU. From a macroeconomic point of view, the balance was maintained due to sound macroeconomic and structural policies adopted by the government. Along with the inflation rate between 2-5% it was ready to adopt Euro in 2009. However, similar to the Czech Republic, it is an open economy depending on export due to weak internal market. This also proved to be a negative side after the outburst of the financial crisis. This situation was worsened by the fact that Slovakia is mainly focused on the production of automobiles which negatively affects other sectors of the economy. The export rate was decreased by 25% and with a higher decrease in imports, the private sector and households started to save more. As a result, private investments and consumption fell by 4.6% and 4.8% respectively. The economy was holding quite well thanks to the adoption of EURO. As a response, the government approved measures focused on specific aspects of the economy, disadvantaged groups and support of employment. Unlike in Poland, Slovakia is vulnerable to financial turmoil, but there should not be problems with the stability of the currency, especially with moderate levels of private and public debts. (Bajer, 2009; EC, 2009; PWC, 2010).

Entering the EU meant access to new markets. This internal market generated in 2014 almost 80% of total exports of Czech Republic, Slovak Republic and Hungary. The largest economic partner, and the main source of foreign direct investments in these countries has been Germany since the early 1990s. This partnership led to a strong automobile and electronic industry, particularly in the Slovak Republic. Among the V4 countries, the strongest relationship was,

traditionally, between Slovak and Czech Republics. The central European countries have several advantages compared to other competing economies. Firstly, they have good geographical locations, bordering to other larger economies in EU like Germany. Secondly, good labour force conditions like low costs and good educational base. The rapid transformation also meant that these countries already had a stable macroeconomic environment. The fourth advantage was a well-established domestic industrial tradition as a result of state industries under the previous regime. (Baláž, et al. 2016). Economic conditions of the country do not have an impact on the national economy but also a quality of inhabitant's life. In the past, many authors faced many possibilities of defining the meaning of quality of life. They tried to define the condition of good quality of life and setting the correct indicators to measure them (Scanlon, 1993). Quality of life, in general, can be defined as the well-being of societies and individuals with all the positive and negative features. This term can be used to describe the life satisfaction, health, and level of education, sociology, psychology, political science, employment, environment and financial status (Andrejovský et al., 2012; Barcaccia et al., 2013). The rapid changes in the quality of life have resulted from rapid globalization activities affecting the national economy. In general, we can use indicators such as GNP, GDP, GDP per capita, inflation (Stiglitz et al., 2009). In the end, we need to remember that measuring the quality of life is a very complex concept influenced by many economic, social, cultural and environmental factors. To measure the quality of life we can use indicators such as Human development index which reflects health, education and living standards (Beslerová, Dzuričková, 2014).

Although the institutional and structural developments have varied in our cases the development and changes in poverty in rural and urban areas were similar. Similar conclusions were achieved by studying rural-urban poverty in transition countries by Macours and Swinnen (2008) or Kiseľáková et al. (2018). They identified several patterns related to the development of poverty. Among others, there was a government distribution of land to rural households to cope with the transition by self-employment. This process meant the destruction of existing agricultural cooperatives. In post-soviet countries located in Asia, this was a good step to promote employment in rural areas. On the other hand, in central and eastern European countries was not measured a comparable success. Agriculture remains the main source of income and employment in the poorest countries. Nevertheless, technological progress played an important role in increasing the labour productivity which has a positive influence on growing added value but on the other hand, this growth can have a negative impact on the employment rate. However, labour productivity is only a portion of the indicators which can affect employment. Among others, we can include changes in economic structure. Firstly, there was an increase in consumption of imported goods and secondly a decreasing trend in domestic consumption. Other changes were recorded in links among sectors in the national economy. These changes can be either positive or negative (Hudcovský, et al., 2017).

2 Data and Methodology

The main objective of the paper was to find out whether the economies of the countries after transition periods and later entering EU were improved. To achieve this objective we decided to study the chosen social and economic indicators to observe their development. The partial objective was to determine whether there was a relation between social and economic development in the countries to confirm that not only the macroeconomic situation but also the living standards of the population were improved. The material of this paper consists mainly of secondary official statistical sources, e.g. Statistical office of the European Union (Eurostat) and national statistical offices related to the V4 region. In observation, we used the following indicators in the period from 2008 to 2016: GDP per capita, unemployment rate, labour productivity per hour, gross annual earnings, FDI stocks inward in million Euro, people at risk of poverty or social exclusion.

Firstly, we analysed these indicators in V4 countries and used charts for illustration. And secondly, we used correlation analysis to find the dependency between the selected groups of economic and social indicators. For this purpose, we conducted the calculations in the SAS programme.

Correlation analysis is a method of statistical evaluation used to study the strength of a relationship between two, numerically measured, continuous variables. Pearson's product-moment coefficient is the measurement of correlation and ranges between +1 and -1. +1 indicates the strongest positive correlation possible, and -1 indicates the strongest negative correlation possible. Therefore, the closer the coefficient to either of these numbers the stronger the correlation of the data it represents.

Pearson's correlation coefficient

$$\rho x, y = \frac{E[XY] - E[X]E[Y]}{\sqrt{E[X^2] - \left[E[X]\right]^2}\sqrt{E[Y^2] - \left[E[Y]\right]^2}}$$

∑xy = sum of the products of paired scores

∑x = sum of x scores

∑y = sum of y scores

∑x2= sum of squared x scores

∑y2= sum of squared y scores

3 Results and Discussion

The following chapter is divided into two basic parts. The first parts focus on the graphic description of selected indicators and their development in V4 countries from 2005 to 2017. We focused on basic economic and social indicators to see the differences in quality of life on one hand and the quality of the business environment on the other hand.

When comparing the living standards among our countries we can use a GDP per capita indicator (in % of EU average) which stands for economic output for the countries' number of inhabitants. The best situation among our studied countries can be seen in the Czech Republic and the Slovak Republic (Figure 1). But on the other hand, we need to underline the fact that large and performing countries usually have lower values of GDP per capita because the GDP is divided among all of its inhabitants. Since Hungary and Poland have a larger population, therefore, this indicator is lower than in other countries.

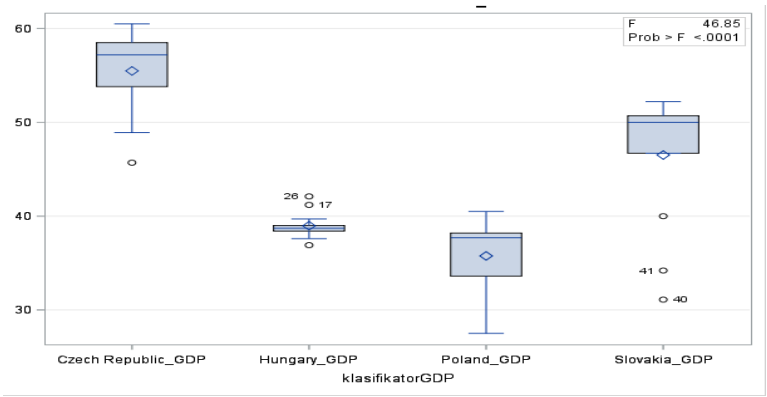


Figure 1
GDP per capita in % of the EU average

As a result of the global financial crisis, the number of unemployed people was constantly rising until 2010, which is considered as an end of this crisis. From this year onwards the number of unemployed was slightly decreasing in all countries almost to the level of pre-crisis. The highest number of unemployed people during the examined period was recorded in Poland and the lowest in the Czech Republic (Figure 2).

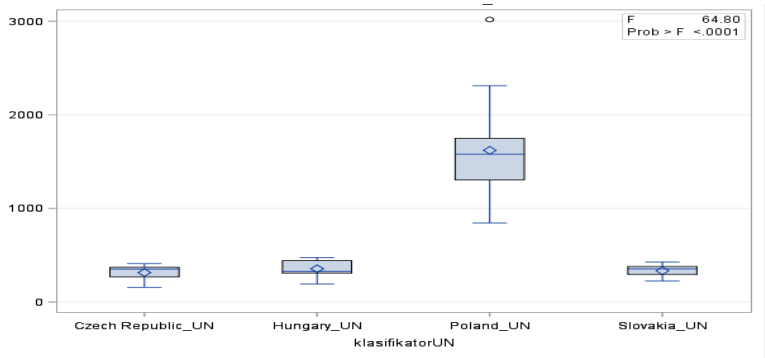


Figure 2
Number of unemployed people in thousands

Labour productivity increased during our examined period in all countries. The best situation among our studied countries can be seen in the Slovak Republic (Figure 3), where labour productivity increased from 10.60 € per hour in 2005 to 20.90 € per hour in 2017. The second-highest labour productivity was observed in the Czech Republic. On the other hand, the lowest level of labour productivity was recorded in Poland, in 2017 it was 14.10 € per hour.

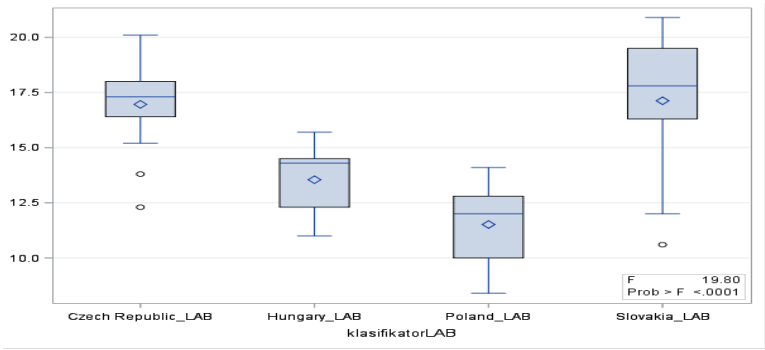


Figure 3
Labour productivity per hour in €

Direct investments were increasing in all countries except for the Slovak Republic where a slight decrease from the level of 71.20% of GDP in 2005 to 68.60% of GDP in 2017 can be observed. A dramatic increase in direct investment was recorded in Hungary, in 2017 they have reached 214.70% of GDP (Figure 4). The development of direct investments in the Czech Republic and Poland had a similar trend until 2014 when there occurred differences in the further amount of direct investment inflow in favour of the Czech Republic.

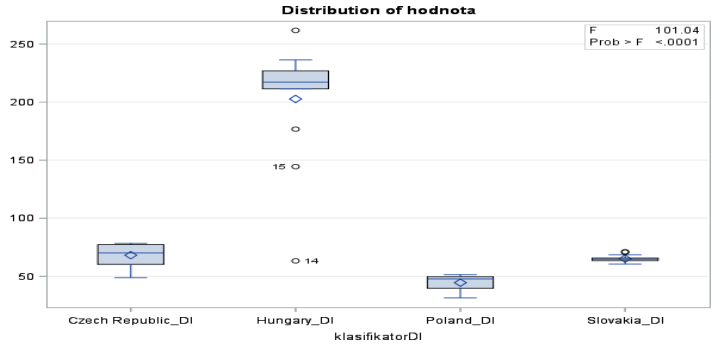


Figure 4

Direct investment in the reporting economy in % of GDP

A relatively stable trend with a slight decrease in people at risk of poverty can be seen in all countries except for Poland (Figure 5). In the examined period the number of people at risk of poverty decreased almost by 10 million (57.40%). This situation can be due to the result of a significant increase in gross annual earnings and a decrease in the number of unemployed persons after 2012.

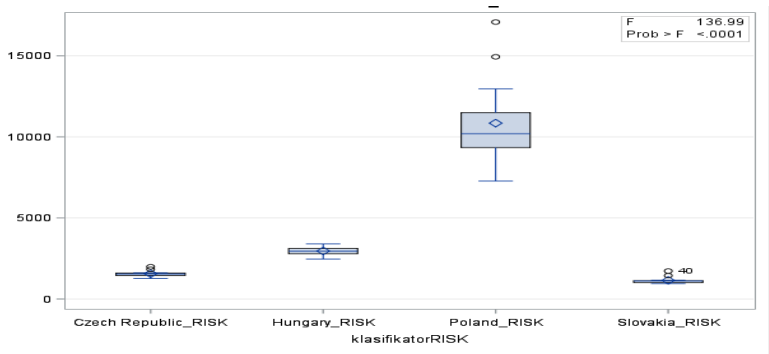


Figure 5

People at risk of poverty or social exclusion in thousands

Table 1 presents descriptive statistics of chosen indicators in the Czech Republic. Direct investments have achieved an average value of 68.20% of GDP during the examined period. In the case of employment, the minimum value of 5,118 thousand pe was recorded in 2005. On the other hand, a maximum of 5,248 thousand people was achieved in 2017. The average GDP per capita was 55.48% of the EU average, which is the highest value among our studied countries. The Czech Republic reached also the highest value of Gross fixed capital formation in a total of 347.4% of GDP. Labour productivity per hour in the Czech economy was in average 16.96 EUR, which is the second-best result after Slovakia. Between 2005 and 2017 we can observe a decrease in the number of people at risk

of poverty or social exclusion of 721 thousand persons. In the case of unemployment, the Czech Republic has achieved the lowest average value of 313.08 thousand persons.

Table 1
Descriptive statistics of chosen indicators, Czech Republic

Simple Statistics					
Variable	Mean	Std Dev	Sum	Minimum	Maximum
Czech Republic_DI	68.20000	10.40385	886.60000	48.90000	78.40000
Czech Republic_EM15	5182	39.87931	67369	5118	5248
Czech Republic_GDP	55.48462	4.45081	721.30000	45.70000	60.50000
Czech Republic_GFCF	26.72308	1.59015	347.40000	24.70000	29.50000
Czech Republic_LAB	16.96154	2.11681	220.50000	12.30000	20.10000
Czech Republic_RISK	1557	186.09027	20246	1267	1988
Czech Republic_UN	313.07692	77.73509	4070	155.00000	410.00000

In Table 2 we can see the results of descriptive statistics of chosen indicators in Hungary. Direct investments have reached an average value of 202.69% of GDP, which is the highest value among analysed countries. The minimum value of employment was recorded in 2009 (4,135 thousand people). And the maximum value of 4,565 thousand people was achieved in 2017. The average GDP per capita was 38.96% of the EU average, with this result Hungary is at the 3rd place among V4 countries. Gross fixed capital formation in total was 281.70% of GDP. The average value of this indicator for the examined period is 21.66% of GDP. Labour productivity per hour in the Hungarian economy was in average 13.54 EUR, with this result Hungary is at the 3rd place. The number of people at risk of poverty or social exclusion has decreased by 720 thousand people. The maximum value of this indicator (398 thousand per) was observed in 2013. Hungary has reached an average unemployment rate of 354 thousand people.

Table 2
Descriptive statistics of chosen indicators, Hungary

Simple Statistics					
Variable	Mean	Std Dev	Sum	Minimum	Maximum
Hungary_DI	202.69231	50.40932	2635	63.30000	261.70000
Hungary_EM15	4292	155.49676	55795	4135	4565
Hungary_GDP	38.96923	1.37622	506.60000	36.90000	42.10000
Hungary_GFCF	21.66923	1.67650	281.70000	19.20000	23.80000
Hungary_LAB	13.54615	1.50090	176.10000	11.00000	15.70000
Hungary_RISK	2961	274.51909	38489	2465	3398
Hungary_UN	354.00000	91.67788	4602	192.00000	473.00000

Table 3 presents descriptive statistics of chosen indicators in Poland. Direct investments have achieved an average value of 44.53% of GDP, which is the

lowest value among studied V4 countries. In the case of employment, the minimum value of 16,610 thousand people was recorded in 2007. On the other hand, maximum of 17,150 thousand people was achieved in 2014. Poland has reached the lowest average value of GDP per capita (35.75% of the EU average). Gross fixed capital formation in total was 261.40% of GDP, which is again the lowest value among V4 countries. The average value of this indicator for the period 2005 – 2017 is 20.10% of GDP. Labour productivity per hour in Poland was 11.51 EUR on average. Between 2005 and 2017 we can observe a decrease in the number of people at risk of poverty or social exclusion of 9 807 thousand people. In the case of unemployment Poland has reached the highest average value of 1,620 thousand people.

Table 3
Descriptive statistics of chosen indicators, Poland

Table 3: Descriptive statistics of chosen indicators, Poland					
Variable	Mean	Std Dev	Sum	Minimum	Maximum
Poland_DI	44.53846	6.46601	579.00000	31.50000	51.50000
Poland_EM15	16934	170.48404	220144	16610	17153
Poland_GDP	35.75385	4.02153	464.80000	27.50000	40.50000
Poland_GFCF	20.10769	1.59398	261.40000	17.70000	23.10000
Poland_LAB	11.51538	1.71894	149.70000	8.40000	14.10000
Poland_RISK	10846	2727	140994	7273	17080
Poland_UN	1620	560.71330	21061	844.00000	3018

In Table 4 we can see the results of descriptive statistics of chosen indicators in the Slovak Republic. Direct investments in Slovakia were on average at the level of 65.26% of GDP. The minimum value of employment was observed in 2005 (2,636 thousand people) and the maximum value of 2,738 thousand people was achieved in 2016. The average GDP per capita was 46.51% of the EU average, which is the second-best result after the Czech Republic. Gross fixed capital formation in total was 303.60% of GDP. The average value of this indicator for the examined period is 23.35% of GDP; it is the second-best result among analysed countries. Labour productivity per hour in the Slovak economy was in average 17.12 EUR (the highest value). The number of people at risk of poverty or social exclusion has decreased by 774 thousand people. The maximum value of this indicator (1 724 thousand people) was observed in 2005 and the minimum was achieved in 2016. The Slovak Republic has reached an average unemployment rate of 332.69 thousand people; it is the second-best result after the Czech Republic.

Further, we decided to measure the relations between selected economic and social indicators to find mutual relations and possible causes of the current economic situation in V4 countries.

Table 4
Descriptive statistics of chosen indicators, Slovakia

Simple Statistics					
Variable	Mean	Std Dev	Sum	Minimum	Maximum
Slovakia_DI	65.26923	3.19332	848.50000	60.50000	71.20000
Slovakia_EM15	2688	31.70295	34943	2636	2738
Slovakia_GDP	46.51538	6.90891	604.70000	31.10000	52.20000
Slovakia_GFCF	23.35385	2.59249	303.60000	20.70000	27.30000
Slovakia_LAB	17.12308	3.15414	222.60000	10.60000	20.90000
Slovakia_RISK	1147	222.37988	13769	950.00000	1724
Slovakia_UN	332.69231	59.88654	4325	224.00000	427.00000

Table 5
Correlation of selected indicators in V4 countries

	Czech Republic	Hungary	Poland	Slovakia
DI - EM15	0,84844	0,369	0,66844	-0,35801
DI - GDP	0,69347	0,2725	0,92698	-0,61074
DI -GFCF	-0,86826	-0,67889	-0,43729	0,38615
DI - LAB	0,90485	0,74594	0,92725	-0,4951
DI - RISK	-0,84204	-0,36414	-0,9121	0,80429
EM15 - GDP	0,62694	0,38208	0,60602	0,84124
EM15 - GFCF	-0,80393	-0,34681	-0,46388	-0,81807
EM15 - LAB	0,79527	0,67362	0,57793	0,92364
EM15 - RISK	-0,88396	-0,55683	-0,58553	-0,79879
GDP - GFCF	-0,45079	-0,012	-0,2784	-0,87082
GDP - LAB	0,87337	0,48568	0,96258	0,96166
GDP - RISK	-0,8186	-0,73435	-0,94794	-0,9186
GDP - UN	-0,44378	-0,55098	-0,77703	-0,34397
GFCF - LAB	-0,6939	-0,71639	-0,44561	-0,84287
GFCF - RISK	0,60474	0,03925	0,30859	0,72194
GFCF - UN	0,20452	-0,36332	-0,04232	0,09405
LAB - RISK	-0,91815	-0,35079	-0,92616	-0,9214
LAB - UN	-0,62497	-0,01714	-0,72858	-0,41691
RISK - UN	0,66423	0,70918	0,86742	0,52215

We have measured the correlation of selected indicators using the SAS programme. The results are shown in the table above. Firstly, we looked for the relation between foreign direct investments (FDI) and the level of employment in 15 to 64 years of age. In all countries, except Slovakia, there is a positive relationship which means that inflow of foreign investments positively affects the employment rate. The second comparison is related to the first and, as in the

previous case, there is a positive correlation in all countries except the Slovak Republic. We can see a strong positive relation between FDI and GDP in the Czech Republic and Poland. In Hungary, there is only a small correlation. The third correlation is connected to the first comparison. We tried to find the relation between FDI and gross fixed capital formation (GFCF). This relation confirmed our assumptions that FDI in Slovakia was focused more on the creation or obtaining capital than creating job opportunities. In all countries except Slovakia, there was a negative correlation which means that FDI in these countries are more focused on creating more job opportunities and thus helping the national economy. These assumptions were later confirmed by finding a relation between FDI and labour productivity in V4 countries. In all countries, except for Slovakia, there is a strong positive correlation between FDI and labour productivity which means that FDI are helping in the creation of job opportunities with higher labour productivity which in the end helps the national GDP. Last observation was focused on finding the relation between FDI and the share of people at risk of poverty. As we mentioned before the FDI in case of Slovakia were more focused on creating or obtaining capital than job opportunities. This was also confirmed by our measurements. In Slovakia, there is a strong negative correlation between FDI and share of people at risk of poverty while in other V4 countries there is a strong negative correlation between these two indicators.

Next, we were looking into relation between employment rate in the age group from 15 to 64 years (we will use EM15 for further reference in the text) and other indicators. Firstly, we looked into the relation of EM15 and GDP rate. In all countries, with the exception of Hungary, we found a strong positive correlation. In Hungary, there was only a moderate correlation with the value of 0.38. The strongest was found in Slovakia. The correlation between EM15 and gross fixed capital formation proved to be negative in all V4 countries which confirmed that investments into capital lead to a decrease in employment. The sound employment rate plays an important role in the economy both in the economic and social point of view. In all V4 countries, we can see rising labour productivity as a result of the rising employment rate. From the social point of view the higher the employment rate the lower the share of the population at risk of poverty. Also, with the rise of GFCF, there is the rise of the share of people at risk of poverty due to an increase in unemployment. We also found a negative correlation between GFCF and labour productivity. This confirms that the rise in the capital may be helpful from the economic point of view on one hand but on the other hand it negatively affects the social side of the economy measured by employment rate and people at risk of poverty. To confirm the connection among the social indicators we decided to measure the correlation of labour productivity and social indicators like unemployment and share of people at risk of poverty. In both cases, we found a negative relationship which means that with higher labour productivity both shares of people at risk of poverty and unemployment will be decreasing. These two indicators have a strong positive relation which shows us that the higher the unemployment rate the higher share of people at risk of poverty.

The following group was focused on finding the relation between GDP and other indicators. Firstly, we wanted to know if there is a relation between GDP and gross fixed capital formation (GFCF). We found a negative correlation in all V4 countries with different level. For example, in Slovakia, there is a strong negative correlation which suggests that with the decrease of GDP a decrease in GFCF will follow. In the Czech Republic, this relation was moderate and in Hungary and Poland, there was observed weak relation. Since we already saw a positive relationship between the employment rate and GDP and also between the employment rate and labour productivity, there is also a strong relation and medium in Hungary, between GDP and labour productivity which confirms us that with the increase in labour productivity the GDP will also increase. Since GDP is an economic indicator which also affects the social side of the economy we decided to look into the relation between GDP and two social indicators, namely share of people at risk of poverty and unemployment rate. In both cases, there was observed a negative relationship which means that an increase in GDP means a decrease in both social indicators.

Conclusions

This paper aimed to measure the development of selected economic and social indicators in V4 countries to see their relation to determine the social conditions in each of the countries after the EU accession. To compare the living standards we decided to focus on GDP per capita and saw its rising trend in all V4 countries, the highest in the Czech Republic. On the other hand, Poland has reached the lowest average value of GDP per capita. The condition after entering the EU was developing fairly well in all new member countries. Unfortunately, due to external global negative impact in the form of financial outburst in the 2008 – 2010 period led to baleful economic and social development. This condition is best described by the number of unemployed people in our studied countries. After 2008, it was constantly rising until 2010 and was stabilized until 2013. Later on, the number of unemployed people started to decrease. The highest number of unemployed people was measured in Poland and the lowest in the Czech Republic. During this period, the labour productivity was slightly increasing except for the Slovak Republic where almost a twofold increase was recorded. From 2005 to 2017 the direct investments were constantly increasing in all V4 countries except for the Slovak Republic. The highest increase can be seen in Hungary. The difference between Slovakia and Hungary in 2017 is almost threefold. One of the most important indicators to measure the social condition in countries is the number of people at risk of poverty. In V4 countries there was a decreasing trend during the whole period. To find the relations between the chosen economic and social indicators we calculated Pearson's correlation coefficient. Through these calculations, we confirmed correlations among various economic and social indicators. The strongest ones were between the employment rate and labour productivity and share of people at risk of poverty. In the course of research, we encountered several minor limitations. The most serious was the availability of

comparable data throughout time. This difference was not only between individual countries but also between data available in one statistical database. For future reference, there is an available capacity to focus on more EU member countries and start collecting and analyzing the data for individual EU members and thus determine their economic and social development after entering the EU.

Acknowledgement

This work was supported by the Grant Agency FESRD projects no. 11-GASPU-2018 - Selected aspects of economic policy and its impacts on the business environment in the Slovak Republic.

References

[1] Andrejovský, P., Gajdoš, J., Hajduová, Z., Andrejkovič, M., (2012) Ecologisation of social development and quality. 12th international multidisciplinary scientific geoconference SGEM 2012, Albena, Bulgaria, 307-312

[2] Androniceanu, A., Tvaronavičienė, M. (2019) Developing a holistic system for social assistance services based on effective and sustainable partnerships. Administratie si Management Public, 33, 103-118, Doi: 10.24818/amp/2019.33-06

[3] Androniceanu, A., Gherghina, R. & Ciobanasu, M. (2019) The interdependence between fiscal public policies and tax evasion. Administratie si Management Public, 32, 32-41, DOI: 10.24818/amp/2019.32-03

[4] Bajer, I. (2009) Global crisis? Crisis visions of Slovakia. In: Hospodárske noviny. Available at: <https://finweb.hnonline.sk/komentare-a-analyzy/349236-globalna-kriza-kriza-vizie-slovenska>

[5] Baláž V., Karasová K., Williams A. M. (2017) Chapter 5: The V4 Countries and the EU: A Comparative Perspective. In: Fish M., Gill G., Petrovic M. (eds) A Quarter Century of Post-Communism Assessed. Palgrave Macmillan, Cham. ISBN: 978-3-319-43436-0

[6] Barcaccia, B., Esposito, G., Matarese, M., Bertolaso, M., Elvira, M., De Marinis, M. G. (2013) Defining Quality of Life: A Wild-Goose Chase? In: Europe's journal of psychology. Vol. 9, No. 1, 2013, Cit. 24.5.2018, Available at: https://ejop.psychopen.eu/article/view/484/html

[7] Békesi, L. (2011) A Magyar gazdaság helyzete, kilátásai, 2002 – 2010 (Position and perspectives of Hungarian Economy, 2002 – 2010). Stratégiai Tanulmányok a Magyar Tudományos Akadémián. Ezredforduló 1, pp. 10-18

[8] Beslerová, S., Dzuričková, J. (2014) Quality of life measurements in EU countries. In: Procedia Economics and Finance. Vol. 12, 2014, pp. 37-47

[9] Bielik, P. Rajčániová, M. (2008) Shift-share analysis of employment growth – the case of the V4 countries. In: Agric. Econ. – Czech, 54 (2008): issue 8, pp. 347-351

[10] Bloomberg (2009) "Poland's Economic Outlook May Be Raised by IMF, PAP Reports"

[11] Chehabeddine, M.; Tvaronavičienė, M. (2020) Securing regional development, Insights into Regional Development 2(1): 430-442, https://doi.org/10.9770/IRD.2020.2.1(3)

[12] Chocholatá, M., & Furková, A. (2018) The analysis of employment rates in the context of spatial connectivity of the EU regions. Equilibrium. Quarterly Journal of Economics and Economic Policy, 13(2), 181-213, https://doi.org/10.24136/eq.2018.010

[13] Civelek, M., Ključnikov, A., Krajčík, V., Žufan, J. (2019) The Importance of Discount Rate and Trustfulness of A Local Currency for the Development of Local Tourism. Journal of Tourism and Services, 10(19): 77-92, https://doi.org/10.29036/jots.v10i19.117

[14] Cseh Papp, I., Varga, E., Schwarczová L., Hajós, L. (2018) Public work in an international and Hungarian context. Central European Journal of Labour Law and Personnel Management, 1 (1), 6-16, http://doi.org/10.33382/cejllpm.2018.01.01, ISSN 2644-4542

[15] Czaja, I., Wach, K. (2009) Zmiany obrotów handlu zagranicznego Polski przed akcesją i po akcesji do Unii Europejskiej. Zeszyty Naukowe No. 799, Kraków: Uniwersytet Ekonomiczny w Krakowie. Cit. 20.7.2018. Available at: < https://mpra.ub.uni-muenchen.de/31675/ >

[16] Czech Statistical Office. Available at:

<https://www.czso.cz/csu/czso/home >

[17] Čepel, M. (2019) Social and Cultural Factors and Their Impact On The Quality Of Business Environment In the SME Segment. International Journal of Entrepreneurial Knowledge, 7(1), 65-73, doi: 10.2478/ijek-2019-0005

[18] Dabrowski, M. (2016) Currency crises in post-Soviet economies - a never ending story?. In: Russian Journal of Economics 2 (2016) 302-326, Available at: <https://rujec.org/article/27973/>

[19] Drozdowicz-Bieć (2013) "Reasons why Poland avoided the 2007–2009 Recession", Collegium of Economic Analysis Discussion Papers, WSE. Cit. 20.6.2018, Available at: <http://kolegia.sgh.waw.pl/pl/KAE/struktura/IRG/publikacje/Documents/pim86_2.pdf>

[20] Duľová Spišáková, E., Mura, L., Gontkovičová, B., Hajduová, Z. (2017) R&D in the context of Europe 2020 in selected countries. Economic

Computation and Economic Cybernetics Studies and Research, Vol. 51, No. 4, pp. 243-261, ISSN 0424–267 X

[21] EC. DG for Economic and Financial Affairs. European Economic Forecast Autumn 2009, Cit. 21.6.2018, Available at: <http://ec.europa.eu/economy_finance/publications/pages/publication16055_en.pdf >

[22] EEIP (2010) Project putputs „Impact of economic crisis on civil society". Cit 21.7.2018, Available at: <http://osf.cz/cs/publikace/vystupy-projektu-dopady-ekonomicke-krize-na-obcanskou-spolecnost/>

[23] EEIP (2013) Analysis of the impact of the economic crisis on the implementation of structural funds and the cohesion fund in the Czech Republic, Cit. 21.7.2018, Available at: < http://www.eeip.cz/en/files/2014/05/140515_Analyza_krize_SF_AJ.pdf>

[24] Egedy, T. (2012) The effects of global economic crisis in Hungary. In: Hungarian Geographical Bulletin 61 (2) 2012, pp. 155-173, ISSN 2064-5031

[25] Eurostat (2018) Living conditions in Europe 2018 edition, ISBN 978-92-79-86498-8, Available at: <http://ec.europa.eu/eurostat/documents/3217494/9079352/KS-DZ-18-001-EN-N.pdf/884f6fec-2450-430a-b68d-f12c3012f4d0>

[26] Eurostat. Available at: < http://ec.europa.eu/eurostat >

[27] FAO (1995) The state of food and agriculture. Rome. 1995. ISBN: 92-5-103700-0

[28] Floyd, D. (2016) The European Banking Crisis Explained. In: Investopedia. Cit. on 22nd May, 2018, Available at: <https://www.investopedia.com/articles/insights/110316/european-banking-crisis-explained-db.asp>

[29] Gnangnon, S. K. Effect of multilateral trade liberalization on foreign direct investment outflows amid structural economic vulnerability in developing countries. In: Research in International Business and Finance 45 (2018) 15-29, ISSN: 0275-5319

[30] Hagemejer, J., Tyrowicz, J. (2017) Upstreamness of employment and global financial crisis in Poland: the role of position in the global value chains. In: GRAPE Working Paper no. 15, ISSN: 2544-2473, Available at: < http://grape.org.pl/WP/15_HagemejerTyrowicz_website.pdf >

[31] Healey, N. M. (1994) The transition economic of central and eastern Europe: A political, economic, social and technological analysis. In: The Columbia Journal of World Business, Vol. 29, Issue 1, 1994, pp. 62-70, ISSN: 0022-5428

[32] Hitka, M., Lorincova, S., Bartakova, GP., Lizbetinova, L., Starchon, P., Li, C., Zaborova, E., Markova, T., Schmidtova, J., Mura, L. (2018) Strategic

Tool of Human Resource Management for Operation of SMEs in the Wood-processing Industry. Bioresources, Vol. 13, No. 2, pp. 2759-2774, ISSN 1930-2126

[33] Hudcovský, M., Lábaj, M., Morvay, K. (2017) Employment Growth and Labour Elasticity in V4 Countries: Structural Decomposition Analysis. In: Prague Economic Papers Vol. 26, No. 4, Available at: <https://doi.org/10.18267/j.pep.623>

[34] Hungarian Central Statistical Office. Available at: < http://www.ksh.hu/?lang=en >

[35] Jašková, D. (2019) Assessment of social development in Slovakia in the context of human resources. Central European Journal of Labour Law and Personnel Management, 2 (2), 21-32, doi: 10.33382/cejllpm.2019.03.02

[36] Kiseľáková, D., Širá, E., Šofranková, B. (2018) The performance of V4 Countries according to ease of Doing Business Index. Acta Oeconomica Universitatis Selye 7 (2), 71-79

[37] Kräussl, R., Lehnert, T. and Stefanova, D. (2016) The European sovereign debt crisis: What have we learned?. In: Journal of Empirical Finance. Vol. 38, part A, 2016, pp. 363-373, ISSN: 0927-5398

[38] Lennartz, C., Arundel, R., Ronald, R. (2015) Younger adults andhomeownership in Europe through the global financial crisis. In: "Population, Space and Place", 2016, Vol. 22, Issue 8, pp. 823-835, ISSN: 1544-8444

[39] Macours, K., Swinnen, J. F. M. (2008) Rural–Urban Poverty Differences in Transition Countries. In: World Development, Vol. 36, Issue 11, ISSN: 0305-750X [on-line] Available at: <https://www.sciencedirect.com/science/article/pii/S0305750X08001113>

[40] Miłek, D. (2018) Spatial differentiation in the social and economic development level in Poland. Equilibrium. Quarterly Journal of Economics and Economic Policy, 13(3), 487-507, https://doi.org/10.24136/eq.2018.024

[41] Mitrega-Niestroj, K. (2011) Foreign trade of Poland during the global financial crisis. In: Financial management of firms and financial institutions. Ostrava 2011, ISBN: 978-80-248-2494-9

[42] Mundell, R. A. (1961) "A Theory of Optimum Currency Areas". American Economic Review. 51 (4): 657-665, JSTOR 1812792

[43] Mura, L., Daňová, M., Vavrek, R., Dúbravská, M. (2017) Economic freedom – classification of its level and impact on the economic security. AD ALTA-Journal of Interdisciplinary Research, Vol. 7, No. 2, pp. 154-157, ISSN 1804-7890

[44] Mura, L., Vlacseková, D. (2018) Motivation of public employees: case study of Slovak teaching and professional staff. Administratie si

Management Public (31) pp. 67-80, ISSN 1583-9583, DOI: 10.24818/amp/2018.31-05

[45] Nagy, B. Z. (2016) Regional inequalities in the European Union. Acta Oeconomica Universitatis Selye 5 (1), 109-118

[46] Nickell, S. (1997) Unemployment and labor market rigidities: Europe versus North America, in "The Journal of Economic Perspectives", American Economic Association, Vol. 11, No. 3, pp. 55-74

[47] Nowak, P. (2018) Regional variety in quality of life in Poland. Oeconomia Copernicana, 9(3), 381-401, https://doi.org/10.24136/oc.2018.019

[48] Okanazu, O. O., Madu, M. A., Igboke, S. A. (2019) A recipe for efficient and corrupt free public sector. Central European Journal of Labour Law and Personnel Management, 2 (1), 29-46, doi: 10.33382/cejllpm.2019.02.03

[49] Olczyk, M., & Kordalska, A. (2018) Determinants of trade balance in Polish and Czech manufacturing sectors. Equilibrium. Quarterly Journal of Economic and Economic Policy, 13 (3), 445-466, doi: 10.24136/eq.2018.022

[50] Pavliková, Ľ., Siničáková, M., (2012) Labor Market Indicators and Their Causalities: the Case of the New European Union Member States, In: "Procedia Economics and Finance". Vol. 3 (2012) pp. 1229-1237, ISSN 2212-5671

[51] PWC. Report on transformation – Central and Eastern Europe Facing the Debt Crisis. Hard Landing 2. Poland 2010, Cit. 15.7.2018, Available at: < https://www.pwc.pl/en/publikacje/hard-landing-2.pdf>

[52] Ram, V. (2009) Crisis Hits Czech Republic. In: Forbes. Cit. on. 25.7.2018, Available at: <https://www.forbes.com/2009/03/25/czech-republic-collapse-markets-equity-crisis.html#1e3484174324>

[53] Reichardt, A. (2011) Poland and the Global Economic Crisis: Observations and Reflections in the Public Sector, pp. 38-48, In: Journal of Finance & Management in Public Service, Vol. 10, No. 1, 2011, ISSN: 1475-1283

[54] Rrutkowski J. (2006) Labour Market Developments during Economic Transition. Policy research Working Paper no. 3894, World Bank. Cit. on 25.5.2018. Available at: <https://openknowledge.worldbank.org/handle/ 10986/8710>

[55] Scanlon, T. (1993) Value, desire, and quality of life. In M. Nussbaum & A. Sem (Eds.), The quality of life (pp. 185-207) Oxford: Oxford University Press

[56] Statistical Office of the Slovak Republic. Available at: <www.statistics.sk>

[57] Statistics Poland. Available at: < http://stat.gov.pl/en/ >

[58] Stiglitz, J. E., Sen, E. A. & Fitoussi J-P. (2009) Report by the Commission on the Measurement of Economic Performance and Social progress. Cit. on 24.5.2018, Available at: <http://ec.europa.eu/eurostat/documents/118025/118123/Fitoussi+Commission+report >

[59] Tomkiewicz, J. (2018) The labour market and income distribution in post-socialist economies – Non-obvious regularities. In: Communist and Post-Communist Studies, Volume 51, Issue 4, December 2018, pp. 315-324, Available at: <https://www.sciencedirect.com/science/article/pii/S0967067X18300618?via%3Dihub>

[60] Tvrdoň, M. (2010) Consequences of the global economic crisis on the Czech economy. Scientific papers of the University of Pardubice. Series D, Faculty of Economics and Administration. 17 (2/2010) ISSN: 1211 – 555X

[61] Volná, J., Papula, J. (2013) Analysis of the Behavior of Slovak Enterprises in the Context of Low Innovation Performance. In: Procedia – Social and behavioral sciences, 2013, Vol. 99, pp. 600-608, ISSN: 1877-0428

Deductive Ergatic Design of Constructive Tasks Solutions

Anatoly P. Beltiukov, Sergey G. Maslov

Udmurt State University, Universitetskaya str., 1, 426034 Izhevsk, Russia
e-mail: belt@udsu.ru, maslov@udsu.ru

Abstract: The deductive approach to the synthesis of solutions of constructive problems with respect to ergatic systems is considered. At the same time, both the principles of deductive synthesis of solutions for ergatic systems and the processes of implementing this deductive synthesis, realized by the systems themselves, are considered.

Keywords: deductive synthesis; ergatic system; constructive realization.

1 Introduction

Providing a high quality of life, for modern people, presents them with tasks that are more and more complex. It is necessary, often, to solve these tasks with limited resources that demand the development of essentially, new, breakthrough technologies, use and organization of vital streams and processes. In this situation, modern people are forced to organize effective interaction with the natural and artificial environment of their habitat on the basis of intellectual and physical amplifiers of their capabilities, that is, to actively use the IT sphere. The key issues here are problem identification, formation and refinement of problem statements, processes of system modeling, synthesis of algorithms and programs based on description of computing environment.

In this paper, we discuss the development of systems for constructing solutions to problems by an ergatic, human-machine environment. From the point of view of the authors, it is necessary to distinguish the control problems associated with the development of a relatively simple control signal for achieving the stated goal, and the task of constructing complex objects. The complexity of the constructed objects is high enough to eliminate the solution of such a problem by looking through all the variants.

The work is carried out within the framework of the paradigm of constructive synthesis: First, we describe the capabilities of the elements of our system in a

certain domain. Then we set and formalize the problem in a language that the ergatic system understands.

Then the competent elements and subsystems build the solution of the task. If the process was successful, then the solution is a structure, which elements may refer to elements of the ergatic system. This structure can now be applied by the system in various specific circumstances (to different incoming objects). The structure can be understood and can be carried out by the elements of our ergatic system.

We set the task to provide a tool for describing what elements of the ergatic system can do in order to use these opportunities to solve the tasks assigned to the system. This work continues a series of authors' works on active layered knowledge systems [6], IT-sphere constructive directions [8], scientific reading in electronic environment [9], scientific networks [31], ergatic networks [32], ergatic systems [33], ERGANET [34], deductive synthesis [35], IT-systems design [36], ergatic intelligence [37], ergatic understanding [38].

2 Definitions

The ergative network is a human-machine information network intended for purposeful activities aimed at creating ideal and material artifacts that support the life processes of the nature-society-human system. The main purpose of the ergatic network (ERGANET) is the effective and reasonable use of knowledge to improve the quality of life of society and man.

Ergatic system is a more general concept, it is an analogue of the "organism," built on natural and artificial components. Important thing in the operation of such systems is the self-improvement of interfaces between components, structures and self-development of the entire system. The life process is the process of a stable developing existence of an object (in particular, an organism). The ergatic system, unlike the information and communication systems, is supplemented with the functions of solving constructive, creative, conative problems, i.e. tasks of constructing objects, development and motivation of subjects. Within the ergatic system itself, knowledge networks, information and communication networks can be maintained. All these components are linked by synergy and symbiosis. Knowledge in the ergatic system is inherent in active implementation (or external and internal computing). The ergatic system lays new grounds for the contexts of augmented reality (not only in visual or other sensory contexts, but also in a conceptual and metaphorical environment).

3 The Current Situation and Trends in the Creation of Information Technology Systems

At the present stage, it is possible to single out the following basic trends in the construction of information technology systems:

- Expansion of the theoretical base, in particular, the formation of a category-theoretic approach to the design of information technology systems (S. V. Kosikov [10], S. P. Kovalev [11], V. V. Antonov [12])
- Synthesis of large data and high-performance computing technologies (see e.g. [27], G. Fox [28], and also [29])
- Expansion of Autopoietic Systems (Sergeev S. F. [13]) on self-organization and self-construction of information technology systems

In this case, information and technological support systems for human activities are created, which are based on alienated knowledge and tend to replace human, arguing that by his capabilities limitations.

A new stage in the development of information technology systems is connected with human-machine systems, which are created based on synergy and symbiosis of the ideal and material, artificial and natural, as well as alienated and inalienable forms of knowledge. These are ergative systems and networks (M. Mikheev et al. [14], S. Maslov and A. Beltiukov [37] and [38]). An important feature of such systems is that in their symbiosis the integrity of a person is preserved.

Another important feature of such systems is that, despite their evolution, they also remain the integrity of man and an artificial system with divided functions of activity and non-formalized knowledge that cannot be translated into an alienated form.

The main purpose of ergatic systems and networks is to ensure the efficiency and continuity of the process of transformation “idea – abstract image – material object”, effective and adequate management, as well as increasing the personal and collective threshold of difficulty to solve emerging problems. Here the principles of building systems are important, which require a revision of the basic concepts from the point of view of computing, ergaticity, attractiveness, autopoieticity, convergence (O. Rudenskiy and O. Rybak [2], S. Sergeev [15]). To this end, the following concepts have been introduced: the ergatic network (erganet), ergatic thinking, ergatic intelligence, ergatic interfaces, ergatic computing, ergatic model, ergatic statement of problems, ergatic solution and a number of others [38]. On the basis of these, the principal components of the architecture of the ergatic system are further specified.

The proposed approach to ergatical systems differs significantly from the existing approach [14] in terms of both functionality and architecture.

In the systems under consideration, the possibility of self-understanding is based on the construction of the model of itself by the system. The types of meta-understanding are: understanding of understanding and understanding of misunderstanding, understanding the boundaries of understanding, understanding and changing the environment of understanding (Metanoia [16]). See also [17].

Questions related to different approaches to the synthesis of program objects are theoretically considered in [30]: Deductive, schematic and inductive synthesis of pure solutions, performed, in particular, in interaction with a man.

Recent investigations in the area of logical-based program synthesis and transformations concern partial evaluation of programs [39], translation of an actor-based languages to the functional languages [40], verifying properties of time-aware business processes [41], synthesis software contracts from programs [42], synthesis of efficient generators for lambda terms [43], knowledge-based systems and many others. In this paper, we are primarily interested in deductive synthesis, not only of solutions, but also of the moduli of their support, performed by the ergatic system as a whole.

4 Ergatic Understanding and Ergatic Solutions of Problems

In this paper, we consider the solution of constructive problems by human-machine systems. Current consideration is limited to the tasks of creating information structures. Issues related to the creation of material objects are not considered here. In particular, we do not even consider the storage of the created structures. Thus, our constructions lie in the framework of computing. This is a generalized concept reflecting the process of changing and transforming qualitative and quantitative descriptions of systems through the processes of calculation, search, navigation, output, construction and management. A more precise mathematical definition of computing can be found in [1]. This approach is of great importance, in particular, due to the increasing spread of digital production [7].

We assert that Ergatic System is able to operate with some languages to formulate problems. The questions of goal-setting and the sources of the formulation of problems are not yet considered here. For the sake of simplicity, we assume that the common encoding problems are solved, all language objects, regardless of the nature of the languages, can be written in the form of character strings.

In order to illustrate our ideas, we consider for example the problems of constructing various information converters. It is clear that this is one of the most important problems. The solutions to problems, the objects to which they apply, and the rationale for these solutions can also be written in certain languages

available to the ergatic system. These records can have direct references to specific objects of the material environment in which the ergatic system operates. Reference can also be made to the elements and subsystems of the ergatic system itself.

The basis of ergatic constructive understanding and ergatical solution of the problems under consideration are statements of the type: "The success of applying the solution *r* of problem *B* to the object *t* is confirmed by the procedure *d*." We shall write these assertions as formulas of the form:

$$d{:}r{:}B{:}t$$

where:

B is a statement, constructively understood as a certain task

r is an object proposed as a solution to this problem

t is an object proposed for the application of this solution (for operating or testing)

d is an object for diagnosing the correctness of the object *t* for the problem *B* and for the solution *r*

These formulas will be called *verification formulas for solutions*. Naturally, to understand such formulas it is required to set the language for tasks *B*, and objects *d*, *r*, *t*. In the ergatic environment, it is required to have a human or subsystem that understands these languages. Understanding means the ability to do this with the expressions and operations described below.

Formula $d{:}r{:}B{:}t$ can be read also as: "The object *r* solves the problem *B* with counteraction *t* and support *d*." Counteraction will sometimes be called a test of the solution of the problem, because when testing a solution, it is really a test object.

From the logical point of view, the formula

$$d{:}r{:}B{:}t$$

can be considered as an abbreviation for the formula

$$(r{:}B)_{\mathrm{D}}(d;t)$$

where the colon is the realization sign according to S. C. Kleene [20] (see also A. Markov [18] and N. Shanin [19]), and *D* is the relation that uses K. Gödel in his "Dialectica" interpretation [21] (see also C. Spector [22], V. de Paiva [23], J. Avigard and S. Feferman [24], M Shirahata [25], A. Troelstra [26]). Kleene and Gödel originally proposed these relations for understanding the statements of the arithmetic of such an ideal object as an infinite set of natural numbers. Here we propose to use a similar design for understanding specific information systems. One of the main differences of the proposed system is the orientation toward the possibility of taking into account the limitations of computing resources at all

stages of the work. For example, we can restrict ourselves to procedures that can be executed in polynomial time. In this respect, this work is a continuation of the works of A. Beltiukov on intuitionistic formal theories [3], polynomially computable realizations [4], and automatic deductive synthesis [5].

Procedures (programs, instructions, etc.) in the ergatic system can be performed both by artificial executors (machines) and by natural ones (people). The executor may also be an entire ergatic subsystem. The reference to the corresponding function f in the description of the ergatic system is given in the form $f = (s,p)$, where s is an executing entity, p is a program (instruction) understood and executed by this subject s record.

$$f(x) = (s,p)(x) = s(p,x)$$

indicates the result of executing by the executor s the instruction p for the object x.

The essence of understanding the statements under consideration is that a special procedure Arb (arbitration) is defined to verify the truth of statements of the form

$$d{:}r{:}B{:}t$$

This procedure produces an appropriate truth value. That is

$$\mathrm{Arb}(d,r,B,t) \Leftrightarrow (d{:}r{:}B{:}t)$$

The execution of this procedure depends on the language system in which object (d,r,B,t) is recorded. This means that in our ergatic system for each language system L, on which object (d,r,B,t) can be described, there is an executor $S[L]$, and instruction $R[L]$ for the performance of the corresponding verification procedure by this executor:

$$\mathrm{Arb}(d,r,b,t) = S[L](R[L],d,r,B,t)$$

is the result of checking, by the executor $S[L]$ the following statement:

$$d{:}r{:}B{:}t$$

by the instruction $R[L]$. In simple cases, the test result is a classical logical truth value (for example, 0 or 1). More complex systems with multivalued logic (including fuzzy ones) are also possible.

Below is an example of how to build an instruction to verify the truth of statements of the form:

$$d{:}r{:}B{:}t$$

for a subject who understands the language of the logic of predicates (without negations and functions) on which the task B is written.

In practice, tasks can be recorded in a variety of languages, which necessitates various instructions for verifying solutions. Let's start with simple problems (i.e. atomic formulas) $B = P(\boldsymbol{c})$ with a predicate P and parameters $\boldsymbol{c}$, $\boldsymbol{c}$ are the names of

objects in the domain to which our problem relates. The corresponding instruction can be written as follows:

$$d{:}r{:}P(\boldsymbol{c}){:}t \Leftrightarrow I[P](J[P],d,r,\boldsymbol{c},t)$$

where:

r is an object used as a solution to a problem $P(\boldsymbol{c})$

t is an object used to test solution r of task $P(\boldsymbol{c})$

d is an object used to diagnose the correctness of the test t for the solution r of the task $P(\boldsymbol{c})$

(I,J) is the interpretation of predicates on the subject domain (a pair of tables, described below)

$I[P]$ is the name of the subject who understands the predicate P

$J[P]$ is the instruction for the subject $I[P]$ by understanding the predicate P

Here, for each predicate P, languages are defined for writing solutions r, tests t and diagnostic procedures d.

The understanding of complex problems (defined by means of logical connectives from simpler ones) can be determined, for example, by the following formulas (obtained by combining the corresponding constructions from [20] and [21]):

$$(p,q){:}(\mathrm{b},\mathrm{c}){:}(B\&C){:}(d,e) \Leftrightarrow (p{:}b{:}B{:}c)\&(q{:}c{:}C{:}e)$$

$$(p,q){:}(0,b){:}(B\vee C){:}(d,e) \Leftrightarrow p{:}b{:}B{:}d$$

$$(p,q){:}(1,c){:}(B\vee C){:}(d,e) \Leftrightarrow q{:}c{:}C{:}e$$

$$(g,h){:}f{:}(B\Rightarrow C){:}(a,b,c,d) \Leftrightarrow$$

$$(a{:}b{:}B{:}g(a,b,c,d)\Rightarrow h(a,b){:}f(b){:}C{:}c)$$

$$g{:}f{:}\forall xB(x){:}(c,b) \Leftrightarrow g(c){:}f(c){:}B(c){:}b$$

$$p{:}(c,b){:}\exists xB(x){:}t \Leftrightarrow p{:}b{:}B(c){:}t$$

As you can see, the executor needs to be able to break pairs into elements, distinguish zeros from ones, divide formulas into immediate components, substitute the name c of the object of the domain instead of the variable x in the formula $B(x)$, apply programs (f, g, h) to their arguments (a, b, c, d). We assume that the programs are written in a language that guarantees the completion of their execution and has the ability to generate structures and program objects, mentioned in these formulas. As a rule, for practical needs, it is necessary to require certain complexity constraints on the execution of generated programs, e.g. polynomial time bounds.

If you want to use negations, you may add a special constant formula "*Impossible"*. The task *Impossible* must have no solutions. It means that

$d : r : \text{Impossible} : t$

is always false. Then, the negation of B can be expressed as ($B \Rightarrow$ Impossible).

5 Ergatic Deductive Synthesis of Problems Solutions

By the synthesis of a solution of the problem B we mean the construction by some ergatic subject by the problem B of such solution r and the procedure for diagnostics d that for any admissible objects t,

$d{:}r{:}B{:}t$

It is assumed that by any formula B, Lr(B), Lt(B), Ld(B) are the languages of admissible solutions r, tests t and diagnostic procedures d, respectively.

A constructive approach involves the automatic extraction of r and d from some construction b, called the constructive proof of formula B or the deductive solution of problem B:

$\text{Xr}(b,B)=r$, $\text{Xd}(b,B)=d$

For functions Xr and Xd, there are also, generally speaking, Xrs and Xds executors and Xrp and Xdp programs respectively:

$\text{Xrs}(\text{Xrp},b,B)=r$, $\text{Xds}(\text{Xdp},b,B)=d$

To construct a deductive solution of problem B, the function Gen of constructing proofs is usually used. The function is applied to task B and produces some object that claims to be the deductive solution of the problem. The function Gen has also an executor Gens and a program Genp:

$\text{Gens}(\text{Genp},B)=b$

Unfortunately, the procedure for constructing a deductive solution is often very complicated, requires the participation of people in the work of the executor and does not always end successfully.

In order to identify a failure, a special verification function *Check* is used:

$\text{Check}(b,B)=1$

if b is indeed a required deductive solution of problem B. Otherwise:

$\text{Check}(b,B)=0$

The function *Check* has an executor *Checks* (as a rule it is an automaton) and a program *Checkp*:

$\text{Checks}(\text{Checkp},b,B) = \text{Check}(b,B)$

Here is an example of rules for checking deductive solutions (proofs) for problems written in the language of predicate logic without functions.

For convenience, we assume that the object to be proved (the problem being solved) has a *sequent* form (see, for example, [20]):

$$\boldsymbol{x}\ \boldsymbol{G} \Rightarrow B$$

where $\boldsymbol{x}$ is a string (array) of names, $\boldsymbol{G}$ is a chain (array) of formulas, B is a formula, $\boldsymbol{G}$ and B can use the names $\boldsymbol{x}$ as free variables. This sequent is equivalent to the formula:

$$\forall \boldsymbol{x}(\boldsymbol{G} \Rightarrow B)$$

We mean signs of conjunction between the formulas $\boldsymbol{G}$. If $\boldsymbol{x}$ and $\boldsymbol{G}$ are empty, then we simply solve the problem $\boldsymbol{B}$ without any parameters $\boldsymbol{x}$ and premises $\boldsymbol{G}$.

A deductive solution of the problem (the proof of the sequent)

$$\boldsymbol{x}\ \boldsymbol{G} \Rightarrow B$$

is an expression (term) t, the structure of which is described below. The statement

$$\text{Check}(t, \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)$$

we write for brevity, in the form

$$t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B$$

This term is an expression which, after interpreting in two different ways, can be transformed both into the actual solution of the problem and the definition of the diagnostic procedure.

We determine the structure of the deductive solution by induction from solutions of simple problems to solutions of more complex ones. We consider formulations of the simplest problems as axioms. The solution of the axiom in this system is given by the term pr(i), where i is a natural number:

$$(\text{pr}(i) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B) \Leftrightarrow G[i]{=}B$$

This means that among the premises of $\boldsymbol{G}$ on the i^{th} place there was the very conclusion (*pr* means "premise reproduction"). That is, you do not have to do anything, the task is solved in one step. One of the arguments is already the result of the solution. It remains only to enter this input to the exit.

Let us give examples of other rules for verifying the solution. Here is the rule for verifying the solution of a composite (conjunctive) problem (*cg* means "conjunction generation"):

$$(\text{cg}(t,u) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\&C)) \Leftrightarrow$$

$$(t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)\ \&\ (u : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow C)$$

It prescribes to solve the problem in parts.

Rules for verifying the solution of a disjunctive problem i.e. problem with the choice of a variant (*dg* means "disjunction generation"):

$$(\mathrm{dg0}(t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B \vee C)) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)$$

$$(\mathrm{dg1}(t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B \vee C)) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)$$

allow you to select the required option.

The rule of checking an implicative task, i.e. task with constructing a function (*ig* means "implication generation"):

$$(\mathrm{ig}(t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B \Rightarrow C)) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G}B \Rightarrow C)$$

extends the list of premises from $\boldsymbol{G}$ up to $\boldsymbol{G}B$ and changes the conclusion to C.

For problems with quantifiers, there are rules (*eg* – "existence generation", *ag* – "ALL generation"):

$$(\mathrm{eg}(i,t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow \exists y B(y)) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B(x[i])$$

$$(\mathrm{ag}(t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow \forall y B(y)) \Leftrightarrow (t : \boldsymbol{x}a\ \boldsymbol{G} \Rightarrow B(a))$$

where a is a new name not found among $\boldsymbol{x}$.

Next, we give the rules for verifying the use of premises.

The rule of checking the use of a complex structure, i.e. conjunction (*cu* – "conjunction usage"):

$$(\mathrm{cu}(i,t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow D) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G}BC \Rightarrow D)$$

where $G[i] = (B \& C)$, lengthens the list of premises, allowing the use of parts of the premise separately.

The rule for checking the use of the variant, i.e. disjunction (*du* – "disjunction usage"):

$$(\mathrm{du}(i,t,u) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow D) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G}B \Rightarrow D)\ \&\ (u : \boldsymbol{x}\boldsymbol{G}C \Rightarrow D)$$

where $G[i] = (B \vee C)$, leads to a verification of the analysis of two cases.

The rule for checking the use of the function, i.e. implication (*iu* – "implication usage"):

$$(\mathrm{iu}(i,t,u) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow D) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)\ \&\ (u : \boldsymbol{x}\ \boldsymbol{G}C \Rightarrow D)$$

where $G[i]=(B \Rightarrow C)$, considers the entire decision process divided into three stages: constructing the solution of B, applying the solution of $(B \Rightarrow C)$, and constructing the solution of D.

The rule of checking the use of the solution of the problem with the quantifier of existence (*eu* – "existence usage"):

$$(\mathrm{eu}(i,t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow D) \Leftrightarrow (t : \boldsymbol{x}a\ \boldsymbol{G}B(a) \Rightarrow D)$$

где $G[i]=\exists yB(y)$, a – новое имя, не встречающееся среди x.

The rule for verifying the use of a task with a quantifier of universality (*au* – "ALL usage"):

$$(\mathrm{au}(i,j,t) : \boldsymbol{x}\ \boldsymbol{G} \Rightarrow D) \Leftrightarrow (t : \boldsymbol{x}\ \boldsymbol{G}B(x[j]) \Rightarrow D)$$

where $G[i]=\forall yB(y)$, Adds a special case of the formula $\forall yB(y)$ to the premise.
Cases that are not covered by the above rules lead the procedure of verifying the solution to the negative result.

Let us demonstrate by examples how, in this case, the programs extracted from the deductive solution of the problem should work. At the input of the realization (task solution) of the sequent, two lists are given: a list of values of variables and a list of realizations of the premises. That is, if f is proposed as a solution of the problem

$$\boldsymbol{x}\ \boldsymbol{G} \Rightarrow B$$

then $f(\boldsymbol{x},\boldsymbol{z})$ must be a solution of the problem B, where $\boldsymbol{z}$ –are realizations of $\boldsymbol{G}$. The test for this sequent consists of the following parts: the values of the variables $\boldsymbol{x}$, diagnostics $\boldsymbol{y}$, realizations z of premises $\boldsymbol{G}$, and test b for the task B. The diagnostics of the sequent under consideration consists of two functions: g и h. In this case, the value of $g(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},\mathrm{b})$ is proposed as a test list for premises $\boldsymbol{G}$, and the value of $h(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z})$ is proposed as diagnostics of B.

We assume the following formula for verifying the solution of the sequent

$$(g,h) : f :\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B :\ (\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},\mathrm{b})$$

if from the fact that for any i

$$y[i]{:}z[i]{:}G[i]{:}g(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)$$

it follows that $h(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}){:}f(\boldsymbol{x},\boldsymbol{z}){:}B{:}b$

It is possible for convenience to break the diagnostic extraction procedure Xd into two parts:

$$(g,h)=\mathrm{Xd}(p,\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B)$$

$$g=\mathrm{Xdg}(p,\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B),\ h=\mathrm{Xdh}(p,\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B)$$

The explanation of how the extraction procedures Xr and Xd should work, we start with the axioms:

$$\mathrm{Xr}(\mathrm{pr}(i),\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B)(x,z)=z[i]$$

$$\mathrm{Xdg}(\mathrm{pr}(i),\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)[i]=y[i]$$

$$\mathrm{Xdh}(\mathrm{pr}(i),\boldsymbol{x}\ \boldsymbol{G}\Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)=b$$

In the second line, the components of the result other than the i-th one are not important and may be chosen arbitrary.

We also show the procedures for extracting solutions and their support for some more complex cases. Here are the formulas for the operator *cg* (operator of generating conjunction, that is, a composite problem):

$\mathrm{Xr}(\mathrm{cg}(t,u)\ ,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\&C))(\boldsymbol{x},\boldsymbol{z}) =$

$\quad (\mathrm{Xr}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{z}),\ \mathrm{Xr}(u,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow C)(\boldsymbol{x},\boldsymbol{z}))$

$\mathrm{Xdg}(\mathrm{cg}(t,u),\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\&C))(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},(b,c))[i] =$

$\mathrm{if\ Arb}(\boldsymbol{y},\boldsymbol{z},G[i],\mathrm{Xdg}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)[i])$

$\mathrm{then\ Xdg}(u,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow C)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},c)[i]$

$\mathrm{else\ Xdg}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)[i]$

$\mathrm{Xdh}(\mathrm{cg}(t,u),\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\&C))(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) =$

$\quad (\mathrm{Xdh}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}),\ \mathrm{Xdh}(u,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow C)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}))$

As you can see, the diagnostic procedure actively uses the verification procedure Arb. Here are the formulas for the operator dg0:

$\mathrm{Xr}(\mathrm{dg0}(t),\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\vee C))(\boldsymbol{x},\boldsymbol{z}) = (0,\mathrm{Xr}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{z}))$

$\mathrm{Xdg}(\mathrm{dg0}(t),\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\vee C))(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},(b,c))[i] =$

$\quad \mathrm{Xdg}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},b)[i]$

$\mathrm{Xdh}(\mathrm{dg0}(t),\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow (B\vee C))(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) =$

$\quad (\mathrm{Xdh}(t,\ \boldsymbol{x}\ \boldsymbol{G} \Rightarrow B)(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}),\mathrm{dummy}(C))$

where dummy(C) is an arbitrary function suitable for diagnostics of C by type (the result of its operation is not important).

Conclusions

The aim of the work was to obtain novel knowledge and technologies, in the creation of IT support, for descriptive and constructive activities. The key focus is directed to the theoretical and technological knowledge related to the manifestation of symbiosis, as well as, to various computing and intellectualization of activities.

Methods for constructing algorithms and computer programs that take into account aspects of counteraction, detection and elimination of errors are investigated.

The transition from classical programming, as a planning of a clear order of actions to the development of task formulations, in particular, in the framework of constructive logic based on the classification of complexity and management of complexity, resource intensity, as well as, the transition to ergatic computing, is explored.

A variant of constructive understanding is also studied: The practical understanding in the face of opposition and support.

References

[1] Volfengagen V. E.: Applicative computing: attempts to establish the nature of computations (Applikativnyy komp'yuting: popytki ustanovit' prirodu vychisleniy). In: V. I. Konov (ed) Sbornik nauchno-populyarnykh statey — pobediteley konkursa RFFI 2006. V. 10. Oktopus, Priroda, Moscow. 2007, pp. 446-459

[2] Rudenskiy O. V., Rybak O. P.: Innovative civilization of the XXI century: convergence and synergy of NBIC-technologies. Trends and forecasts 2015-2030 (Innovatsionnaya tsivilizatsiya XXI veka: konvergentsiya i sinergiya NBIC-tekhnologiy. Tendentsii i prognozy 2015-2030). Informatsionno-analiticheskiy byulleten' 2010. 3

[3] Beltiukov A. P.: Intuitionistic formal theories with realizability in subrecursive classes. *Annals of Pure and Applied Logic*, 1997, 89: pp. 3-15

[4] Beltiukov A. P.: A strong induction scheme that leads to polynomially computable realizations. *Theoretical Computer Science*, 2004, 322: pp. 17-39

[5] Beltiukov A. P.: Small complexity classes and automatic deductive synthesis of algorithms (Malyye slozhnostnyye klassy i avtomaticheskiy deduktivnyy sintez algoritmov). *Izvestiya instituta matematiki i informatiki UdGU*, Izhevsk, Russia, 1995, 2: pp. 3-89

[6] Maslov S. G., Beltu'kov A. P.: Active layered terminology system" (Aktivnaya rassloyennaya terminologicheskaya Sistema). *Ustoychivoye innovatsionnoye razvitiye: proyektirovaniye i upravleniye*. Dubna, 2011, Vol. 7, 3(12): pp.103-113

[7] Kovacs G.: Role of artificial intelligence and robots in digital production and beyond. In: *Proceedings of the 18th international workshop on computer science and information technologies* (*CSIT'2016*), Vol. 1, USATU, Ufa, Russia, 2016, pp. 40-44

[8] Maslov S. G., Beltu'kov A. P., Morozov O. A.: IT-sphere Constructive Directions. In: *Proceedings of the 11th international workshop on computer science and information technologies (CSIT-2009)*, UGATU, Ufa, Russia, 2009, pp. 131-135

[9] Beltu'kov A. P., Maslov S. G.: On the problems of readers and the process of reading in an electronic environment (O problemakh chitateley i protsesse chteniya v elektronnoy srede). *Vestnik Udmurtskogo universiteta. Mathematics. Mechanics. Computer science*. UdGU, Izhevsk, Russia, 2010, 4: pp.101-111

[10] Kosikov S. V.: Information systems: a categorical approach (Informatsionnyye sistemy: kategornyy podkhod). YurInfoR-Press, Moscow, 2005

[11] Kovalev S. P.: The theory-categorical approach to the design of software systems (Teoretiko-kategornyy podkhod k proyektirovaniyu programmnykh system) *Fundament. i prikl. matem.* 2014, 19:3: pp. 111-170

[12] Antonov V. V.: The method of designing an adaptive software package based on the methodology of the formal model of an open domain (Metod proyektirovaniya adaptivnogo programmnogo kompleksa na osnove metodologii kategoriynoy formal'noy modeli otkrytoy predmetnoy oblasti) *Vestnik UGATU*, 2015, Vol. 19, 1(67): pp. 258-263

[13] Sergeev S. F.: Autopoietic basis of biotechnosphere evolution (Autopoeticheskiy bazis evolyutsii biotekhnosfery). *Obrazovatel'nyye resursy i tekhnologii*, 2015, 1(9): pp. 57-65

[14] Mikheev M. Yu., Zhashkova T. V., Semochkina I. Yu., Roganov V. R, Shcherban A. B.: Mathematical and information-structural models of ergatic systems (Matematicheskiye i informatsionno-strukturnyye modeli ergaticheskikh sistem). Penza, 2015

[15] Sergeev S. F.: Humans within the Framework of Technobiotic Evolution *Russian Federation European Journal of Psychological Studies*, 2014, Vol. 3, 3 pp. 93-101

[16] Levenchuk A. I.: System-Engineering Thinking (Sistemnoinzhenernoye myshleniye). *Electronic resource*, (30.05.2015), http://techinvestlab.ru/systems_engineering_thinking

[17] Chudova N. V.: Understanding: the subject of research and the object of modeling (Ponimaniye: predmet issledovaniya i ob"yekt modelirovaniya) *Artificial Intelligence and Decision Making (Iskusstvennyy intellekt i prinyatiye resheniy),* 2012; 4: pp. 3-31

[18] Markov A. A.: An attempt to construct the logic of constructive mathematics (Popytka postroyeniya logiki konstruktivnoy matematiki). In: *Studies in the theory of algorithms and mathematical logic (Issledovaniya po teorii algorifmov i matematicheskoy logike)*, Moscow, 1976, Vol. 2, pp. 3-31

[19] Shanin N. A.: On the hierarchy of ways of understanding statements in constructive mathematics. *Tr. Matem. in-ta AN SSSR*, 1973, т. 129, pp. 203-266

[20] Kleene S. C.: Introduction to metamathematics, North-Holland, 1951

[21] Gödel, K.: Über eine bisher noch nicht benützte Erweiterung des finiten Standpunktes. In: Feferman, S., Dawson, Jr., J. W., Kleene, S. C., Moore, G. H., Solovay, R. M., and van Haijenoort, J. (ed) *Collected Works*. Oxford University Press, 1990, vol. II, pp. 240-251

[22] Spector C.: Provably recursive functionals of analysis: a consistency proof of analysis by an extension of principles in current intuitionistic mathematics. Recursive Function Theory. *Proc. Symposia in Pure Mathematics.* 1962, pp. 1-27

[23] de Paiva V.: The Dialectica Categories. University of Cambridge, Computer Laboratory, PhD Thesis, Technical Report 213, 1991

[24] Avigad J, Feferman S.: Gödel's Functional ("Dialectica") Interpretation. In: Buss S. R. (ed) *Handbook of Proof Theory*, Elsevier Science, 1999

[25] Shirahata M.: The Dialectica Interpretation of First-order Classical Affine Logic. *Theory and Applications of Categories,* 2006. Vol. 17, 4: pp. 49-79

[26] Troelstra, A. S., Smoryński C. A., Zucker J. I., Howard W. A.: Metamathematical Investigation of intuitionistic Arithmetic and Analysis. Springer Verlag, Berlin. 1973. pp. 1-323

[27] "Big Data Meets High Performance Computing" (WHITE PAPER Intel Enterprise Edition for Lustre* Software High Performance Data Division), 2014. https://www.intel.com/content/www/us/en/lustre/intel-lustre-big-data-meets-high-performance-computing.html

[28] Fox G.: High Performance Computing and Big Data, 2016. - https://www.slideshare.net/Foxsden/high-performance-computing-and-big-data

[29] "NIST Big Data Interoperability Framework". 2015. - http://dx.doi.org/10.6028/NIST.SP.1500-3

[30] Basin D., Deville Y., Flener P. Hamfelt, A., Nilsson J. F.: Synthesis of Programs in Computational Logic. In: Bruynooghe M., Lau K.-K. (Eds.) *Program Development in CL*, 2014, LNCS 3049: pp. 30–65

[31] Maslov S. G., Beltiukov A. P.: Problems of constructing a natural scientific network of knowledge of descriptive and constructive activity (Problemy postroyeniya yestestvenno-nauchnoy seti znaniy deskriptivno-konstruktivnoy deyatel'nosti). In: *XII Vserossiyskoye soveshchaniye po problemam upravleniya. VSPU-2014*, IPU RAN, Moscow, Russia, 2014, pp. 639-640

[32] Maslov S. G., Beltiukov A. P.: Ergatic network as the basis of professional activity in the paradigm of sustainable development (Ergaticheskaya set' kak osnova professional'noy deyatel'nosti v paradigme ustoychivogo razvitiya). In: Electronic scientific publication "*Sustainable innovation development: design and management*". Dubna, 2015. Vol. 11. No. 1(26): pp. 36-50. http://www.rypravlenie.ru/wp-content/uploads/2015/04/03-Maslov_Beltyukov.pdf

[33] Beltiukov A. P., Maslov, S. G.: Organizing understanding in the framework of ergatic system In: *Proc. of 17th International Workshop on Computer Science and Information Technologies (CSIT'2015)*, Vol.1, USATU, Ufa, Russia, 2015, pp. 60-64

[34] Maslov S. G., Beltiukov A. P.: On the problems of intellectual activity in ERGANET (O problemakh intellektual'noy deyatel'nosti v ERGANETE) In: *Materials of the 8th All-Russian Multiconference (Materialy 8-y Vserossiyskoy mul'tikonferentsii)*. 3 Vol. Rostov-on-Don: Southern Federal University Publishing House, 2015, pp. 142-144

[35] Beltiukov A. P., Maslov, S. G.: Logical-deductive synthesis of program-information objects in decision-making systems (Logiko-deduktivnyy sintez programmno-informatsionnykh ob"yektov v sistemakh prinyatiya resheniy). In: *ITIDS'2016: Proceedings of the 4th International Conference on Information Technologies for Intelligent Decision Making Support.* Vol. 1, USATU, Ufa, Russia, 2016, pp. 25-30

[36] Maslov S. G., Beltiukov A. P.: Current situation and trends in the design of IT systems (Sovremennaya situatsiya i tendentsii v proyektirovanii IT-sistem). In: *ITIDS'2016: Proceedings of the 4th International Conference on Information Technologies for Intelligent Decision Making Support*. Vol. 1, USATU, Ufa, Russia, 2016, pp. 150-154

[37] Maslov S. G., Beltiukov A. P.: Information and technological support of ergatic intelligence. CSIT'2016: Proceedings of the 18th International Workshop on Computer Science and Information Technologies, Czech Republic, Prague-Kunovice, September 26-30, 2016, V.1, – Ufa: Ufa State Aviation Technical University, 2016, pp. 40-44

[38] Beltiukov A. P., Maslov, S. G.: On understanding within the framework of the ergatic system (O ponimanii v ramkakh ergaticheskoy sistemy). In: *International cooperation: Integration of educational spaces. Materials of the III International Scientific and Practical Conference (Mezhdunarodnoye sotrudnichestvo: Integratsiya obrazovatel'nykh prostranstv)*. UdSU, Izhevsk, 2016, pp. 145-151

[39] Alpuente M., Cuenca-Ortega A., Escobar S., Meseguer J.: Partial Evaluation of Order-Sorted Equational Programs Modulo Axioms. In: Hermenegildo M., Lopez-Garcia P. (eds) Logic-Based Program Synthesis

and Transformation. LOPSTR 2016. Lecture Notes in Computer Science, vol 10184 (2017) Springer, Cham, pp. 3-20

[40] Albert E., Bezirgiannis N., de Boer F., Martin-Martin E.: A Formal, Resource Consumption-Preserving Translation of Actors to Haskell. In: Hermenegildo M., Lopez-Garcia P. (eds) Logic-Based Program Synthesis and Transformation. LOPSTR 2016. Lecture Notes in Computer Science, vol 10184 (2017). Springer, Cham, pp. 21-37

[41] De Angelis E., Fioravanti F., Meo M.C., Pettorossi A., Proietti M.: Verification of Time-Aware Business Processes Using Constrained Horn Clauses. In: Hermenegildo M., Lopez-Garcia P. (eds) Logic-Based Program Synthesis and Transformation. LOPSTR 2016. Lecture Notes in Computer Science, vol 10184 (2017). Springer, Cham, pp. 38-55

[42] Alpuente M., Pardo D., Villanueva A.: Symbolic Abstract Contract Synthesis in a Rewriting Framework. In: Hermenegildo M., Lopez-Garcia P. (eds) Logic-Based Program Synthesis and Transformation. LOPSTR 2016. Lecture Notes in Computer Science, vol 10184 (2017). Springer, Cham, pp. 187-202

[43] Tarau P.: A Hiking Trip Through the Orders of Magnitude: Deriving Efficient Generators for Closed Simply-Typed Lambda Terms and Normal Forms. In: Hermenegildo M., Lopez-Garcia P. (eds) Logic-Based Program Synthesis and Transformation. LOPSTR 2016. Lecture Notes in Computer Science, vol 10184 (2017). Springer, Cham, pp. 240-255

Challenges of Burnout Prevention in Slovac SMEs– Focus on Optimal Employment

Enikő Korcsmáros, Renáta Machová

J. Selye University, Faculty of Econommics, Bratislavska str. 3322, 945 01 Slovak Republic, korcsmarose@ujs.sk (corresponding author); machovar@ujs.sk

Abstract: Labor shortages have become widespread in Slovakia in recent years. Numerous studies deal with the difficulties of finding a skilled, motivated workforce and the difficulties of retantion. The aim of this study is to introduce the tools used by managers in HR with special regard in examining the efforts companies make to prevent burnout. The study provides a statistical analysis of the results of primary data collection on a sample of 431 SMEs the current employment policy issues in Slovakia, with a particular focus on recruitment, motivation and retention. SMEs are the engine of the European Economy, which is why it is very important that this machinery works well, is able to produce continuously and thus contribute to the economic development of the country. One of the prerequisites for this is that the human resources available to them are properly managed. Our goal is to showcase the opportunities and tools that a manager or HR department uses when it comes to employing a company, and to try to find a solution for the problem of retaining an effective workforce. Based on the obtained data related to burnout syndrome, we can conclude that 76.38% of the surveyed companies address the issue of employee burnout. 86% of the employees are at risk of burnout, since burnout is the diesease of our modern civilization. 68% of the companies struggle with more than a 15% workforce fluctuation, which can be declared a loss for the company.

Keywords: employment; motivation tools; burnout syndrome; SMEs competitiveness; Slovakia

1 Introduction

Since SMEs are an engine of the European economy, it is important to create a well-functioning SME sector that contributes to economic development of the country [13]. One of the basic prerequisites for this condition is the availability of the properly managed human resources capital. Our objective is to introduce the opportunities and tools used by managers and HR when addressing the employment issue, and find the most appropriate solution for the problem of retaining an operational workforce.

Increasing the employment and the level of employability are the most common measures to tackle the long-term unemployment in the EU and Slovakia, as well. Mutual effects can be achieved by integrating tools since economic growth and employment cannot be achieved in isolation.

Employment is a complex economic and social function, in which the specific and different approaches of both sciences should be applied [16]. Therefore, the labor market is a part, not only, of the economic, but of the social sector.

Employment policy is an external system of the labor market that makes the labor market function more harmoniously [1]. The social activities can be applied easily [16]. It is important to differentiate the employment policy and the labor market policy since different actors are involved and their issues require different solutions. While employment policy is more concerned with the labor market demand and regulation of the economy, the labor market policy is addressing the issue of unemployment and the social tensions resulting from the problem [5].

The definition of burnout was set by Maslach as "a psychological syndrome of emotional exhaustion, depersonalization, and reduced personal accomplishment" which occurs as a response to emotional and interpersonal stressors among individuals. [17] According to the studies deals with burnout perceived stress was positively correlated with all burnout dimensions but there is no significant correlation between gender and burnout. [20]

This work highlights key HR tools that can reduce burnout within the company. Section 2 explain the theoretical background of the problems and describe the 3 models of employment policy, Maslow´s hierarchy of needs and in addiction to motivation, present the problem of burnout-syndrome and its stages. Methodology of our research is describe in Section 3. Section 4 presents the result of the research, including the main findings. The contribution of the article is to present and evaluate the burnout-syndrome among employees in Slovac SMEs. Section 5 presents the relevant conclusions.

2 Theoretical Background

The most important task of employment policy is to ensure ideal work conditions and possibilities in accordance with the employee abilities. The instruments of employment policy can help to meet the labor market supply and demand. The employees have to remain flexible to meet the labor market demand. They can find new jobs easier. These tools provide an opportunity to decrease the labor market supply in different sectors by decreasing training opportunities. It is also important to help those who have lost their jobs because of external circumstances [16]-[15].

Three (3) models of employment policy are distinguished. The first is the social model of full employment, which is primarily based on the socio-political perspectives. The state eliminates the unemployment by introducing compulsory employment. This is achieved by creating workplaces to meet the demand. The biggest disadvantage of the model is the phenomena of internal unemployment since it is creating a useless but employed workforce that results in decrease of the market mechanisms (decreasing performance, inadequate productivity, decreasing competitiveness). The second is the general model of employment, which is based on the autonomy of the labor market. It provides conditions for the business organizations to employ the amount of workforce they require. The principle of efficiency is applied. Since it is impossible to provide workplace for everyone, the unemployment cannot be eliminated. The last is the model of full employment. The main objective is the elimination of unemployment, uncertainty and discrimination. It focuses on utilizing the available workforce the most efficient way. [2]-[8] The elimination of unemployment and efficient utilization of workforce would be a primary social objective in order to achieve higher productivity. However, in dynamic economies a certain level of unemployment is unavoidable that should be managed without resulting in social tension [25].

Although employment policy is the driving force of labor market processes, it is not enough to find solution for all the emerging problems. The process can be influenced by applying other policy tools as well. [14] The economic policy can determine the path of the economic growth, influencing the demand on the labor market. Demographic trends and the ratio of economically active workforce can be influenced by the population policy. It also has impact on the labor supply. The income policy can influence the willingness to work. It can regulate the purchasing power and the demand. [10] The employment can be incentivized by applying financial and fiscal policy tools since the price level and the regulation of household income has impact on the productivity of the businesses and their labor demand. Employment policy is supported by social policy that helps the unemployed. [19] The workforce mobility can be enhanced by education policy. Increasing the duration of trainings and education can postpone the labor market entry. [21] The cooperation of labor market players can be supported by the work of different interest groups that might contribute to reduction of tension on the labor market. The law protects the employers by formulating rules supporting the conclusion or termination of the work contract [25].

Active and passive tools of employment policy are differentiated. The active tools are designed to achieve equilibrium of workforce supply and demand, and help the re-entry of unemployed on the labor market by supporting employment trainings and providing possibilities to start business activity. The mentioned tools incentivize the employment. The passive tools cannot influence the employment directly (e.g. unemployment benefit). They rather help the unemployed [5].

Retaining a workforce means using different motivational tools to keep the employee within the company. It is not a simple task, since numerous

motivational tools are can be applied to motivate different types of employees. There are many motivational theories, which try to find the roots of human motivation. One of the oldest, the most controversial and undoubtedly the most influential is the theory of Maslow. Abraham Maslow was the author of the theory of motivation based on a hierarchy of needs. According to Maslow's Hierarchy of Needs, everybody is motivated by five needs.

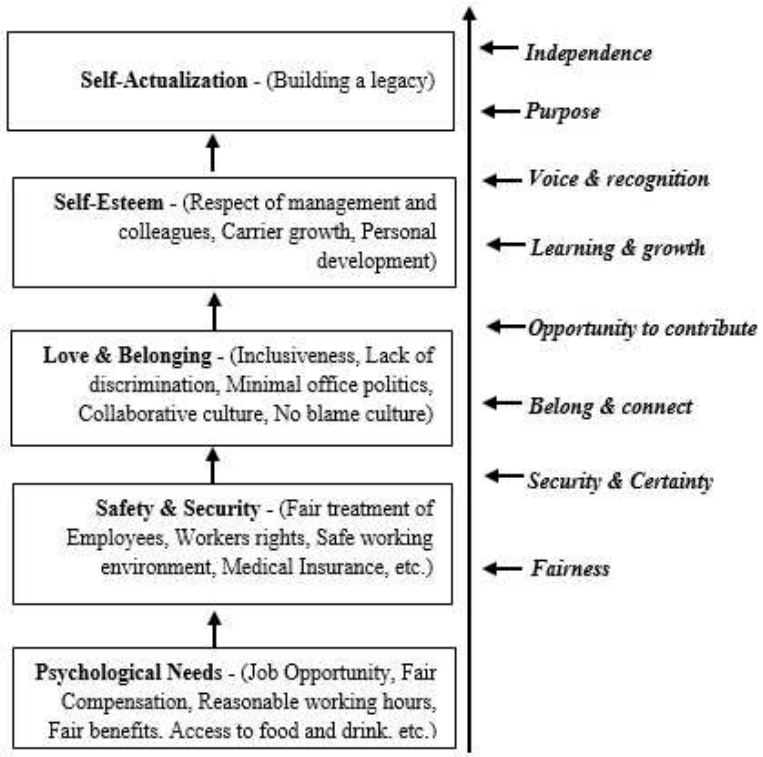


Figure 1

Maslow's Hierarchy of Needs in connection with employees' motivation

(Source: own editing based on [18]*)*

Maslow stated that individuals must satisfy lower level needs before progressing to meet the higher level growth needs [18].

However, motivation by pay is adequate up to certain level, but not enough to progress and meet a higher level of satisfaction. Daniel H. Pink in his work *The Surprising Truth about What Motivates Us* explained that good salary is essential to retain the employee, but not enough to maintain an employee's motivation. Money has no long-term motivating effect. Pink emphasized that different motivational tools should be applied for the representatives of Generation X and Generation Y [23]. The employees should know that their work is important.

There should be an internal incentive to complete the work, financial incentive is not enough to achieve employee satisfaction. If it is missing, the employees might be easily attracted by a slightly higher wage offered by competitors. [7] The motivational tools can be learned, but majority of the SME leaders underestimate the power of motivation. However, the leadership with incentives increases not only the productivity, but the employees have increased willingness to perform better [3].

In addition to motivation, there is another factor playing role in retaining or losing an employee. This factor is the burnout-syndrome. Burnout is a physical, mental and emotional exhaustion that occurs as a reaction to chronic workplace stress [27]. The long-term stress in SME sector is a result of overwork, unclear expectations, lack of feedback and workplace recognition, but also the workplace insecurity. The burnout-syndrome has different stages.

The first stage is characterized by over-enthusiasm, setting unrealistic goals and lively interaction with colleagues. The stage of idealism is followed by the phase of realism. The employee is still committed to his/her job; this phase is characterized by cooperation and interest in tasks.

The performance and interest start to decline in stagnation phase. The interaction focuses only on the necessary issues. In stage of frustration, the individual is experiencing failure and a sense of powerlessness. The efforts do not visibly pay off and the performance is falling. They refuse the help of colleagues and all of those they work together with become annoying. The last stage is apathy. Despair and disillusionment occur, the interaction falls into the minimum and the individual is resigned and indifferent. The relationship with colleagues is becoming hostile, while the individual loses all hope and trust in the organization. It is important to emphasize that burnout is a cyclically repetitive process, so it does not end with the fifth stage, but different stages of burnout will repeat [27]-[6]. The process usually ends with the employee leaving the company. Either the employees resign to escape the situation or they are dismissed because of falling performance. The stages of burnout are presented in the following figure (Fig. 2).

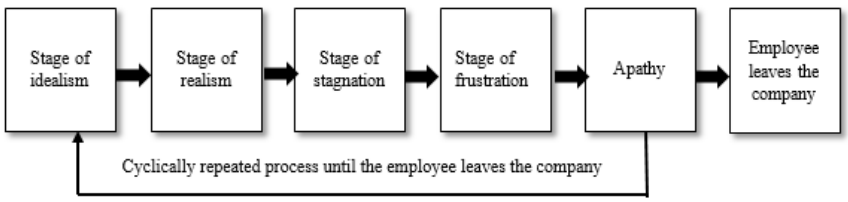


Figure 2
Flowchart - Stages of burnout
(Source: own editing, based on [27])

Burnout has a very serious impact on the individual, the team and the organization as well. It is the most common type of stress-related illnesses, affecting 86% of the Hungarian employees [22]. This is why it is important to put more emphasis on prevention. The prevention can be examined at organizational and individual level. Our study will examine prevention at organizational level. The easiest way to avoid burnout is to minimize or eliminate the possible roots of burnout. It means that managers of organizations should promote healthy work-life balance and will not put additional burden on the employee. The manager should clearly define the tasks and responsibilities; provides a regular feedback about the employee performance. [24] Employees are involved in tasks and issues closely related to their work. They have to be informed how their activity is contributing to the company strategy. A pleasant workplace atmosphere should be created, which can be achieved by organizing team building programs [11].

Motivation and strategies applied to prevent burnout are two important factors if companies would like to retain the workforce. A complete paradigm shift is required by SME leaders to understand that retaining workforce is an essential task. Nowadays, when most of the companies are struggling with labor shortage, retaining a workforce is seen as a new form of the recruitment process [12]. This is the reason why we considered it important to formulate our Assumption 1 to analyze if the widespread use of motivational tools has positive influence on the prevention of burnout syndrome.

3 Methods and Methodology

The theoretical background of the issue was defined in the prevoiuse section of the article, so we are currently dealing with methodological issue. The aim of the study is to introduce the tools used by managers for HR in special regard to examine the efforts the companies make to prevent burnout. The goal of the research is to address the main employment issues of SMEs in terms of retaining the workforce. The recruitment strategies of SMEs and the strategies for retaining employees will be examined. The sub-goals of the research is to analyze what type of employment patterns are offered by SMEs, how flexible they are, what kind of motivational tools are used, are there any forms of atypical employment offered and what kind of measures are taken to prevent workforce leaving the company. We also investigate whether the employers consider the work-life balance important, do they feel the employees motivated and take measures to prevent burnout, which is one of the major social problems nowadays resulting in employees leaving the company. Studying the theoretical background to the issue, all of the mentioned aspects are important in order to retain the workforce.

A questionnaire survey was intsigated in Slovakia (February-April, 2018) to collect the primary data. The questionnaire contained 23 questions, mapping the

basic information about the companies and the motivational tools applied to retain their employees. A snowball method was used in the questionnaire survey. We randomly selected 200 SMEs in Slovakia to whom we sent the questionnaire in form of direct mail and ask them to forward it to other SMEs as well. The total number of submitted questionnaires form SMEs was 503, but 72 questionnaires had to be excluded, since they were submitted by self-entrepreneurs running their company on their own without employing other employees. The analysis of obtained data is based on the remaining 431 questionnaires. The authors used the SPSS software statistical program to investigate the proposed relations.

The present study introduces only partial data, which is closely connected to Assumption 1. According to Assumption 1, the widespread use of motivational tools has positive influence on the prevention of burnout syndrome.

In addition to basic descriptive statistical methods (distribution, standard deviation, modus) the Pearson's Chi-square and Cramer V were used to analyze the obtained data.

The Pearson's Chi-square Test expresses the statistical significance of the relationship between the two nominal variables.

$$\chi^2 = \sum_{total\ cells} \frac{(f_0 - f_e)^2}{f_e} \tag{1}$$

The relationship is primarily based on the comparison of expected (f_e) and observed (f_0) values.

To express the strength of the relationship, the Cramer V indicator was used, where N refers to size of the sample and k expresses the number of categories [9]:

$$V = \sqrt{\frac{\chi^2}{N(k-1)}} \tag{2}$$

The Cramer V given this index ranges from 0 to +1. The higher the indicator is, the stronger the association is.

4 Primary Data Assessment

With regard to basic characteristics of the surveyed sample, we should emphasize that the vast majority of the businesses surveyed have been conducting their business activity for less than 10 years (27.6% - 0-5 years, 30.4% - 6-10 years, 21.5% - 11-15 years, 16.2% - 16-20 years, 4.3% - more than 20 years). Considering the size of the surveyed enterprises, the leaders of micro-enterprises represented the majority (61%). They represent 2/3rd of the respondents.

The leaders of small companies represented 27% of the respondents, while 12% of the respondents represented the medium-sized enterprises.

In connection to our research assumption, we examined the opinion of the company leaders regarding the workplace atmosphere. The healthy workplace environment serves as a basis for smooth operation of business, increases the competitiveness on the market and helps to retain the staff. Most of the companies (43%) reported a balanced workplace atmosphere. 29% of the surveyed businesses reported stressful workplace environment, while 28% described it rather relaxed. As a positive result, none of the companies indicated continuous stress and tension of the workplace environment.

As a further step, we examined the motivational tools applied by the surveyed companies.

Table 1

Sample characteristic (N=431) – years of companies establish and applied motivational tools

Years	**%**	**Valid %**	**Applied motivational tools**	**%**	**Valid %**
0-5	27.60	27.60	financial benefits	53.70	53.70
6-10	30.40	30.40	verbal praise, recognitions	29.60	29.60
11-15	21.50	21.50	carrier advancement opportunities	8.40	8.40
16-20	16.20	16.20	non-material benefits	7.60	7.60
more than 20	4.30	4.30	prospect of penalties and sanctions	0.70	0.70
Total	**100.00**	**100.00**	**Total**	**100.00**	**100.00**

Source: Authors' analysis

According to Table 1, the least motivating factors are penalties and sanctions. Only 0.7% of the respondents indicated this option. 8.4% of the leaders motivate with chance of promotion; 7.6% use non-financial incentives (e.g. entrance tickets, coupons) as a motivational tool. 29.6% of the leaders motivate with verbal praise and recognition. However, most of the leaders responded that financial incentive is still the most motivating factor (53.7%). Employee motivation is closely linked to the corporate climate. If employees are motivated, they are trying to do their best, demoralization and fluctuation is decreasing, stress is falling and the competitiveness is increasing. The next 2 questions addressed the issue of team building within the company. If team building events are organized, how often and of how much importance is it to make the trainings popular among the employees. Well-organized team building programs help the company to function as a whole and focusing on how to exploit the hidden skills of the employee. The efficiency can drastically increase in the organization, where employees work as a team, pay attention and help each other. Cooperation and respecting each other reduces the chance of burnout.

55% of the surveyed company leaders organize team building programs. 42% of these leaders organize the trainings annually, while 13% of them organize trainings every six months. 61.8% of the leaders organizing team building programs agree that employee satisfaction is important. Although the company leaders can see the team building events satisfactory, the opinion of employees about team building is not asked. 31.6% of the leaders conducting a survey in order to make their team building programs more colorful. 6.6% of the leaders organize team building, whether or not the employees are satisfied with the program.

In addition to team-building programs, an annual dinner is organized in most of the companies. The executives usually talk about the mission and vision of the company on annual dinner events, so the employees can feel the importance of their contribution to company success as well as how their contribution is related to the success of the company. This is a great opportunity for executives to express their appreciation to their employees. According to our study, 74% of the executives organize annual dinner.

Beside the importance of company atmosphere and team building events, we were interested in the employment policy applied in the companies. The executives had to evaluate 15 statements regarding their company on a 4-point Likert scale, where 1is disagreement with the statement and 4 is complete agreement with the statement. Which statement is characteristic for the company was determined by an average; standard deviation was used to gain accurate results; and relative standard deviation was used to express this value in percentage. In order to get the most frequently option, the mode was calculated (Table 2).

Table 2
Statistical analysis of the Likert scale

Statement	*Mean*	*Standard Deviation*	*Reative Standard Deviation*	*Mode*
Employee well-being is important (material and moral esteem)	3.45	0.64	18.50%	4
Work-life balance should be encouraged	3.31	0.66	19.90%	3
Employees must receive regular confirmation of their work	3.49	0.71	20.46%	4
There must be an excellent relationship with all employees	3.18	0.80	25.31%	4
The employees are motivated	3.24	0.71	21.88%	3
All employees are aware of their role and responsibilities	3.56	0.67	18.77%	4
The employees are loyal and committed to the company	3.09	0.81	26.33%	3

Employees must be involved in issues that affect their work	3.08	0.87	28.19%	4
It is often that employees have to work overtime	2.46	0.88	35.63%	2
A leader must be consistent	3.86	0.35	8.99%	4
A leader must be a good conflict handler	3.88	0.32	8.38%	4
It is important for a leader to continuously train himself / herself as a leader	3.52	0.61	17.27%	4
Employee satisfaction needs to be measured regularly (quarterly or semi-annually)	2.53	0.84	33.28%	2
It should be recognize in time if an employee is about to terminate	2.97	0.84	28.35%	3
Labor shortages are not typical of the economic sector represented by our company	1.99	0.95	47.93%	1

Source: Authors' analysis

The survey results reveal that executives address great importance to well-being of their employees. Most of them chose the highest option 4, the average was 3.45 and the relative standard deviation 18.50%, which indicates a moderately variable sample for the statement. The healthy work-life balance is also supported, but option 3 was chosen by most of the executives. The standard deviation was below 20%. It was also revealed that employees are provided a regular feedback about their performance; they have also agreed that maintaining excellent relationship with employees is also important. The executives feel their employees motivated, most of them chose option 3, the average was 3.24 and the relative standard deviation 21.88%. Most of the employees are aware of their tasks and responsibilities in the company. According to executives, the employees are loyal to the company. Most of them chose option 3, the average was 3.09. The relative standard deviation was 26.33%, which means that part of the employers chose option 2. They do not seem to be confident about employee loyalty. Similar results were gained regarding the statement that the employees should be engaged in the issues related to their work. The mode calculation was 4 in this case. The average was 3.09; and the relative standard deviation 28.19%. In case of overtime, the average was 2.46, accompanied with a relative standard deviation of 35.63%. It means that most of the executives chose option 2, but the results were close to option 3. It can be declared that the employees have to work overtime several times. The following three statements were about the executives. The leader should be consistent, good in conflict management and should be trained as a leader. The respondents completely agree with the first two statements. Similar results were achieved in both cases. Most of the respondents chose option 4, the average was close to 3.9 and the relative standard deviation below 9%. It means that the executives are consistent and show willingness to solve conflicts.

Statement 3 shows a slight deterioration of values. The executives find important to participate on leadership trainings. The most frequently chosen option was 4, but the average decreased to 3.52 and the relative standard deviation increased to 17.27%. The executives did not entirely agree with conducting an employee satisfaction survey. Most of them chose option 2, the average was 2.53 and the relative standard deviation 33.28%. They also expressed disagreement with the statement that one has to recognize in time if an employee is about to terminate. It is true that most of the respondents chose option 3, which means that they agree with the statement, but the average was 2.97, and the value of relative standard deviation 28.35%. This result is high enough to remain close to choose option 2. Our last statement was about the general labor shortage. The executives had to decide how much the labor shortage is characteristic in their sector. Most of the executives chose option 1. The average (1.99) was high and the relative standard deviation was 47.93. According to most of the executives, the labor shortage is high, but we are closer to value 2, which is considered moderately high. When examining the standard deviation, we should note that smaller the standard deviation is, the more the executives involved in the survey agree, so we can speak about a reliable average.

We have now reached the questions related to the fluctuation and termination of the employees. Our primary focus was on the average time employees stay with the company. 41.6% of the companies reported that employees are staying with the company for 1-3 years, while 36.2% of the companies reported an average of 4-5 years. The maximum of 1 and 6-10 year intervals was reported by 9.1% and 9.7% of the companies, while an employee working 10 years for the company was reported by 3.4% of the companies (Table 3).

Table 3
Sample characteristic (N=431) – years of companies establish and average time employees are staying with the company

Years	%	Valid %	Average time employees are staying with the company	%	Valid %
0-5	27.60	27.60	probation - 1 year	9.10	9.10
6-10	30.40	30.40	1 - 3 years	41.60	41.60
11-15	21.50	21.50	4 - 5 years	36.20	36.20
16-20	16.20	16.20	6 -10 years	9.70	9.70
more than 20	4.30	4.30	more than 10 years	3.40	3.40
Total	**100.00**	**100.00**	**Total**	**100.00**	**100.00**

Source: Authors' analysis

As a next step, we surveyed the reasons of the employee termination. There might be many reasons why employees are leaving the company. The most frequently chosen answer in this survey was the change in living circumstances of the employee (31.5%). It was followed by low wage (24.1%) and the lack of progress

(18.3%). 11.9% of the respondents reported the difficulty of work and 8.3% left because of the work conditions. Workplace grievances were mentioned by 5.9% of the respondents (Figure 3).

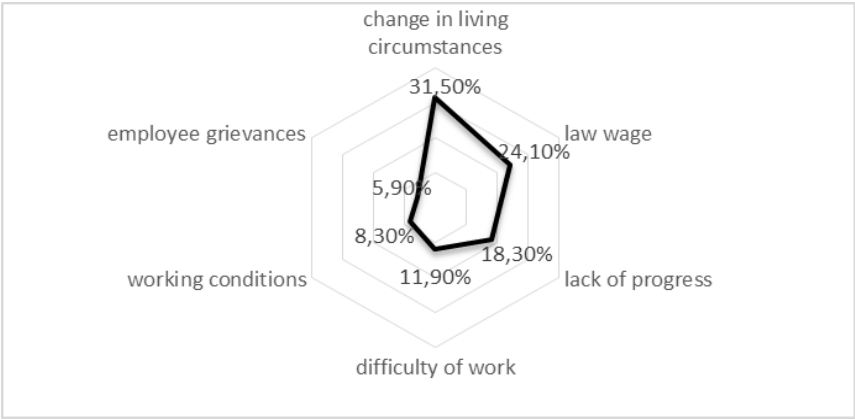


Figure 3

The most common reasons of employee termination

(Source: own editing based on primary data)

In terms of the research, we found it important to examine the fluctuation of the past 5 years in the companies. 45% of the companies reported 16-30% fluctuation, while 38% of them showed a fluctuation of 0-15%. 12% of the companies faced 31-45% workforce fluctuation, while 5% of the companies reported workforce fluctuation over 45%.

The fluctuation rate was compared to the motivational tools. We were interested in the level of the fluctuation at those companies where financial incentive is the main tool of motivation (Table 4).

Table 4

Table 3: Motivational tools vs workforce fluctuation

How you typically motivates your employees?	***Fluctuation rate in the last 5 years***	***Distribution***
Financial benefits	0-15%	15%
	16-30%	30%
	31-45%	7%
	Over 45%	2%
Financial benefits - Total		**54%**
Penalties, sanctions	31-45%	1%
Penalties, sanctions -Total		**1%**
Career advancement opportunities	0-15%	2%
	16-30%	3%

	31-45%	1%
	Over 45%	2%
Career advancement opportunities – Total		**8%**
Non-material benefits	0-15%	3%
	16-30%	4%
Non-material benefits - Total		**7%**
Verbal praise, recognition	0-15%	18%
	16-30%	8%
	31-45%	3%
	Over 45%	1%
Verbal praise, recognition - Total		**30%**
TOTAL		**100%**

(Source: own editing based on primary data)

We can summarize that 54% of the SMEs use financial incentive as a motivational tool. 39% of these companies reported higher than 15% workforce fluctuation. It means that they fall into the higher category. The executives using financial incentive as a motivational tool have to face high workforce fluctuation.

The purpose of this study was to examine the efforts the companies make to prevent burnout. As it is known from collected data, 55% of the companies organize team building programs, however 4% of these companies organize team building as a necessary company occasion. We can sum up that 51% of the companies emphasize the importance of team building programs. The executives of the company used a 4-point Likert scale, where 1 is absolutely disagree and 4 is absolutely agree. The answers provided for individual statements are introduced in groups.

Table 5
Prevention of burnout syndrome (%)

Statement	*1*	*2*	*3*	*4*
Employee well-being is important (material and moral esteem)	6%		94%	
Work-life balance should be encouraged	11%		89%	
Employees must receive regular confirmation of their work	9%		91%	
All employees are aware of their role and responsibilities	6%		94%	
It is often that employees have to work overtime	58%		42%	
Employee satisfaction needs to be measured regularly (quarterly or semi-annually)	52%		48%	
The employees are motivated	14%		86%	

(Source: own editing based on primary data)

It can be summarized that 94% of the surveyed companies find important the employee well-being (financial and moral appreciation), while 89% of the companies agree with the supporting the work-life balance. The regular employee feedback is supported by 91% of the executives. 94% of the executive's agree that employees have to be aware of their tasks and responsibilities. 58% of the companies have no regular overtime. 48% of the executives conduct employee satisfaction survey on regular basis. 80% of the companies reported employee satisfaction.

Based on calculations of average and standard deviation, 76.38% of the companies introduce measures against burnout. The standard deviation (not the relative standard deviation) is high (18.95%).

In order to test our assumption, the H_0 Hypothesis was formulated, as an alternative we formulated H_1 hypothesis.

H_0: There is no significant correlation between the motivational tools used in SMEs and the prevention of burnout syndrome.

H_1: There is a significant correlation between the motivational tools used in SMEs and the prevention of burnout syndrome.

The Pearson Chi square table is used to show the correlation between the variables. The observed value of the indicator is 30.429. The value at two-tailed significance test is lower than 0.05. It means, that Hypothesis 0 – there is no significant correlation between the variables - can be rejected.

Table 6

Pearson's Chi-square Test

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	30.429	7	0.000
N of Valid Cases	431		

(Source: own editing based on primary data)

To analyze the strength of association between two nominal variables based on Pearson's Chi-square statistics we used Cramer V indicator.

Table 7

Value of Cramer V about the prevention of burnout syndrome

	Cramer V	Approx.Sig.
Prevention of burnout syndrome	0.159	0.000

(Source: own editing based on primary data)

According of value of Cramer V the association between the motivational tools used in SMEs and the prevention of burnout syndrome is greater than medium, so

we consider widespread use of motivation tools in SMEs, because they have a statistically significant positive effect on the prevention of burnout syndrome.

Conclusions

According to our study, the most difficult recruitment problem is hiring a motivated workforce. The general labor shortage was only the second problem indicated. Surprisingly, Executives are missing the appropriately motivated staff. We believe that the employees have to be motivated by the Executives, as it is very rare that SMEs own a brand similar to multinational companies, where the candidate is motivated by chance to work for a company with a well-known brand. Addressing the issue of motivation, it has also turned out that 54% of the employers still find financial incentive the most motivating tool. The employees are considered to be motivated and committed to company values (Likert scale). However, the companies using financial incentive as a motivation tool experience higher employee fluctuation.

Based on the obtained data about burnout syndrome, we can conclude that 76.38% of the surveyed companies address the issue of employee burnout. The achieved result is good despite a standard deviation of 18.95%. The scientific literature has reported a much poorer rate than the survey results. As the survey results show, 86% of the employees are at risk of burnout, since burnout is the disease of our moder civilization.

Workforce retention is still a serious problem for the SME sector. 68% of the companies fight with more than 15% workforce fluctuations, which can be a knowledged as a loss for the company. It is important the company Executives recognize appropriate motivational tools, the importance of atypical employment patterns and team building programs in order to become more competitive and profitable in the future.

In order to make practical suggestions based on the results of our research HR managers need to delve deeper into the characteristics of the different generations present in the labor market based on these their motivational factors. The aim of the present article is not to map the motivational factors in detail for different generations, but it can be generally stated that there are three major HR challenges connected with generational differences (attract and retain while working, the changing nature of work and careers and career achievement). [26] For Generation Y it is characteristic, that their promotion self-enhancement in terms of valuing money and promotion is also viewed as an advancement at the workplace, etc. Generation Z have been found to hold stronger similar and even the same values most prominently. [4]

The limitation of the research can basically be identified in the elements of the sample. In order to show more accurate results, it is necessary to increase the number of elements in the sample. In future research the aim will be to cover a detailed and more comprehensive study from the point of view of generations in

order to avoid burnout-syndrome. The problem can also be explored in terms of cultural differences.

References

[1] Belás, J. et al. (2014) Business risk and the level of entrepreneurial optimism of SMEs in the Czech and Slovak Republic. Journal of competitiveness, 2014, 6(2), pp. 30-41

[2] Belás, J.; Bilan, Y.; Demjan, V.; Sipko, J. (2015) Entrepreneurship in SME Segment: case study from the Czech Republic and Slovakia. Amfiteatru Economic. 2015, 17 (38), pp. 308-326

[3] Bertalan, P.; Boldizsár, B. (2015) Globális trendek és a HR. Acta Scientiarum Socialium. 2015, 44.(1), pp. 151-160

[4] Črešnar, R.; Nedelko, Z. (2020) Understanding Future Leadres: How Are Personal Values of Generations Y and Z Tailored to Leadership in Industry 4.0? Sustainability, 12, 4417, doi: 10.3390/su12114417

[5] Csehné, P. I. (2011) Foglalkoztatáspolitika. (Employment policy) [online] Szent István University. Available on the internet https://webcache.googleusercontent.com/search?q=cache:STTQCUJ0u5MJ:https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0019_foglalkoztataspolitika/2010-0019_foglalkoztataspolitika.pdf+&cd=1&hl=hu&ct=clnk&gl=hu

[6] Dobák, M. (2008) Szervezeti formák és vezetés. (Organizational forms and leadership) Akadémiai Kiadó (Publisher) 2008, 264 p

[7] Eccles, R. G.; Perkins, K. M.; Serafeim, G. (2012) How to Become a Sustainable Company. Mit Sloan Management Review. 2012, 53 (4), pp. 43-51

[8] Gašparíková, J.; Brzica, D.; Nemcová, E. (2004) The Impact of Industrial and Regional Differentiation on SMEs in Slovak Republic. Ekonomický časopis (Economic Journal), 2004, 52 (7), pp. 820-834

[9] Gravetter, J. F. – Wallnau, L. B. (2013) Statistics for the Behavioral Science, 9th Edition, Cengage Learning, 615 p.

[10] Ivanová, E. (2017) Barriers to the Development of SMEs in the Slovak Republic. Oeconomica Copernicana, 2017, 8 (2), pp. 255-272

[11] Kollár, Cs.: A munkahelyi kiégés (burnout szindróma) elméleti megközelítése, kutatási irányai és közgazdaságtudományi aspektusa. (Theoretical approach, research directions and economic aspects of burnout syndrome) Fluentum, 2014, 1 (3), pp. 1-19

[12] Kozubíková, L. et al. (2015) Personal characteristics of entreúreneursin the context of perceptions and management ob business risk in the SME segment. Economics & Sociology, 2015, 8 (1), pp. 41-54

[13] Lazíková, J.; Bandlerová, A.; Roháčiková, O.; Schwarcz, P.; Rumnovska, Ľ. (2018) Regional Disparities of Small and Medium Enterprises in Slovakia. Acta Polytechnica Hungarica, 2018, 15 (8)

[14] Lazányi, K. (2014) Entrepreneurs of the future. Serbian Journal of Management. 2014, 9 (2), pp.149-158, doi: 10.5937/sjm9-6257

[15] Lesáková, Ľ. (2009) Innovations in Small and Medium Enterprises in Slovakia. Acta Polytechnika Hungarica, 2009, 6 (3), pp. 23-34

[16] Lipták, K. (2009) Foglalkoztatáspolitika Magyarországon, különös tekintettel az időskorúak foglalkoztatására. (Employment policy in Hungary, with special regard to the employment of elderly) Észak-magyarországi Stratégiai Füzetek. (Northern Hungary Strategic Booklets) 2009, 6(1), pp. 3-16

[17] Maslach, C.; Goldberg, J. (1998) Prevention of Burnout: New Perspectives. Applied & Preventive Psychology, 7 (1), 63-74

[18] Maslow, A. (1954) Motivation and personality. Harper&Row. 1954, 411 p.

[19] Mura, L.; Ključnikov, A.; Tvaronavičiene, M.; Androniceanu, A. (2017) Development Trends in Human Resource Management in Small and Medium Enterprises in the Visegrad Group. Acta Polytechnica Hungarica, 2017, 14 (7)

[20] Nikodijevic, A.; Andelkovic Labrovic, J.; Dokovic, A. (2012) Academic Burnout Among Students at Faculty of Organizational Sciences. Journal for Theory and Managemet. 2012, 64, pp. 47-53, doi: 10.7595/management.fon.2012.0019

[21] Petrů, N.; Havlíček, K. (2017) Family Entrepreneurship in the Czech Republic on the Verge of First Generation Handover. Journal of International Studies. 2017, 10 (4), pp. 119-130, doi: 10.14254/2071-8330.2017/10-4/9

[22] Piac&Profit. (2015) Kiégtek, stresszesek a magyar munkavállalók. (The Hungarian workers are burned out and stressed) [online] Piac&Profit. 2015, Available on the internet: https://piacesprofit.hu/kkv_cegblog/ kiegtek-stresszesek-a-magyar-munkavallalok/

[23] Pink, D. H. (2009) Drive: The Surprising Truth About What Motivates Us. 1st edition. Riverhead Hardcover. 2009, 256 p.

[24] Rajnoha, R.; Dobrovič, J. (2016) The Globalization of Business Management in Slovac Companies. Proceeding of MANAGEMENT 2016: 6th International Scientific Conference on International Business and Management, Domestic Particularities and Emerging Markets in the Light of Research. Prešov, 2016, pp. 291-296

[25] Sebők, M. (2018) A munka világa a 21. század elején. (The world of work at the beginning of the 21st Century) Saxum Kiadó (Publisher) 2018, 431 p.

[26] S.W. Ng, E.; Parry, E. (2016) Multigenerational Research in Human Resource Management. In. Review in Personnel and Human Resources Management, pp. 1-41, ISBN 978-1-78635-264-4, doi: 10.1108/S0742-730120160000034008

[27] Tandari-Kovács, M. (2010) Érzelmi megterhelődés, lelki kiégés az egészségügyi dolgozók körében. (Emotional strain, mental burnout among healthcare workers) Doctoral dissertation. Semmelweis University 2010, 167 p.

People's Behavior, in the Context of Living Standards Changes and Sustainable Development, Exemplified by the Carpathian Euroregion

Yuriy Bilan[1], Katarzyna Chudy-Laskowska[2], Elżbieta Szczygieł[3], Teresa Piecuch[2]

[1] University of Social Sciences, 9 Sienkiewicza St., 90-113 Łódź, Poland; Sumy State University, Rymsʹkoho-Korsakova St, 2, Sumy, Ukraine, y.bilan@prz.edu.pl

[2] Rzeszów University of Technology, Faculty of Management, Department of Quantitative Methods, Department of Enterprise Management, 8 Powstańców Warszawy St. 35-959 Rzeszów, Poland, kacha877@prz.edu.pl, tpiecuch@prz.edu.pl

[3] Pedagogical University of Krakow, Faculty of Social Science, Institute of Law and Economics, Department of Entrepreneurship and Social Innovation, 2 Podchorążych St. 30-084 Kraków, Poland, elzbieta.szczygiel@up.krakow.pl

Abstract: This paper is an attempt to present changes of living standards, as an element of sustainable development. In the article, the authors present a literature review concerning the sustainable development concept and its dimensions, as well as, its linkage with the living standard concept (and broadly – with the quality of life category). The main goal is a statistical analysis of the living standards of the inhabitants of the Carpathian Euroregion, which was conducted using the data from the years 2008-2016. Within the analysis, the authors presented three groups (clusters) of regions belonging to Euroregion and analyzed the differences between them, as well as, the main factors responsible for belonging to the applicable group. In the article, three hypothesis were examined. Only two of them were confirmed (one in limited scope).

Keywords: people's behavior; living standard; quality of life; sustainable development; the Carpathian Euroregion

1 Introduction

Generally speaking, the living standard refers to the objective, material-living conditions of a given society. On the other hand, a subjective evaluation of people happiness coming from meeting various needs or state of satisfaction in different

areas of human life (e.g. social position, health, good education, various ways of spending free time etc.) refers to the quality of life. An important goal of sustainable development is to improve people's quality of life. There is a very strong relation between these categories. The higher living standard and – in effect – quality of life, results in paying more attention to climate or environment issues.

The lack of respect of sustainable development assumptions affects the large disproportions regarding the standard and quality of life. Only the meeting of sustainable development requirements (which means maintaining the balance between the economic, social and ecological dimensions) gives a guarantee of obtaining a higher standard and quality of life. Discussing these topics altogether makes the analysis more complex, it also draws attention to the well-being of the entire generation, living in particular historical circumstances (both poor and rich societies) with respect to natural resources and environmental requirements.

In the present paper, the standard of living was analyzed in the context of the sustainable development concept and was carried out for the Carpathian Euroregion. This area is highly diverse; therefore it creates a possibility to carry out a wide range of different research. A limited access to the data necessary for the analysis may be a problem, but nevertheless the research conducted can provide many interesting conclusions. The main thesis accepted in the paper stated as follows: socio-economic changes affect the similarity of areas within the Euroregion. In the analysis eleven indicators of the living standard were used. The analysis was carried out using chosen statistical methods: Cluster analysis (with Ward's method), Spearman's Rank correlation and Wilcoxon matched pairs test (for verification of the formulated hypotheses). The present analysis was conduct due to the fact, that the Carpathian Euroregion units the regions differing in many ways. The main aim of constitute the Carpathian Euroregion is to ensure the socio-economic development by supporting development processes in the field of territorial cooperation. The analysis of main factors influence on this process seems to crucial, but this subject is not so often taken into consideration (for ex. the number of scientific papers concerning the Carpathian Euroregion in *SCOPUS* database amount 13, while in *Web of Science* – only 8; in *Google Scholar* – 14). In 2023, the Carpathian Euroregion will celebrate the 30th anniversary of the uprising. It is needed, to deliver the consistent analysis of the development factors, influencing the selected parts of the Euroregion (regions) and allows for planning the strategical actions aiming at convergence of whole. The present analysis refers to the latter one, concerned with the standard of living of the Carpathian Euroregion's inhabitants [44], but now is expanded: the time span covers years 2008 and 2016, and the indicators have been divided into two groups.

2 The Quality of Life and Living Standard as an Element of Sustainable Development Concept – Literature Review

2.1 Sustainable Development as a Base for Activities Related with Increasing the Quality of Life

The most common definition of the sustainable development has been written in Brundtland Report [8]. It has stated that sustainable development is "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Although, these matters have been already discussed (ex. in Stockholm Declaration) [58], [33], the concept of sustainable development based on the Brundtland definition and - despite many inconsistencies [26] - is constantly developing. This positive undertone of that definition is more and more often replaced by the doubts regarding the possibilities of achieving it. As J. Stiglitz, A. Sen and J-P. Fitoussi have written [52]: *Sustainability poses the challenge of determining whether we can hope to see the current level of well-being at least maintained for future periods or future generations, or whether the most likely scenario is that it will decline.* Nevertheless, the attempts to achieve the sustainability of the economy (or wide-understanding – our development as the humanity) require the standardization of terms used during the discussion. Using this concept in a variety of contexts affects *limitation of its credibility, called into question its practical application and the significance of associated achievements and, overall, limited the progress in environmental and social developments which it was designed to underpin* [30], [11], [42]. It causes the need to define this concept every time when it is used, as well as operation, e.g. while carrying out the statistical analysis with the use of the set of the given indicators [2], [53]. Reviewing the definitions, one can state that the most often characteristic features appearing in the papers are: conserving resources for future generations [15], high environmental, economic and socio-cultural standards of living within the earth's endurance [50], [63] level of education and competencies [59], [62], social justice today and in the future [25], [26].

Most authors agree that the sustainable development has three dimensions (pillars): society (with a culture), environment and economy [6], [12], [13], [15], [19], [23], [38], [50][1]. These dimensions' merge and penetrate each other. The relations between them are different and depend on the dimensions, e.g. between

[1] It is worth noticing that some authors suggest other concepts, e.g. the relationship between human society and nature [19], [49] or using four dimensions (adding "institutional" [51], but we can assume that all of them are based on primary relation between "economic" and "environment" [37], [64].

"economy" and "environment" it should be *viable*, which means that the economic side of the development process concerns the humanity, and it should be conducted respectfully of the natural resources we have and use [61], [16]. Today's societies should not behave as the sole owners of the natural resources, but ought to think about future generations and their possibility to use them. The relation between "environment" and "society" should be *bearable*, which means that both aspects should be considered as equally important, without any preference or distinction. We could define the optimal relation between "economy" and "society" as *equitable*. Omission of any element affects that the development should not be *sustainable*, which implies a balanced development in economic, socio-cultural aspects without damaging environment [61]. These "pillars" approach allows to show the interconnection between the different spheres and - due to this - it is easy to understand the final effects. R. Emas [15] stated, that the main goal of sustainable development *is the long-term stability of the economy and environment through the integration and acknowledgement of economic, environmental, and social concerns throughout the decision making process.* It seems that the final receivers of all those efforts are people, and the same long-term stability in various aspects also guides other concepts, e.g. the quality of life [65]. Using different-time perspective in sustainable development activities caused taking into consideration the strength of the activities carried out. Similarly, as we can consider *weak* and *strong* sustainability [4], [15] or other variants [17], so we can think about different spheres of our life which should be improved. Sustainability development is perceived as *an unashamedly anthropocentric concept* [18], [33] because each of its element serves finally to an increase of the humans' well-being. This situation caused that each efforts for balanced improvement in the mentioned sustainable development's pillars should lead to increasing quality of life.

2.2 The Environmental Aspects in Quality of Life and Living Standard Measurement

Similarly, to sustainable development, the quality of life and related with it - standard living concept - are also categories without the common definition. We assume that quality of life has multi-dimensional character, which broadly encompasses how an individual measures the 'goodness' of multiple aspects [48], [56]. Intangible, immeasurable issues, which are related with the quality of life sphere, should be operated into objective measures (a set of indicators) [44]. However, this process is very difficult because the assessment of the quality of life is related with subjective categories, what causes that direct inter-personal comparison of this category is doubtful [54]. In effect, the comparison of objective categories is needed to apply. These categories include the living standards. Between the quality of life and the living standards there is an essential difference in character of the assessment (objective and subjective). This caused that the precision of measurement was very important and sometimes decided on the

quality of the results. However, to compare the living standard or – broader – the quality of life (whereas reservations described above), some indices are commonly used. We quote the two well-known ones: Human Development Index (HDI) and Quality of Life Index. Despite the usefulness, the critique of their structure and measure methods is broad [29], [41], especially as it concerns the single indices using for synthetic indicator's construction or areas taken into consideration. In the last case, in the subject literature one can observe more and more frequent underlying the environmental issues (or broad – sustainable development matters) which should be included into the construction of living standard's indicators [9], [31], [40], [45], [47]. The necessity of finding a new measurement of the living standard and quality of societies' life is emphasized by international organizations and especially scientists [35], [60]. In effect, there is a proposition of the Environmental Human Development Index, but it is not used so often in practice. Considering this, we have to underline that the direct assessment of living standard with relation to the sustainable development concept is very difficult and require an systematic operationalization of the appropriate indicators[2]. An example of an attempt of this approach in cross-border analysis of quality of life could be the research conduct by T. Borys, M. Kusterka-Jefmańska and the research team in 2012-2013 [5], [28]. They took into consideration the set of 6 different kinds of living satisfaction (with the state of: health, education, place of residence's safety, cultural and sports offer, financial and professional situation and with the place of residence) which were operated by using 43 detailed indicators (objective and subjective). The analysis was conducted on the base of direct interviews with 873 inhabitants of the district of Zgorzelec and the district of Görlitz. The most important factors influenced on the overall living satisfaction were the following: 1) on the Polish side - the satisfaction with the place of residence, with the financial and professional situation and with the state of health; 2) while on the German side of the bord - with the financial and professional situation and with education [28]. Among the detailed indicators used in this research and related with the environmental aspects influenced on quality of life and standard of living were: (1) access and condition of green areas, (2) image of the place of residence (cleanliness, aesthetics, etc.), (3) quality of drinking water, (4) waste management, (5) quality of the air, (6) state of the acoustic climate, (7) the ability to move around by bicycle or (8) by public transport. Here, worthy of underlining, the results of the research required the conducting of interviews and were not based on the public statistics data, what affects that the cyclical nature of such research depends only on the researchers' capabilities (without them it is impossible to compare the changes taking place). In other study conducted by A. Matušková, J. Preis and M. Rousová in selected Euroregions [32] the environmental aspects of quality of life was taken into consideration only cursorily, without conducting the detailed analysis. Based on this we could

[2] For conducting in-depth analysis of relation between quality of life and environmental problems could be used various sets of them, ex. [55].

conclude, that environmental factors, are not so often analyzed in the cross-border research and therein is observed, an analytical gap for future surveys.

3 Research Assumptions and Data Used to Analyze

3.1 The Limitation for Data Access

The area covered by the analysis is the Carpathian Euroregion. It was established in 1993 by the decision of representatives of cross-border regional authorities of four countries: Poland (Podkarpackie region), Ukraine (Chernivets'ka oblast', Ivano-Frankivs'ka oblast', L'vivs'ka oblast' and Zakarpats'ka oblast'), Slovakia (Východné Slovensko) and Hungary (Észak-Alföld and Észak-Magyarország). In 1997 Romania joined the Eurergion (Centru, Nord-Est, Nord-Vest). The Euroregion is very diverse in many ways, and therefore – it is cognitively a very interesting area. The analysis of that kind of territory poses a lot of problems. In many cases, there is a lack of comparable data characterized the socio-economic situation on similar level of aggregation [46]. The Euroregion consists of the area both being a part of European Union (Hungary, Poland, Slovakia, Romania) as well as not belonging one (Ukraine). It makes impossible to obtain comparable data for the whole area, inter alia due to the different statistical standards of collecting data, lack of regional data, different requirements for elaborated reports or analyses, etc. The problem also results from different administrative divisions in each country and - in effect - different levels of areas includes of the Euroregion (most often the obligation to prepare the socio-economic reports lies on the equivalent of Polish voivodeships, and the Euroregion often consists of only fragments, e.g. part of the Central region and part of the Nord-Est region in Romania, so the data concerns the whole region, not the appropriate part only). It should be emphasized that the collection of data that concerns the Euroregion is periodically. In effect, there is a lack of data between the years 2017 and 2020. The last available comes from 2016, and next is supposed in 2021 (the data are collecting every four years). All this makes it difficult or - in some areas - even impossible to conduct an analysis, direct comparisons or propose the recommendations. It also negatively implies on elaboration of specific tools aimed at convergence, and limit the disparities between the regions. *Only reliable and harmonized data allow for the creation of real economic and social programs for the development of euroregions* [34].

The present work concerns spatial living standards. The literature on the subject underlines that in that kind of analysis even a several dozen indicators, grouped in appropriate categories, are used [1], [3], [14], [22], [36]. In the present paper we have collected 11 indices. It probably does not fully reflect the diversity of the area studied, but it allowed conducting the statistical analysis and gave the

opportunity to formulate interesting conclusions. The analysis undertaken concerns living standard in the context of sustainable development, but this aspect appeared also problematic due to the lack of environmental data coming from the whole Euroregion area. For years' environmental aspects have been considered as the most complicated and problematic in the analysis of euroregions [34]. They were not included in the conducted analysis and the attention was paid to economic and social aspects such as two dimensions of sustainable development. Bearing in mind the previous comments (especially in the field of analysis of environmental aspects in cross-border surveys), for the future analysis we postulate to add a set of environmental indicators to public statistics surveys which allows to assess the sustainable development the Carpathian Euroregion in coherent way. It will require to choose the appropriate ones and accept them by the Steering Committee of National Statistics Offices responsible for delivering data concerning the Carpathian Euroregion, but in our opinion ensuring the providing the sustainable development data will be needed in nearest future due to the increasing the interest of this subject[3] and the acceptance of the strategical dimension of this concept by the each countries.

3.2 The Research Design

The area covered by the analysis is the Carpathian Euroregion. The main thesis assumed in the article is the following: socio-economic changes affect the similarity of areas within the Euroregion. On this basis three hypothesis were accepted for testing:

- H_1 - The most important changes were observed in social area.
- H_2 - The changes observed in economic area are significant for development of the Euroregion.
- H_3 - The changes observed in economic area influence the social area.

To analyze the changes in the development process of the Carpathian Euroregion one of the cluster analysis – a multivariate comparative analysis method – was used. This method was described by Tryon [57] and developed by Cattell [10]. It allows dividing the units analyzed (the regions in the present paper) into similarly groups (clusters) based on multiple features. This statistical procedure leads to the extraction of a full hierarchy of clusters with a monotonically increasing level of similarity. The obtained, higher-order groups contain disjoint lower-level groups. In this kind of methods, each unit (a single element of a group) is initially a separate group, and then the number of existing groups is successively reduced, sequentially by joining them into higher-order groups. The procedure is completed when one group includes all analyzed units. The main advantage is the possibility

[3] For example in "Acta Polytechnica Hungarica" some Authors took up topics related to environmental aspects [7], [24], [39].

to present the classification results in a compact graphic form using a connection tree (dendrogram), which illustrates subsequent connections of higher and higher order groups [20], [21]. In the present analysis, we use Ward's method (based on the analysis of variance approach) [21]. In this method, the sum of squared deviations of any two clusters (at each stage of the analysis) is minimized. Besides the multivariate analysis, it is also important to analyze the structure of each separated cluster, which allows to obtain information about what features decided to create individual clusters. In this context, the effective procedure is the arithmetic means method that consists of the following stages:

- Matrix calculation for the entire output of the arithmetic means of the following characteristics (x_i),
- Calculation of arithmetical means for each clusters (x_n),
- Calculation of structural ratio of each cluster which is given by quotient:

$$\frac{x_n}{x_i} \tag{1}$$

The verification of the assumed hypothesis was conducted using Wilcoxon matched pairs test, which allows to testify whether the level of analyzed variable changes in regions between two periods of time.

The last method that was used for the hypothesis verification is Spearman's Rank correlation coefficient, which takes values from the range between (-1) and (1). An interpretation of the coefficient is similar to Pearson's correlation coefficient, but Spearman's Rank correlation coefficient shows any monotonic relationship (also non-linear). The higher the value of the correlation coefficient, the greater the relationship between the variables. If the value is close to 0, it means that there are no dependencies between them.

4 An Analysis of Spatial Diversity of Living Standards in the Carpathian Euroregion

For the study of living standards in the Carpathian Euroregion, 11 diagnostic variables were selected ([E] – means variables concern "economic" area and [S] – "social" area):

x_1 - natural increase per 1000 population [S]

x_2 - dwellings completed per 1000 population [S]

x_3 - students of higher education institutions per 10 thousand population [S]

x_4 - doctors per 10 thousand population [S]

x_5 - beds in general hospitals per 10 thousand population [S]

x_6 - tourists accommodated totally per 1000 population [S]

x_7 - gross domestic expenditures on R&D activity in % of GDP [E]

x_8 - Gross Domestic Product *per capita* in euro [E]

x_9 - ascertained crimes per 1000 population [S]

x_{10} - employment rate [E]

x_{11} - unemployment rate [E]

The availability of variables was accounted for the above choice. The analysis was carried out twice: for the year 2008 and 2016. Using descriptive statistics, the variables used for the study were characterized. Thanks to non-parametric Wilcoxon matched pairs test it was checked whether the accepted for the research features statistically significantly differed in levels during the analyzed period of time (Table 1; ***p**** - statistically significant difference; $p<0.05$).

Table 1

The basic descriptive statistics of the examined diagnostic variables

	2008			2016			
Var.	$(\bar{x} \pm \sigma)$	V_z	K	$(\bar{x} \pm \sigma)$	V_z	K	p
x_1	(-0.4±2.2)	-504.9	-0.4	(-1.3±1.9)	-151.4	1.5	**0.0293***
x_2	(2.8±0.9)	33.7	2.2	(2.3±1.2)	50.4	-0.6	0.1095
x_3	(365±126)	34.6	3.4	(259±100)	38.6	1.9	**0.0033***
x_4	(35.7±16.5)	46.2	-1.5	(38.2±14.5)	38.0	-1.1	**0.0468***
x_5	(74.6±15.7)	21.0	-0.3	(68.9±10.1)	14.6	0.8	0.1095
x_6	(314.5±213.4)	67.9	-1.1	(511.8±309.3)	60.4	-0.2	**0.0033***
x_7	(0.4±0.2)	56.2	1.0	(0.5±0.4)	75.2	04	0.3739
x_8	(4129±2356)	57.1	-2.0	(5172±3396)	65.7	-1.6	**0.0408***
x_9	(15.9±13.9)	87.2	1.4	(14.1±5.6)	40.0	-0.6	0.8588
x_{10}	(51.6±5.3)	10.3	-1.1	(53.5±3.3)	6.1	04	0.3065
x_{11}	(8.5±3.2)	37.4	-0.7	(7.8±2.9)	37.4	-0.1	0.7213

Note: $\bar{x}$ – mean , σ – standard deviation, V_z – variance coefficient, K – kutrtosis coefficient

Source: own calculations

An average natural increase rate in the analyzed regions has negative values in both periods. Comparing these two values, we can state that the value has decreased and the difference is statistically significant $p<\alpha$, (p=0.0293). In 2008 the smallest values were recorded in Hungary, in Észak-Magyarország (-4.1), and the highest in Slovakia - Východné Slovensko (3.4). Similarly, the extreme values were observed in the same regions in 2016 (-4.2 and 3.0). In 2008, the coefficient of variation of natural increase was very high (-504.9%), what indicates significant variation and is additionally confirmed by the negative value of kurtosis. In 2016, the coefficient of variation decreased (151%) and kurtosis changed the sign on positive, which means that the natural increase rates in the

analyzed regions were more homogeneous. In most regions, the natural increase rate decreases, although in recent years there has been a slight increase in three regions: Východné Slovensko, Podkarpacie, Nord-West.

An analysis of the number of dwellings completed per 1000 population indicates that in year 2008, on average 3 dwellings per one thousand were completed while in 2016 only 2. The highest value of the indicator was recorded: in 2008 in Romania, in Nord-Vest region (5.0) and in 2016 in Poland, in Podkarackie region (4.0); the lowest value was recorded in Hungry in Észak-Magyarország region: (1.5) in 2008 and (0.3) in 2016. The large diversity was observed in 2016, which is evidenced by the high value of coefficient of variation and kurtosis. The conducted test shows that the changes in the indicator level were not statistically significant (p = 0.1095).

An average level of higher education students in 2008 amounted to 365 persons (per 10 thousand population) while in 2016 it decreased to the level of 259. The highest values were recorded in both years in Ukraine, in L'vivs'ka oblast' (accordingly: 679 and 493 persons). In 2008 the smallest value was noticed in Romania, in Nord-Est region (171) while in 2016 – in Hungary, in Észak-Alföld (151). The diversity between the regions increased in 2016 (in relation to the year 2008), which is evidenced by the high value of coefficient of variation and kurtosis. The was statistically significant difference between the values of indicator (p=0.30033).

The next two variables concern the health care. Average number of doctors (per 10 thousand population) increased from 35.7 in 2008 to 38.2 in 2016. Larger diversity concerned this indicator was placed in 2008, later the data were more coherent. The smallest numbers of doctors were observed both in 2008 and in 2016 in Poland in Podkarpackie region (18.1 and 21.3), while the highest was observed in Ukraine, in 2008 in Chernivets'ka oblast' (61.8) and in Ivano-Frankivs'ka oblast' (60,9). The three Ukrainian regions: Chernivets'ka oblast', Ivano-Frankivs'ka oblast' and L'vivs'ka oblast' stand out definitely. During the analyzed period, the lowest values were observed in Podkarpackie region and in Romanian Nord-Vest region. The difference between number of doctors was statistically significant $p<\alpha$ (p=0.0468).

The second variable that concerns the health care is the number of beds in general hospitals per 10 thousand population. The analysis indicates that this variable was changed significantly in the analyzed period $p>\alpha$ (p=0.1059). The average amount of the indicator decreased in the analyzed period from 74.6 (2008) to 68.9 (2016). The lowest values were observed in Poland, in Podkarpackie (accordingly: 46.6 in 2008 and 48.6 in 2016) and the highest ones were observed in Ukraine, in Lvovska oblast (accordingly: 99.1 and 86.2). The diversity of the variable values decreased and the data became more homogeneous.

The variable responsible for the popularity of the region is the number of tourists accommodated totally per 1000 population. It testifies about public interests of the

region, which can lead to an increase in the investment rate. An analysis shows that the increase that took place is statistically significant $p<\alpha$ (p=0.0033). The indicator increased in the analyzed period from 314.5 persons on 1000 population in 2008 to 511.8 persons in 2016. The least frequented by tourists region is Chernivets'ka oblast' in Ukraine (the rate of analyzed indicator amounted accordingly: in 2008 – 81 people per 1000 population and in 2016 - 120 people per 1000 population). Most people used accommodation in 2008 in the Slovak region - Východné Slovensko (693) and in 2016 in Romania in the Centru region (1108 people per 1000 population). There is also the most aggressive increasing of the studied indicator.

The difference between the level of expenditures on R&D were not statistically significant in the analyzed period $p>\alpha$ (p=0.3739). An overall amount of expenditures for all regions increased slightly (from 0.4% in 2008 to 0.5% in 2016). The differentiation (disparities) between the level of indicator for each region increased. In 2008, the lowest value was observed in Romanian Centru region (0.15%), while in 2016 in Ukrainian Ivano-Frankivs'ka oblast' (0.09%). The highest level of expenditures were observed in Ukrainian L'vivs'ka oblast' and in Hungarian Észak-Alföld region (both 0.86%), while in 2016 in Poland, in Podkarpackie region (1.29%).

One of the most frequently analyzed indicators that reflects the level of development of a given country or region is Gross Domestic Product *per capita*. Within the test, the statistical signification of the difference between the level of the analyzed variable was examined. The test showed a significant increase in GDP in the analyzed regions $p<\alpha$ (p=0.0408) from € 4129 in 2008 to € 5172 in 2016. The highest values of GDP *per capita* were observed in Slovak in Východné Slovensko region (accordingly: € 6900 in 2008 and € 10200 in 2016). The lowest – in Ukrainian Chernivets'ka oblast' (accordingly: € 1065 and € 839). The disparities in the surveyed regions in terms of GDP *per capita* increased significantly. Východné Slovensko region definitely stands out from the rest of the analyzed regions both in the level and the growth rate of the examined indicator.

The level of citizen security affecting the living standard was characterized by the indicator on ascertained crimes per 1000 population. The changes in the average level of examined indicator were not statistically significant (p=0.8588). The average number of crimes decreased slightly from 15.9 in 2008 to 14.1 in 2016. The differentiation in the group of regions decreased. The highest number of crimes were ascertained in 2008 in Hungary in Észak-Alföld region (46.3) and in 2016 in Észak-Magyarország (23.8). The lowest number of assertion of the crimes took place in Ukrainian Ivano-Frankivs'ka oblast' (accordingly: 3.8 and 7.2).

The last two variables concern the labor market. The first one is an employment rate and the second one – an unemployment rate. Changes of both variables are not statistically significant. In relation to the employment rate, there was a slight increase in the average level (from 51.6 in 2008 to 53.5 in 2016). However, the

variation between regions decreased. The highest rates of employment were observed in Ukrainian Zakarpats'ka oblast' (59.9) in 2008, and Romanian Nord Est region (58.7) in 2016. The lowest rates were noticed in Hungarian Észak-Magyarország region (43.7) in 2008 and Romanian Centru (47.0) in 2016. Two Hungarian regions are definitely standing out. An increase of the employment rate was significant. These regions changed the ranking position from the last one in 2008 to the middle one in 2016. The unemployment rate increased between 2008 and 2012, then the rate decreased. The average level of this indicator amounted 8.5% (2008) and 7.8% (2016). The unemployment rate was the lowest in two Romanian regions: Nord-Vest and Nord-Est and the highest in Slovak in Východné Slovensko. The differentiation between regions has not changed.

From 11 chosen variables, only five were statistically significant, four out of them were related with "social" area and only one – with "economic". We can state, that the most important changes were observed in "social" area, and *ipso facto* – the first hypothesis (H_1) was confirmed for analyzed period of time. Due to this, the second hypothesis (H_2) should be rejected.

5 The Attempt to Assess the Living Standard in the Carpathian Euroregion in the Analyzed Period of Time

Between variables, used for conducting the analysis of living standard, the correlation coefficients were calculated in purpose to check possible dependencies between them and possible removal of those which show high linear correlation. We use data from extreme years: the first (2008) and the last one (2016). Some dependencies changed the direction as in the case of the unemployment rate and the natural increase rate per 1000 population. In 2008, the correlation coefficient amounted (-0.25) but in year 2016 – (0.76). The strength of the dependencies decreased (e.g. between the unemployment rate and tourists accommodated per 1000 population, from 0.57 in 2008 to (-0.08) in 2016. In result of the correlation analysis, we can state that there are no reasons to remove any of the variable adopted for the study. Depending on the studied period, they take different values.

Bag Plots show high dependencies between the unemployment rate and ascertained crimes per 1000 population and the employment rate (Figure 1). It is possible to observe that the strength and the direction of dependencies in two analyzed years changed significantly.

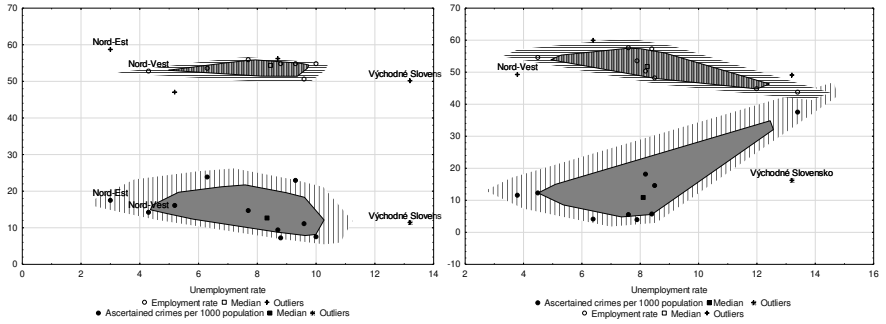


Figure 1

Relations between the unemployment rate (x_{11}) and the rate of ascertained crimes per 1000 population (x_9) and the employment rate (x_{10}) in 2008 and 2016

Source: own elaboration

The studied areas of the Carpathian Euroregion were subjected to the grouping procedure using the Ward's method to isolate the groups of regions similar to each other in terms of diagnostic features (selected for testing). The results of the grouping are presented in Figure 2 and Table 3.

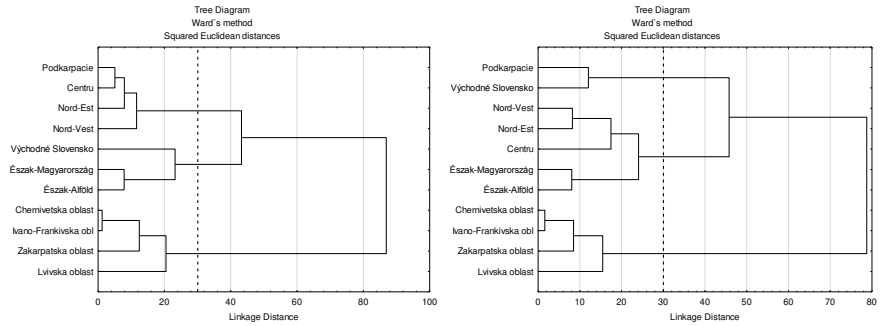


Figure 2

Tree diagram – Ward's Method for clusters in 2008 and 2016

Source: own elaboration

Both, in 2008 and 2016, three groups of regions similar to each other in the scope of the inhabitants' living standard were identified (with the use of the characteristics selected for the research). The first two groups changed the number of regions, while the third group remained unchanged. In 2008, the region from Poland (Podkarpackie) was similar to the Romanian regions (Centru, Nort-Vest, Nord-Est) while in 2016 only the region from Poland and Slovakia (Východné Slovensko) formed one cluster, while the Romanian regions merged with the Hungarian ones (Table 2).

Table 2

The assignment of regions to the appropriate group (for year 2008 and year 2016)

Gr.	2008 - Country: Region	Gr.	2016 - Country: Region
A	PL: Podkarpacie, RO: Centru, Nord-Vest, Nord-Est	**A**	PL: Podkarpacie SK: Východné Slovensko
B	HU: Észak-Magyarország, Észak-Alföld SK: Východné Slovensko	**B**	RO: Nord-Vest, Nord-Est, Centru HU: Észak-Alföld, Észak-Magyarország
C	UKR: Zakarpats'ka oblast', Chernivets'ka oblast', Ivano-Frankivs'ka oblast', L'vivs'ka oblast'	**C**	UKR: Zakarpats'ka oblast', Chernivets'ka oblast', Ivano-Frankivs'ka oblast', L'vivs'ka oblast'

Source: own elaboration

For the separated clusters, an analysis of group averages was carried out in purpose to check which variables determined the resulting clusters (Table 3 and Figure 3).

Table 3

Dominant variables in each group for year 2008

Year	A	B	C
	The highest value of variable		
2008	x_1, x_2	x_6, x_7, x_8, x_9, x_{11}	x_3, x_4, x_5, x_{10}
2016	x_1, x_2 , x_7, x_8, x_{11}	x_6, x_9	x_3, x_4, x_5, x_{10}
	The lowest value of variable		
2008	x_4, x_5, x_7, x_{11}	x_1, x_2, x_3, x_{10}	x_6, x_8, x_9
2016	x_3, x_4, x_5, x_{10}	x_1, x_2, x_{11}	x_6, x_7, x_8, x_9

Source: own elaboration

In 2008, the "A" group included the areas from Poland and Romania. They were characterized by high rates of: natural increase (x_1), dwellings completed per 1000 population (x_2). The lowest values were assumed here by indicators regarding: R&D expenditures (x_7) and unemployment (x_{11}), as well as the indictors related with health care [numbers of doctors (x_4) and numbers of beds in hospitals (x_5), both per 10 thousand. population). The levels of analyzed indicators for all clusters are shown in Figure 3. In 2016, the "A" group included Podkarpackie and Východné Slovensko. These regions were characterized by the highest rate of natural increase (x_1) and dwellings completed per 1000 population (x_2). The highest were also expenditures on R&D (x_7) and GDP *per capita* (x_8). Unfortunately, the rate of unemployment (x_{11}) was also high, as well as the condition of health care was bad [number of doctors (x_4) and beds in general hospitals per 10 thousand population (x_5) were very low]. Also, the employment rate (x_{10}) and the number students of higher education institutions (x_3) were low.

In 2008, in the group "B" there are two Hungarian and one Slovakian regions. These areas were characterized by a very low rate of natural increase (x_1), the fewest number of flats given for use (x_2), number of students (x_3) and the

employment rate (x_{10}) was the lowest from all the analyzed factors. The most significant indicators (the highest values) were that of tourists accommodated total per 1000 population (x_6), R&D expenditure (x_7), GDP *per capita* (x_8) and ascertained crimes (x_9). Unfortunately, the unemployment rate (x_{11}) also took the highest value. In 2016, in "B" cluster there were Hungarian and Romanian regions. These areas had the highest values of tourists accommodated total per 1000 population (x_6) and ascertained crimes (x_9). Whereas, on the lowest level was a natural increase (x_1) and dwellings completed (x_2). The unemployment rate (x_{11}) was also the lowest in these regions.

In 2008, the "C" cluster was composed of Ukrainian regions. These areas were characterized by a negative natural increase rate (x_1), the lowest value of GDP *per capita* (x_8), as well as the lowest value of ascertained crimes (x_9). On the other hands the indictors related to health care took the highest values (x_4, x_5), as well as students of higher education institutions (x_3) and the employment rate (x_{10}). The analysis conducted for the year 2016 confirmed the uniformity of Ukrainian regions that still stick together. The health care indicators (x_4, x_5) were one of the highest, together with the number of students (x_3) and – the highest among all clusters – the employment rate (x_{10}). The lowest values of indicators were observed for accommodated tourists (x_6), expenditures on R&D (x_7) and GDP *per capita* (x_8). In that regions also the number of ascertained crimes (x_9) were the lowest.

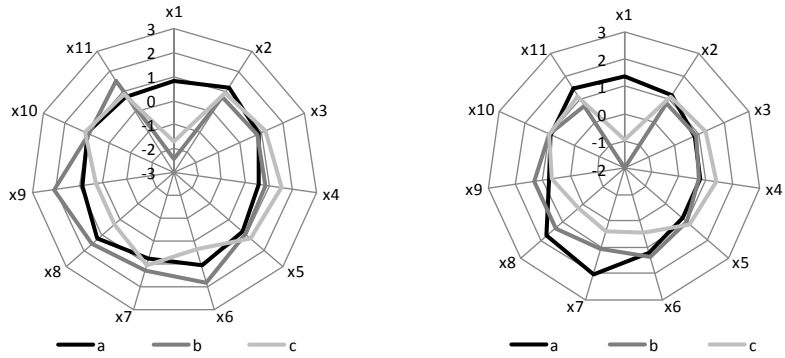


Figure 3
The indicators of group averages in analyzed clusters

Source: own elaboration

Using Spearman's Rank correlation, the existence of relation between "social" and "economic" area was verified. Based on the variables used within the present analysis, the new synthetic variables were formulated: one for "economic" matters and the other one – for "social". The synthetic variable indicator ranges from 0 to 1. The high value of that indicator, the higher level of "social" or "economic" area. The analysis indicated, that in 2008 the Spearpman's Rank correlation coefficient (R_S) was not statistically significant $p>\alpha$ (p=0.7495) and the value

amounted R_S=0.11, which means the lack of any relation between synthetic variables. Whereas in 2016, the coefficient amounted R_S= (-0.71) and was statistically significant $p<\alpha$ (p=0.0352). Since the dependence is negative, as the level in the economic area increases, the value of the indicator in the social area decreases (Figure 4).

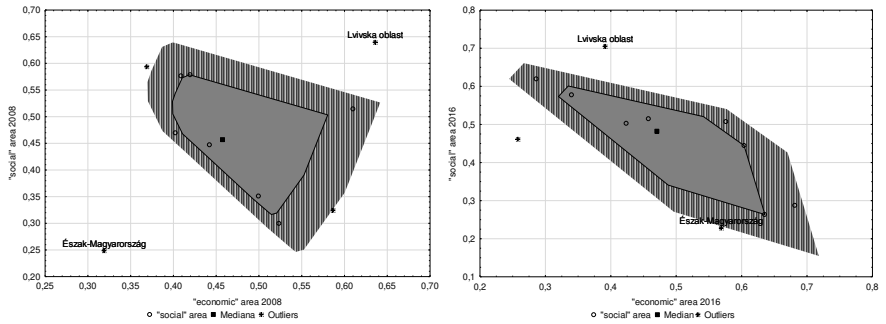


Figure 4

The relations between "economic" and "social" area in 2008 and 2016

Source: own elaboration

As the result the third hypothesis (H_3) was not confirmed for the analysis of the year 2008, but the assumed dependence was confirmed for the year 2016. To confirm whether this dependence is indeed permanent, the analysis for the next periods is needed (e.g. for year 2020 what could be a contribution to further research).

Conclusions

This study presents an analysis of the spatial diversity of the living standards of the inhabitants of the Carpathian Euroregion, comparing two periods of 2008 and 2016 in the context of sustainable development. However, this article is the second one that is concerned with the subject of the living standard of the Carpathian Euroregion's inhabitants [44], however, we take into consideration the sustainability elements and consider the linkages between them. The analysis, both theoretical (based on the subject's literature) and empirical (with using the statistical data) allows us to state that there is a need to deepen the consideration concerning sustainable development and quality of life, as well as, the linkage between them. These two immeasurable categories, with a broad definition (and ways to understand) require preparation of a coherent proposition of the measurement method. Actually, we could only observe (finally draw the conclusion) a limited number of aspects related with the categories mentioned. Based on the example, which refers to our assumed hypothesis, we could state that for the Euroregion's development, the "social" area is more important than the "economic" one, and – what could be surprising – the "economic" sphere could have a negative influence on the "social" one. Our considerations concerned, also,

the need of using the environmental aspects and the limitations for data access. These elements probably will require preparation of a new methodology of measurement (including collecting and aggregation of the data), but in our opinion, it is needed, to conduct a wide range analysis. Conducting a common development policy requires using a common base (e.g. definitions, data, reports, etc.). Proposition of adequate improvements should lead to the development of the area, but it is impossible to achieve without a coherent framework. An increase of the living standard is a common goal for all societies, despite the borders (both Country or EU). We hope that our analysis will be taken as a suggestion, to make an effort, aiming at elaboration of an appropriate set of indicators, describing our development in the context of sustainability.

Acknowledgments

This research was co-funded by the grants from the Ministry of Education and Science of Ukraine (No 0120U102002, No0120U102001).

References

[1] Alborz A.: The Nature of Quality of Life: A Conceptual Model to Inform Assessment, Journal of Policy and Practice in Intellectual Disabilities, 2017, 14(1): 15-30

[2] Barrera-Roldán A., Saldívar-Valdés A.: Proposal and application of a Sustainable Development Index, Ecological Indicators, 2002, 2: 251-256

[3] Biagi B., Ladu M. G., Meleddu M., Royuela V.: Tourism and the city: The impact on residents' quality of life, International Journal of Tourism Research, 2020, 22(2): 168-181

[4] Beckerman W.: Sustainable Development: Is it a Useful Concept?, Environmental Values, 1994, 3(3): 191-209

[5] Borys T., Knippschild R. (eds): Jakość życia w obszarze przygranicznym - wzmocnienie ponadgranicznych przepływów dla wspólnego zrównoważonego rozwoju i planowania regionalnego, Ad Rem, Jelenia Góra, 2014

[6] Brown, B. J., Hanson, M. E., Liverman, D. M., Merideth R. W. Jr.: Global sustainability: Toward definition. Environmental Management, 1987, 11: 713-719

[7] Brożyna J., Mentel G., Szetela B., Renevable Energy and Economic Development in the European Union. Acta Polytechnica Hungarica, 2017, 14(7): 11-34

[8] Brundtland G. H.: Our Common Future. Report of the World Commission on Environment and Development, United Nations, 1987

[9] Busato F., Maccari N.: The Environmental Human Development Index, Rivista di Studi Sulla Sostenibilita', 2016, 14: 31-44

[10] Cattell R. A.: Note on correlation clusters and cluster search methods, Psychonometrica, 9, 1944, pp. 169-184

[11] Ciegis R., Ramanauskiene J., Martinkus B., The Concept of Sustainable Development and its Use for Sustainability Scenarios, Inzinerine Ekonomika-Engineering Economics, 2009, 62(2): 28-37

[12] Constantinescu A., Platon V.: Sustainable development paradigm – synopsis, Annals of the University of Oradea, Economic Science Series, 2014, 23(1): 116-124

[13] Diaz- Sarachaga J. M., Jato- Espino D., Castro- Fresno D.: Is the Sustainable Development Goals (SDG) index an adequate framework to measure the progress of the 2030 Agenda?, Sustainable Development, 2018, 26: 663-671

[14] Dziubińska-Michalewicz M.: Wybrane wskaźniki poziomu życia - analiza porównawcza Polski i RFN, Kancelaria Sejmu, 2002, 895

[15] Emas R.: The Concept of Sustainable Development: Definition and Defining Principles, GDRS report 2015, Florida International University 2015

[16] Fyliuk, H., Honchar, I., & Kolosha, V.: The Interrelation between Economic Growth and National Economic Competitiveness: The Case of Ukraine. Journal of Competitiveness, 2019, 11(3): 53-69

[17] Fiedor B., Czaja S., Graczyk A., Jakubczak Z.: Podstawy ekonomii środowiska i zasobów naturalnych, C. H. Beck, Warsaw 2002

[18] Gibson R. B.: Sustainability assessment: basic components of a practical approach, Impact Assessment and Project Appraisal, 2006, 24(3): 170-182

[19] Giddings B., Hopwood B., O'Brien G.: Environment, economy and society: fitting them together into sustainable development, Sustainable Development, 2002, 10: 187-196

[20] Ginevicius, R.: Quantitative Assessment of the Compatibility of the Development of Socioeconomic Systems. Journal of Competitiveness, 2019, 11(2): 36-50

[21] Grabiński T.: Metody taksonometrii, Publisher of the Cracow University of Economics, Cracov 1992

[22] Hancock S., Wells Y.: The change in quality of life for older Australians: A rural and urban comparison, Australian Journal of Rural Health, 2019, 27

[23] Hansmann R., Mieg H. A., Frischknecht P.: Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability, International Journal of Sustainable Development & World Ecology, 2012, 19(5): 451-459

[24] Hrbáčková L., Stojanović A., Tuček D., Hrušecká D., Environmental Aspects of Product Life Cycle Management and Purchasing Logistics: Current Situation in Large and Medium-Sized Czech Manufacturing Companies. Acta Polytechnica Hungarica, 2019, 16(7): 79-94

[25] Hope J.: Globalising sustainable development: Decolonial disruptions and environmental justice in Bolivia, Area, 2020 (Early View):1-9

[26] Hopwood B., Mellor M., O'Brien G.: Sustainable development: mapping different approaches, Sustainable Development, 2005, 13: 38-52

[27] Johnston P., Everard M., Santillo D., Robèrt K. H.: Reclaiming the definition of sustainability. Environmental Science and Pollution Research International, 2007, 14(1): 60-66

[28] Kusterka-Jefmańska M., Determinanty jakości życia w kontekście badań transgranicznych. Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania, Uniwersytet Szczeciński, 2015, 40(2): 251-261

[29] Kovacevic M.: Review of HDI Critiques and Potential Improvements. Human Development Research Paper, 2010, 33

[30] Lee K.: Global sustainable development: its intellectual and historical roots. *In* Global Sustainable Development in the 21st Century, Lee K., Holland A., McNeill D. (eds), Edinburgh University Press, Edinburgh 2000: 31-47

[31] Maccari N.: Environmental sustainability and Human Development: a greening of Human Development, Working Paper available at SSRN, 2014

[32] Matušková A., Preis J., Rousová M., Quality of Life and Cross-Border Relations in Selected Czech Euroregions, *In* T. Havlíček et al. (eds.), Borders in Central Europe After the Schengen Agreement, Springer 2018: 179-196

[33] Meadows D., Meadows D., Randers J., Behrens W.W.: The limits to growth, Universe Books, New York 1972

[34] Metodyczne i praktyczne problemy statystyki Euroregionów, Statistics Poland, Warsaw-Jelenia Góra 1994

[35] Migała-Warchoł A., Szczygieł E.: Classification of the European Union countries with an application of the modified Human Development Index, SGEM2018 Conference Proceedings, 2018, 5(3.3): 87-94

[36] Migała-Warchoł A.: Ocena zróżnicowania poziomu życia mieszkańców województwa podkarpackiego, *In* Metody Ilościowe w Badaniach Ekonomicznych, 2010, XI/2: 222-321

[37] Munasinghe M.: Environmental Issues and economic Decisions in Developing Countries, World Development, 1993, 21(11): 1720-1748

[38] Murphy K.: The social pillar of sustainable development: a literature review and framework for policy analysis, Sustainability, 2012, 8(1): 15-29

[39] Németh-Katona J., Biologically Qualified Environment, Ecologically Evaluated Conditions. Acta Polytechnica Hungarica, 2008, 5(3): 101-104

[40] Neumayer E.: The human development index and sustainability - a constructive proposal, Ecological Economics, 2001, 39: 101-114

[41] Noorbakhsh F.: The Human Development Index: some technical issues and alternative indices, Journal of International Development, 1998, 10: 589-605

[42] Phillis Y.A., Andriantiatsaholiniaina L.: Sustainability: an ill-defined concept and its assessment using fuzzy logic, Ecological Economics, 2001, 37(3): 435-456

[43] Piecuch T., Chudy-Laskowska K.: Jakość życia przedsiębiorców ze szczególnym uwzględnieniem kobiet prowadzących działalność gospodarczą, Studia i Materiały. Miscellanea Oeconomicae, 2007, 21(3): 343-354

[44] Piecuch T., Chudy-Laskowska K., Szczygieł E.: The living standard of the inhabitants of the Carpathian Euroregion, Production Management and Business Development, B. Mihalčová, P. Szaryszová, L. Štofová, M. Pružinský, B. Gontkovičová (eds.), CRC Press Taylor & Francis Group, Leiden 2019: 179-184

[45] Rudra A., Chattopadhyay A.: Environmental change of coastal Sundarbans: Impact on livelihood and standard of living status of indigenous people, Environmental Quality Management, 2019, 29(2): 77-84

[46] Potencjał społeczno-gospodarczy Euroregionu Karpackiego 2008-2010, Statistics Poland branch Rzeszow, Rzeszow 2012

[47] Ranis G., Stewart F., Samman E.: Human Development: Beyond the Human Development Index, Journal of Human Development, 2006, 7(3): 323-358

[48] Rapley M.: Quality of Life Research: A Critical Introduction, SAGE Publications, London 2003

[49] Robinson J.: Squaring the Circle? Some Thoughts on the Idea of Sustainable Development, Ecological Economics, 2004, 48: 369-384

[50] Rogall H.: Ekonomia zrównoważonego rozwoju. Zysk & S-ka, Poznan 2010

[51] Spangenberg J.H., Bonniot O.: Sustainability indicators: A compass on the road towards sustainability, Wuppertal Papers 1998, 81

[52] Stiglitz J. E., Sen A., Fitoussi J-P.: Report by the commission on the measurement of economic performance and social progress, 2009

[53] Stigt R. van, Driessen P., Spit T.: On the Necessity of an Integrated, Participative and Adaptive Approach to Sustainable Urban Environmental

Quality Planning, Environmental Policy and Governance, 2017, 27: 193-206

[54] Szczygieł E.: Ocena użyteczności dochodu i jej wpływ na oszczędności gospodarstw domowych, WNT, Warsaw 2014

[55] Tartaglia S., Conte E., Rollero Ch.: The influence of coping strategies on quality of life in a community facing environmental and economic threats, Journal of Community Psychology, 2018, 46: 251-260

[56] Theofilou P.: Quality of Life: Definition and Measurement. Europe's Journal of Psychology, 2013, 9(1): 150-162

[57] Tryon R.: Cluster Analysis, McGraw-Hill, New York 1939

[58] United Nations, Declaration of the United Nations Conference on the Human Environment, Stockholm 1972

[59] Volchik, V., Oganesyan, A., Olejarz, T.: Higher education as a factor of socio-economic performance and development. Journal of International Studies, 2018, 11(4): 326-340

[60] Zakrzewska B.: Zrównoważony rozwój a jakość życia, Autobusy: technika, eksploatacja, systemy transportowe, 2019, 229(4): 38-41

[61] Zikic S.: A modern concept of sustainable development. Progress in Economic Sciences, 2018, 5: 143-151

[62] Zainol, N. R., Al Mamun, A., Ahmad, G., & Simpong, D. B.: Human Capital and Entrepreneurial Competencies towards Performance of Informal Microenterprises in Kelantan, Malaysia. Economics and Sociology, 2018, 11(4): 31-50

[63] Zarghami E., Fatourehchi D., Karamloo M.: Impact of Daylighting Design Strategies on Social Sustainability Through the Built Environment, Sustainable Development, 2017, 25: 504-527

[64] Zielińska A.: Comparative Analysis of Circular Economy Implementation in Poland and other European Union Countries. Journal of International Studies, 2019, 12(4): 337-347

[65] Živčicová, E., Bulková, K., Masárová, T.: Comparison of the Selected Indicators of Work Life Balance in European Union Countries, Economics and Sociology, 2017, 10(1): 222-231

Possibilities for the Utilization of an Automatized, Electronic Blockchain-based, Students' Attendance Register, using a Universities' Modern Security Cameras

Krisztián Bálint

Óbuda University, Doctoral School on Safety and Security Sciences, Népszínház u. 8, H-1081 Budapest, Hungary, e-mail: balint.krisztian@phd.uni-obuda.hu

Abstract: This article introduces a solution for a security camera system, based on artificial intelligence, capable of an automatized composition of a students' attendance register, which helps in managing the in-school administrative burdens, and lessens the required paperwork, which has encumbered teachers to this day. So far, such a solution has not yet been implemented at any University. Furthermore, to keep the data storage process secure, blockchain technology will be implemented. This way, data will be stored after encryption on various nodes, increasing data security compared to the traditional, cloud-based data storage. The camera system is capable of monitoring the students' attendance of lectures. To be eligible for a so-called digital subject approval, each time a student attends a lecture, a record of facial features must include a timestamp, with the classroom number, the name of the lecturer, and the designation of the subject in question. Last, but not least, the system could be utilized in fire protection too, as, in the case of an eventual evacuation, the camera system would be able to indicate the exact position of each student within the premises, so it would provide a great asset to the rescuers and/or firemen.

Keywords: security camera; blockchain; attendance register; fire protection

1 Introduction

Presently, security cameras are undergoing rapid developments. These systems utilize numerous analytic solutions with large resolution, in high detail. The built-in artificial intelligence has appeared, lessening the task of rescue personnel. To further increase efficiency, the implementation of new technologies is also recommended, which were not used to these days in such a complex, composite manner. The connection of blockchain technology with the cameras' NVR (Network Video Recorder) system for data storage represents an outstanding solution. The following innovations have been brought to fruition:

- Recently, there was a profound evolution in the use of information technology [1]. Blockchain-like data storage, will have a broad expansion in the next 3-5 years, as the presently utilized, cloud-based data storage solutions, are centralized, so users must trust providers [2]. In the case of decentralized cloud-based data storage, the clients' data are not stored on a central server, but are distributed on the blockchain's nodes [3].
- What's more, in some mid-level educational institutions, the behavior or individual pupils is monitored by cameras capable of face recognition. These cameras recognize the following patterns of behavior: writing, reading, reporting and paying close attention [4].
- These days, the Universities may compose their blockchains, aiming to close smart contracts with their students. The system is capable of monitoring students' semi-annual grades trough the in-school Neptun system, thus forming an automatized bursary payment system. If a student completes the conditions stipulated in the contract, then, he/she receives the bursary, automatically, without any need for outside intervention or supervision [5].
- The newest research has pointed out that blockchain-based data storage could be used as part of smart cities. The security cameras would save their video recordings in a blockchain. The cameras monitoring public spaces could save their data as to become irrefutable evidence in courts. This method could come to fruition through a blockchain of unalterable main ledger. The main ledger would prove that the video recordings have not been compromised, respectively, that these fully depict the true happenings in cases given [6].
- Research is moving toward issuing University Certificates, not only in a paper-based form, but also as an electronic document, issued through a blockchain. Data stored in a blockchain provides a high degree of security. With the implementation of such a method, the number of misuses could be minimized, as there were several cases of the applicants producing fake certificates to the employers [7].
- With the majority of blockchains, the records are posteriorly, not erasable, thus, Universities may constitute their own records for their students. These records would contain information about the classes visited and any payments for the tuition fees. If inaccurate data were saved in a given record, then, a new record needs to be made. By the implementation of this method, both the old and the new record would remain visible, with the divergence, that the corrected record would become relevant. By the applying of this approach, the amendments would become easily traceable and retraceable [8].

The automatized, electronic, blockchain-based, students' attendance register composed by the system, connected with the security cameras, is considered an outstanding solution in the educational institutions. The university which would be first to implement this feature would vouch for a modern, innovative solution.

It may be stated that the off-chain based blockchain was already composed in practice, as well as the UDSC – Universities Data Storage Chain. The blockchain technology has been linked with a security camera featuring analytical abilities and facial recognition in practice. The gained results are discussed in the paper.

This work is structured as follows: After the introduction of modern-day security camera systems, the present article discusses the blockchain-based data storage, the UDSC, the in-school off-chain software architecture, as well as the possibilities of the utilization of automatized, electronic, blockchain-based attendance registers in the educational system.

2 Constituting Elements of a System for Composing an Automatized, Electronic, Attendance Register

A system composing of an automatized attendance register of students, consists of numerous components, such as:

- Security cameras
- An NVR-unit
- A blockchain
- The Neptun in-school system (Student record system)

2.1 Modern Security Camera Systems

The administration before and during lectures is a necessary, albeit an encumbering task. It includes the register of attendance considering students and lectures. This task can be automatized by security cameras. During the practical realization of this system, security cameras were implemented featuring the following functions:

- Facial detection
- Facial recognition
- Headcount
- Black and white list
- Deep learning

The mentioned camera functions are essential, as without these, the students' automatic recognition is not accomplishable at the universities. Moreover, it is necessary to install an NVR-unit which manages the cameras, and it stores all the recording data on its hard disk. It is expedient that the NVR would feature the following capabilities:

- Operation system. This way, the possibility is provided for the NVR's configuration, regarding all the relevant details. It is recommended to choose an NVR containing a Linux operation system for the stability of performance.
- Artificial intelligence, through which the cameras' capabilities can be fully utilized.
- Functions, such as, trigger events, like PTZ (Pan-Tilt-Zoom), video push, snapshot, or the possibility of sending automatic emails.

2.2 Blockchain-based Data Storage

In order to obtain secure data storage, and, if needed, a long term data saving solution, it is recommended to keep data in blockchains. The decentralization of data provides greater security and data protection. This is partly since it is harder to corrupt it in comparison with the traditional storage methods. The files are distributed between the nodes in parts, on hardware located anywhere in the world, and even the nodes involved cannot view the content of the whole file altogether [9].

As a part of the system for composing an automatized attendance register of students, a unique and proprietary, university-based blockchain was created, which is titled UDSC (Universities Data Storage Chain).

This blockchain saves the video recordings of students, and their photos (Photo IDs) utilized for personal recognition.

The solution's advantages:

- Posterior changes to the existing blockchain are almost impossible, except with the agreement of the majority of users operating the network. For an individual to be able to manipulate the blockchain, that person would have to possess at least 51% of the network (in reality, the chances for this are very slim).
- Some cloud-based providers may even amend the personal data or may delete them, or in extreme cases, may exclude a user. In the case of a blockchain, these cases cannot happen, thanks to the data savings distributed between the nodes.

2.3 The Connection of the NVR-Unit with the Security Cameras and the Blockchain

To achieve the infallible operation of the in-school blockchain in practice, attention is needed to its numerous elements, by adequate configuration. As a first step, the security cameras need to be connected to the NVR-unit, as this unit is required to the cameras' operation. Next, the pitfalls are listed, which were experienced in the time period during testing stages. These were:

- The number of allocated channels from the NVR. During the testing period, a system with 4 ports was required, as there were 3 cameras installed, each with different capabilities. The institutions of education are recommended to consider a 24 port capable NVR-unit, as the number of ports determines the number of cameras in question.
- Attention must be directed to the types of compressing possibilities. The implementation of codec designated as H.264 may achieve a suitable rate of data compression, while the most effective solution is the codec H.265. Thus, valuable data storage space may be saved.
- The bandwidth and future speed of the Internet should be also considered well in advance. During the testing period, the first choice was an NVR-unit which supported a slower Internet-bandwidth as the one present in the given institution of education. The supported bandwidth of the NVR was 80 Mbps, while the faculty's Internet speed was 150 Mbps. Thus, the whole bandwidth available cannot be utilized entirely. After the change of the NVR-unit, the data communication became faster, 150 Mbps of speed was achieved through Wifi connection. As a remark, it can be added that the NVR may support different LAN or Wifi speeds.
- The maximal HDD capacity determines at each port the capacity of the hard drive, which may be connected to that port. In practice, the hard disks of 1TB capacity were chosen. It was more than enough for 3 cameras. In case of 24 cameras, implicitly, a greater capacity would be needed. If a long term application is needed, the capacity of 4TB seems to be an optimal choice.

Moreover, on the interface of the NVR, as a secondary saving place of the data recorded, the blockchain should be designated, by inserting its accurate IP address. The following school-related data is saved within the database of the blockchain:

- Photo IDs of students
- Video footage from students (it's recommended to keep these footages for just a short period, if no incidents happened, as these recordings take up a significant amount of space in the database)

- The timetable of every student for each semester
- The timetable of every lecturer for each semester
- The timetable for every classroom including time and subject

2.4 The Neptun In-School System

The Neptun in-school system may be connected with the system for composing the automatized, electronic attendance register, including the blockchain. The Neptun system is a software used by institutions of higher education in Hungary. It is a unified scholastic system (ETR), readily accessible through the Internet by the students and the employees in higher education alike. The Neptun system consists of two modules: the one for students and the one for teachers. With the help of the students' module the students are able to:

- Select a subject
- Enlist for an exam
- View descriptions of subjects they have selected
- Pay exam fees through an escrow account

The module for the teachers allows for:

- The provision of information for students through email
- The designation of grades for the subjects taken by individual students
- The reservation of rooms for exams
- The courses of action in connection with the term papers

3 The Constitution of UDSC (Universities Data Storage Chain)

In order to achieve secure data storage, as a part of realization in practice, a blockchain was created. The NVR has saved its recordings to this UDSC-blockchain. It is recommended to direct attention to the following aspects when creating such a type of blockchain:

- The accessibility address of the database. This consists the accessibility to both the sending and the receiving party
- The address of the camera system

- The designation of a correct server address. In order to increase the security and to keep the system at continuous readiness, it is recommended to have two servers allocated to the blockchain.

As long as the blockchain has been created correctly, the genesis block will appear. Table 1 introduces the steps of the blockchains' creation:

Table 1
The database based blockchain creating process [5]

University chain-util generate UDSC the default settings would be used: */default ~ universitychain/UDSC/chainsettings.dat* *chainsettings.dat include:* *Database addresses [receiver (cloud storage) IP address, sender (university) IP address], Camera system addresses [receiver (Neptun system) IP address, sender (NVR) IP address], Terms of GDPR database.* Next, the UDSC blockchain would be initialized, and the genesis block would be created *universitychain UDSC* The server will be started in those few seconds after the genesis block has been found, then the node address needs to be connected: *UDSC@192.168.0.1:8008* After these steps, the connection can be attempted from a second server: *universitychain UDSC@192.168.0.1:8008* After the message confirming the chain has been initialized, the permission is not given for connection to the database. The address would be copied and pasted: 192.168.0.2 finally, permission for connection would be granted: *universitychain UDSC grant 192.168.0.2 connect*

4 Possibilities of the Utilization of an Automatized, Electronic Blockchain-based, Students' Attendance Register in the Educational System

These days, intelligent security cameras possess numerous abilities that have been unthinkable just a few years ago. These would be the following abilities:

- Detection of sabotage
- Rambling
- Detection of over-crowding
- Identification of license plates

The mentioned video analytic solutions, however, can be utilized only less efficiently in the education, contrary to the possibility of the composition of an electronic attendance register.

The in-school administrational burdens have kept growing lately, and the tasks to be completed have not been significantly diminished either. Furthermore, the digitalized data should be specially attended, due to its sensitivity, or rather, to avoid its corruption. Complying with the GDPR law is not an easy task either, putting a considerable burden on the IT experts, and the school management. The storing of the recorded footage by a blockchain would be a secure solution foreshadowing progress.

The USDC system's structure and its operation is happening in the following manner:

1) As a first step, students' names (first and last names in correct order) need to be uploaded into the camera's database. Next, the categorization is recommended to separate the students' names by study groups, branches, on behalf of better transparency. This is needed because it may happen that the camera's artificial intelligence cannot recognize the student, thus it is unable to allocate a name to the face given. In such situations, the manpower should step in, and a member of the security personnel should identify the student in question. Seeking out a student's name from a manageable database is a much easier and more efficient solution.

2) As a second step, profile images in high resolution (at least in HD) are allocated to the names. Based on these two important data (by possessing the name and the Photo ID of a student), the system is capable of the student's identification. This is not only necessary because of the attendance register, but also for filtering out the trespassers more easily, thus raising the level of security applied. This solution operates based on a black and white list, which ability is already included in modern cameras.

3) Following these steps, the number and designation of the classrooms must be uploaded into the camera's database. It is recommended to register all the classrooms within the system. By designations, the specificities of the mentioned classrooms are meant, like computer science, chemistry or biology classrooms.

4) The timetable represents the next step. In the long term, this is the most time-consuming task in this system, as the timetable is changed in each semester, and it is necessary to record it twice a year. To increase efficiency, importing from the Neptun software is recommended.

5) After the uploading of the complete database, the identification of the individuals follows, within this, the face detection, which is an essential part of this technology. Face detection is a very complex task, as in the case of an educational institution, the camera needs to sense multiple faces in a single time frame.

6) After the camera has detected a face, it needs to be identified, by matching it with a database entry, which gets assigned with a name by the system.

7) In possession of adequate data, the system would compose an attendance register. Its most crucial condition is the successful identification, and the gaining and mutual connection of preprogrammed data.

8) As the last step, data is sent in predefined periods. This may happen:
   - Daily
   - Weekly
   - Monthly
   - Semi-annually

It is important to determine who is receiving these notifications. It is recommended to designate a lecturer, a student, and the Neptun system respectively. In that case, the lecturer and the student both receive the report about the attendance. This way, even the eventual misunderstandings may be corrected, which would stem from an incorrect identification, and the problem may be solved in a short time.

5 Experiences Gained During the Realization in Practice

There were numerous hardships and problems which have surfaced during the realization of the system for composing an attendance register. One of these is the huge data quantity generated by the cameras, which was, at first, saved on the

NVR hard drive. After this, the system has forwarded the data to the blockchain. The subject of the examination was the control of the cameras' face recognition capability, respectively the examination of the efficiency.

5.1 The Data Quantity Generated by the Cameras

The cameras' deployment was completed in 3 phases. This was done in the following manner:

- First, the cameras with minimum HD resolution, were installed and tested
- Then, the cameras with 2 MP resolution were implemented
- Last, but not least, modern 10 MP capable security cameras were tested

During the testing phase, the most efficient compressing process was implemented, namely, the standard H.265. The obtained results lead to the following conclusions:

- The security cameras with HD resolution are capable of producing recordings of sufficient quality. The higher resolution has produced a significantly larger data quantity, which represents a greater problem than it would be an advantage during the daily use. The HD resolution has proven to be sufficient, because these cameras were deployed indoors, with the premises lacking great distances. The cameras were placed in front of the classrooms' entrances, so it was possible to produce recordings of sufficient quality of students passing in front of the cameras.
- The cameras featuring 2 MP of resolution have produced a much larger data quantity, but their capabilities of face recognition have proven higher.
- The security cameras featuring 10 MP of resolution have produced recordings in astounding detail. Hypothetically, the broad implementation of these devices is an image from a farther future, since their high price may hinder the propagation. The greatest problem was, however, the data quantity, generated on a daily basis. Currently, storing of huge data quantity represents a problem for the in-school systems.
- Furthermore, the increased data traffic must be taken into account, as this has significantly burdened the Internet managing system of the educational institution in question. This was mainly typical for the cameras featuring 10 MP resolution. The data transfer to the blockchain is recommended to take place in the evening hours, when there is no other data traffic in the educational institution. The second table shows the data quantities generated by the security cameras:

Table 2
The data quantity generated by the security cameras in practice

Resolution	Process of compression	Number of cameras	Number of days	Number of daily hours in use	Bandwidth of the network	Data quantity
1.3 MP (HD)	H.265	3	5	12	150 Mbit/s	470 GB
2 MP (HD)	H.265	3	5	12	150 Mbit/s	710 GB
10 MP	H.265	3	5	12	150 Mbit/s	3.2 TB

5.2 The Cameras' Efficiency of Identification

Presently, facial recognition represents one of the most significant challenges in these fields of technology. According to past experiences, the comparison of camera images with database entries is not a simple task. If the system handles a substantial database, these interfering effects could highly debase the success rate of recognition [10].

The cameras' testing in practice was performed in the following manner:

- The entire testing period lasted 6 weeks
- There were 2 weeks assigned for each of the 3 camera types

It is important to note, that these cameras were all featuring built-in artificial intelligence. Since the testing was performed at the university, there were encumbering circumstances uncovered during the trials, which have negatively influenced the success of the identification. The following factors were encountered:

- Facial expression:
  - The identification may be hindered even by a smile, as it changes the lineaments of a face.
- Various coverings:
  - In front of the classroom entrances, the students may cover each other's faces, even by chance.
- Image quality:
  - Insufficient lighting conditions, improper shading (regardless of which, the sunshine is still obstructing the lens),
  - Choice of the appropriate resolution, image frequency, and color depth.

- Presence or absence of facial traits:
  - Hair, beard, mustache, glasses,
  - A multitude of colors, shapes, and sizes [11].

There were 57 students participating in the present research, all studying the subject Computer Science 1. In practice, this meant 3 groups. An important aspect was, that in case of all 3 cameras, the participants were the same. This way, the possibility was given for determining the cameras' capability and precision of identification. The six-week period has lasted from mid-January to the end of February 2020. It was a relevant aspect that the cameras be implemented in quick succession. During the winter season testing, the clothing habits and hairdo of the students was similar in the time period examined. If some of the cameras were deployed in winter and some tested in the summer, the precision of the identification would have shown greater discrepancies, which would have had a negative influence on the accuracy of the measurement. Therefore, the primary aim was the provision of nearly equal conditions. The results of the identification are shown in the third table:

Table 3
The cameras' efficiency of identification

Groups of resolution	**Accurate identification of students during week 1**	**Accurate identification of students during week 2**
1.3 MP (HD) camera	43	51
2 MP (HD) camera	46	52
10 MP camera	51	55

As it can be seen, the cameras were operating more efficiently during week 2, as the week before. This was due to the built-in artificial intelligence. The cameras were learning continuously, thus, the efficiency of the identification was improved significantly at the end of the testing period. Based on the results obtained, it may be stated:

- While the camera featuring 1.3 MP resolution has identified the students with 75% of efficiency during the first week, it succeeded to identify them correctly with 89% efficiency during the second week.
- The camera featuring the 2 MP resolution could reach efficiency of 80%, during the next week it was operating with 91% efficiency.
- Last, the camera featuring 10 MP of resolution has reached 89% of efficiency during week 1, and 96% during week 2.

Presumably, the higher pixel density has great influence on the efficiency of the identification, but the real answer is a more complex one. With the increasing of the number of pixels, the strength of the cameras' processors has proportionately increased. Henceforth, the discrepancy between the built-in artificial intelligence

software may be examined, but the manufacturer did not share this information on the packaging, nor it is featured on their home websites.

Moreover, the connection between the NVR and the blockchain has been established successfully, so the safe storage of the data was secured. The nodes have stored the data (video recordings and photographs alike) but this has taken longer than the anticipated time was. The traditional, cloud-based systems are thus faster. The presumable answer is, that the blockchains will become truly efficient, if these run on a high number of machines. Only two machines were utilized during the present research. The detailed examination of this problem would definitely require further research, in multiple directions.

6 Modern Solutions for Fire Protection

In fire protection, the human factors' influences are majorly appearing during evacuations. Individuals are not properly prepared, they may be confused, unable to measure correctly, and often make faulty decisions, which may cost their lives [12].

Although the universities may have practice drills of correct steps of evacuation, possibly saving students' lives. This does not need additional financial support or any investments, as it is merely a question of organization. Hence, in case of a fire alarm, the students will know the proper behavior and may evacuate the educational institution in an orderly manner [13].

Despite this, it is presumable that there would be some students who would be puzzled or forgot to behave correctly in case of a fire. The camera system introduced in this paper would help even in these situations, as the system is capable of composing an attendance register, so it has to know by name, who is where and in which classroom in a given moment. This would facilitate the firemen's efforts, as they would receive important information on potential wounded and stuck individuals left behind.

7 The General Data Protection Regulation and Laws Governing Electronic Surveillance Systems

The in-school security cameras are necessary, but one must not forget that if these record information containing names, then it may violate the given individuals' rights. The images, recorded for security reasons may always be misused for illegal purposes. In these circumstances, it is self-explanatory that the use of such systems must be regulated by law [14].

The EU has reached an agreement on the 6th of April, 2016 about the great reform of its legal framework regulating the data protection, by implementing the reform package containing the General Data Protection Regulation, which has superseded the twenty-year-old Directive 95/46/EU and the Police Directive. As the GDPR's provisions have been mandatory from 25th May 2018, to comply with her set of regulations about data protection with the GDPR, Hungary has, on the 25th of August 2018 passed the first amendment of her Act of the Informational Self-determination and Liberty of Information, first implemented as Act no. CXII of 2011 while, on the 26th of April 2019 the GDPR – 'Salad' Act [15] has been proclaimed, which will be discussed in detail on the following pages.

7.1 Data Usage of Electronic Surveillance Systems – GDPR 'Salad' Act

The retention of security footage has, up to these days, been regulated to last for a set time. The camera footage has had to be erased after 3 workdays. The majority of security systems have deleted the footage automatically within the set time, but this has caused complications too, as it was impossible for the system to interpret the notion of workdays. Furthermore, causes have surfaced, at the data managers' side, which required a longer time for data retention. These restrictions were lifted from the 26th of April. According to the new regulations, the data managers behave correctly even if they prolong the time of safekeeping if need be.

Before the amendment, a person entering an area under camera surveillance has had to accept the surveillance's data handling by seeing the notices put forth, and proceeding to the area. If the person did not agree, the data management was not equitable. The norms of the new EU regulation unambiguously exclude the consent given by behavior. After the amendment, the data managers had to face a new situation: they act equitably if they declare the legal base for their personal and goods protection surveillance as a legitimate interest. Therefore, in that case, no consent is needed, but an interest measuring test is required, which confirms the legal interest for data management considering every camera, yielding the possibility for data management this way [16].

The strict regulations concerning recorded footage were deleted, thus, nobody would need to prove his/her right to gain insight into the recorded footage. In the future, the camera footage will not only be used in case of jurisdiction or governmental processes.

As a new regulative of the mentioned law, the electronic records are acknowledged as official records [17].

Conclusions

As a summary, it can be stated, that the system constituting an attendance register based on security cameras consists of many components. The constitution of a

proprietary, university-based blockchain may be suggested, which would facilitate the storing of the data on its nodes. The connection of the NVR with the UDSC would provide a possibility to secure data storage, furthermore, it would become possible to send the data through the Internet to the university based Neptun system. Thus, a student is recorded each time upon visiting a class, in the given semester. It is expedient to use a security camera featuring a Deep Learning function, as facial detection, facial identification and head counting are functions utilized during the identification.

It is noteworthy, that the system could be successfully utilized in fire protection too, regarding the rescue of human lives, as the camera system keeps track of the location of every student within the premises. Thus, it is possible to find lost students.

In addition, the amended GDPR law of data protection enables data storage for longer than 3 days, which is necessary in these cases, as it is recommended to keep the students' data for one whole semester, e.g. 6 months.

Last, student awareness has also been explored, considering a camera system capable of facial recognition and composing of an attendance registry/study behavior. 59% of the students find that a solution capable of generating an attendance registry is important and the majority stated they would not be offended by the facial recognition technology.

References

[1] Dóra Mattyasovszky-Philipp, Bálint Molnár: An Architectural Approach to Cognitive Information Systems, Acta Polytechnica Hungarica, Volume 17, Issue Number 2, 2020

[2] Huffpost: 5 Blockchain Applications That Are Shaping Your Future, https://bit.ly/39YlWDU (Download time: 2020-02-27), 2017

[3] Cathy Sturges: Cointelegraph - How Can Blockchain Improve Date Storage, https://bit.ly/2GXBrzC (Download time: 2020-02-27), 2020

[4] Dezső András: The digital dictatorship has been built before our eyes, (A szemünk előtt épült ki a digitális diktatúra) https://bit.ly/392zwpW, (Download time: 2020-02-27) 2018

[5] Bálint Krisztián: Connecting Bitcoin Blockchain with Digital Learning Chain Structure in Education, Acta Polytechnica Hungarica, Volume 16, Issue Number 1, 2019

[6] Prince Waqas Khan, Yung-Cheol Byun,Namje Park: A Data Verification System for CCTV Surveillance Cameras Using Blockchain Technology in Smart Cities, MDPI Journal Electronics, 2020

[7] Getting Smart: How Blockchain Could Impact Education in 2020 and Beyond, 2020. https://bit.ly/3jo7utd (Download time: 2020-10-24), 2020

[8] Maureen Hance: What is Blockchain and How Can it be Used in Education, https://bit.ly/34pffea (Download time: 2020-10-24) 2020

[9] Patrick Nelson: How Data Storage Will Shift to Blockchain, https://bit.ly/31seGNG (Download time: 2020-02-27) 2019

[10] Őszi Arnold: E-Commerce Requirements for Biometrics Business Development in the 21st Century, (Az e-kereskedelem elvárásai a biometriával szemben Vállalkozásfejlesztés a XXI. században), Business development in the XXI. century, Budapest 2014

[11] Mastusinka Roland: Basics of Face Recognition and Face Detection, (Az arcferlismerés és arc detektálás alapjai), National University of Public Service, https://bit.ly/2vfgsFO (Download time: 2020-02-27) 2014

[12] Schüller Attila: Examination of the human factor and technical realizations during fire alarms, (Az emberi tényező és a technikai megvalósítások vizsgálata tűzriadók során), Hadmérnök, 2, Number, 37-46, 2012

[13] Bálint Krisztián: Experiences of Secondary School Teachers from Subotica, Vojvodina Regarding Electronic and Mechanical Protection at School, FMTÜ XXIII, 2018

[14] André Vitalis: Camera surveillance, security and liberties, (Kamerás megfigyelés, biztonság és szabadságjogok), Information Society 2.1: 56-57, 2002

[15] Detektor Plus The Security of Page: GDPR Major Changes (A GDPR kapcsolatos fontosabb változások), Volume 26, Number 6, https://bit.ly/396g8bG (Download time: 2020-02-27) 2019

[16] Réti, Várszagi és Társai Ügyvédi Iroda: GDPR Salad Leaf 1. - Rules for Camera Surveillance and Electronic Access Control Relaxed GDPR Salátalevél 1, (Lazultak a kamerás megfigyelés és az elektronikus beléptetés szabályai), https://bit.ly/31x8F2s, (Download time: 2020-02-27), 2019

[17] Mihola Réka: The rules for camera surveillance have been relaxed, (Lazultak a kamerás megfigyelés szabályai), https://bit.ly/3bAzyXF, (Download time: 2020-02-27), 2019

Support Vector Regression based on Grid Search method of Hyperparameters for Load Forecasting

Tran Thanh Ngoc, Le Van Dai, Chau Minh Thuyen

Faculty of Electrical Engineering Technology
Industrial University of Ho Chi Minh City
12 Nguyen Van Bao, Ward 4, Go Vap District, Ho Chi Minh City, Vietnam
tranthanhngoc@iuh.edu.vn, levandai@iuh.edu.vn, chauminhthuyen@iuh.edu.vn

Abstract: Support Vector Regression is becoming one of the most attractive models for load forecasting, in recent years. The performance of Support Vector Regression deeply depends on its hyperparameters, such as, Kernel function, Kernel function parameters and a penalty factor. This paper proposes a methodology for the Grid Search hyperparameters of the Support Vector Regression model. In the training process, the optimal hyperparameters will specify conditions that satisfy requirements for minimizing evaluation indexes of Root Mean Square Error, Mean Absolute Percentage Error, Symmetric Mean Absolute Percentage Error and Mean Absolute Error. In the testing process, the optimal models will be used to evaluate the obtained results along with all other ones. It is indicated that the evaluation indexes of these optimal models are close to the minimum values of all models. Load demand data of Tasmania State, Australia, and Ho Chi Minh City, Vietnam were utilized to verify the accuracy and reliability of the Grid Search methodology.

Keywords: Load forecasting; Grid Search; Support Vector Regression; evaluation index

1 Introduction

Electrical load forecasting is an important element of any electrical power system, including, generation, transmission, distribution and the retail sale of electricity. According to the period of prediction time, load forecasting can be divided into four categories: Very Short Term, Short Term, Medium Term, and Long Term [1, 2]. In recent years, Support Vector Regression (SVR) has been becoming an attractive tool for time series forecasting, especially for load forecasting [3-13]. Generally, SVR shows better generalization performance with the rule of Structural Risk Minimization in comparison with other learning methods such as Neural Networks that are based on Empirical Risk Minimization [3-5, 12]. However, the performance of SVR strongly depends on its hyperparameters. The

more different the hyperparameters, the more different the output values of the SVR model. In this regard, the hyperparameters chosen for an SVR model is essentially important to get reliable forecasting results [14-16]. A variety of methods, such as Genetic Algorithms or Grid Search, have been considered to optimize the hyperparameters. Grid Search is a tuning technique that is performed to obtain the optimum values of hyperparameters by going through all combinations of hyperparameters in the search range. To evaluate the performance of hyperparameters in case of load forecasting, different evaluation indexes can be used, such as Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Symmetric Mean Absolute Percentage Error (SMAPE), Mean Absolute Error (MAE), etc. According to recent studies, most Grid Search methods have only focused on the parameters of the SVR model, such as penalty coefficient **C**, kernel function **K**, and kernel parameter $\boldsymbol{\gamma}$ [17-22]. In addition, the criterion to evaluate the performance of the model is mostly based on one unique evaluation index, which is usually either MAPE or MSE [17, 19-22]. In this study, the SVR Grid Search methodology is proposed with the consideration of the hyperparameters that not only determine the SVR network structure, like conventional Grid Search methods, but also represent the characteristics of input data. The first proposed hyperparameter is the number of lag observation of data used as input of the model, and the second hyperparameter is the differencing order of data. In addition, the study investigates simultaneously four most common evaluation indexes, including RMSE, MAPE, SMAPE, and MAE, to evaluate the performance of the SVR model during the training and testing processes. In the training process, optimal hyperparameters are obtained to meet the minimum requirement of evaluation indexes. In the testing process, these optimal models will be compared to all other ones to evaluate the Grid Search methodology. Load demand data of Tasmania State, Australia, and Ho Chi Minh City, Vietnam, will be analyzed through the training and testing processes to verify the accuracy and the reliability of the Grid Search methodology. The experiments were implemented using the scikit-learn library in the Python environment with Google Colab, a free GPU on the cloud for running large-scale machine learning projects.

This paper is organized as follows, in Section 2, a brief introduction to an SVR model along with proposing the SVR Grid Search methodology is presented. In Section 3, experiments and an analysis of the obtained results are discussed. The conclusions are shared in Section 4.

2 Research Method

2.1 Supporting Vector Regression

Considering a set of data $\{x_i, y_i\}$, i =1, …, N; where $x_i \in R^n$ is the input vector with n dimension, $y_i \in R$ is the target value, and N is the total number of data patterns. The basic concept of the SVR is to map nonlinearly the original input data x into a higher dimensional feature space R^h by using a non-linear mapping function $\varphi() : R^n \to R^h$. Hence, the SVR function is formulated as follows [3-7, 24, 33]:

$$f(x) = \omega^T \varphi(x) + b \tag{1}$$

where ω represents the weight vector and b is a bias term. The coefficients ω and b are estimated by minimizing the regularized risk function R as shown in (2):

$$R = \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{N} L_\varepsilon(y_i - f(x_i), x_i) \tag{2}$$

where *C* is the regularized constant determining the trade-off between the regularization term (the first term) and the empirical error (the second term). The term ε defines the ε zone as shown in Figure 1 [4, 7], and L_ε is called the ε insensitive loss function as follows:

$$L_\varepsilon(y - f(x), x) = \begin{cases} 0, |y - f(x)| \le \varepsilon \\ |y - f(x)| - \varepsilon, otherwise \end{cases} \tag{3}$$

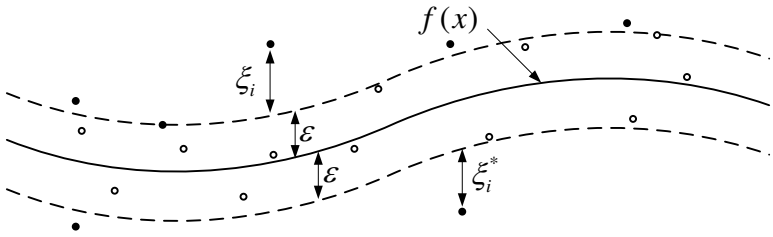


Figure 1
Definition of ε, ξ_i, ξ_i^* of SVR

ξ_i, ξ_i^* are slack variables that quantify how far data is above or below the ε tube. As can be seen from Figure 1, the training data points that lie outside of the ε insensitive tube can be obtained by:

$$\begin{aligned} &\left|y - f(x)\right| - \varepsilon = \xi, \ points\ above\ the\ tube \\ &\left|y - f(x)\right| - \varepsilon = \xi^*, \ points\ below\ the\ tube \end{aligned} \tag{4}$$

By substituting the equations (4) and (3) for (2), the equation (2) can be expressed by (5) and subject to constraints expressed in (6):

$$R = \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{N}(\xi_i + \xi_i^*) \tag{5}$$

$$\begin{aligned} &y_i - (\omega^T \varphi(x_i) + b) \le \varepsilon + \xi_i \\ &(\omega^T \varphi(x_i) + b) - y_i \le \varepsilon + \xi_i^* \\ &\xi_i, \xi_i^* \ge 0; i = 1, 2, ..., N \end{aligned} \tag{6}$$

The parameters of the f(x) can be found by using the Lagrange function as shown in (7), where α_i^*, α_i are Lagrange multipliers and $K(x_i, x)$ are Kernel function, defined as the dot product between $\varphi(x_i)^T$ and $\varphi(x)$:

$$f(x) = \omega^T \varphi(x) + b = \sum_{i=1}^{N}(\alpha_i^* - \alpha_i)K(x_i, x) + b \tag{7}$$

2.2 Hyperparameters Tuning of Supporting Vector Regression

The selection of several hyperparameters of the SVR model that can be listed as a type of Kernel function **K**, parameters of Kernel function **γ**, as well as the regularized constant **C**, is important to the prediction accuracy and have been considered in many recent works of literature [21-24]. In order to improve the accuracy of the SVR model, some hyperparameters of the characteristic of input data such as a number of lag observations that are used as input data, and differencing order of input data are proposed to be in combination with the above-mentioned hyperparameters [25]. Hence, we focus on the following hyperparameters in this section:

Number of input data N:

Usually, in regression and time series forecasting problems, a large amount of data is stored in the form of time series: stock indices, weather measurements, electricity load, etc. Time series data is a set of observations on the values that a variable takes at different times according to a uniform time-frequency and can be defined by (8), where N is the number of observation values:

$$x(t) = \{x(t_1), x(t_2), ..., x(t_N)\} \tag{8}$$

The input variables of the SVR model are named by the lag time series values $x(t_1), x(t_2), ..., x(t_N)$ and the predicted output values are referred to the next values $x(t_{N+1})$. The number of input N is pre-specified by the available data that represents the number of lag observations used as input as shown in Table 1. Because of the seasonality of load times series, the number of input N can be chosen as the multiples of the period of time series. For instance, with the period of half-hourly time series of 48, the period of hourly time series is 24, …, and so on.

Table 1
The input and target values for times series

Input	Target
$x(t_1), x(t_2), ..., x(t_N)$	$x(t_{N+1})$
$x(t_2), x(t_3), ..., x(t_{N+1})$	$x(t_{N+2})$
…	…
$x(t_h), x(t_{h+1}), ..., x(t_{N+h-1})$	$x(t_{N+h})$

Data differencing order: *d*

Differencing is a method of transforming a time series dataset that can be used to remove the series dependence on time. Differencing is performed by subtracting the previous observation from the current observation as shown by (9), where d=0: no differencing, d=1: first differencing, and d>1: seasonal differencing.

$$dy(t) = y(t) - y(t-d) \tag{9}$$

Kernel functions and their parameters

The main function of the Kernel functions is to take low dimensional input space and transform it into a higher-dimensional space. Some basic Kernel functions are linear, Radial Basis Function (RBF), and sigmoid. The mathematical formulas are presented as follows:

Linear:

$$K(x, y) = x^T y \tag{10}$$

RBF:

$$K(x, y) = e^{-\gamma \|x-y\|^2} \tag{11}$$

Sigmoid:

$$K(x, y) = \tanh(\gamma x^T y + r) \tag{12}$$

where x and y are input vectors, r ≥ 0 is a free parameter, **γ > 0** is the parameters of Kernel function.

Regularized constant C

C is the penalty parameter, which represents the error term between forecast values and observation values. C specifies the trade-off between errors on training data set and margin maximization. A smaller C will lead to more errors and usually produce a larger margin. When C increases to infinity, SVR becomes a hard-margin.

2.3 Methodology of SVR Model

According to Section 2.2, the hyperparameters of the SVR model considered in this paper consist of the following ones: number of input data **N**, data differencing order **d**, Kernel functions **K**, a typical Kernel function parameter **γ**, and Regularized constant **C**. Based on the SVR structure and these hyperparameters, the methodology of the SVR model is proposed in Figure 2.

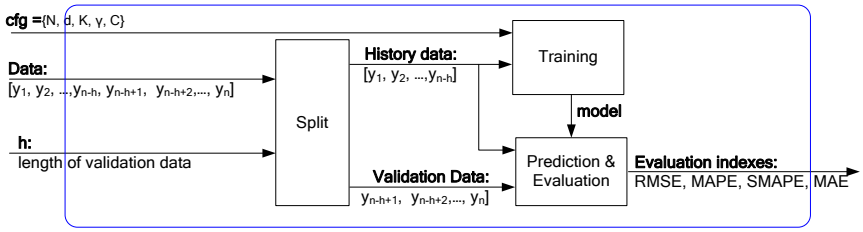


Figure 2
The methodology of the SVR model

The input of SVR model in the paper consists of the hyperparameter **cfg**={N, d, K, C} that was predefined at certain values as mentioned in section 2.2, the **Data,** and the length (dimension) of the validation data **h**. The function of the SVR model is calculating evaluation indexes at the output as shown in Figure 2 which following three steps:

Step 1: The original data ($[y_1, y_2, \ldots, y_n]$) are split into history data ($y_1, y_2, \ldots, y_{n-h}$) and validation data ($y_{n-h+1}, \ldots, y_n$) using split function. The validation and history data have lengths of **h** and **n-h**, respectively. The history data used for the training process to build the SVR model, the validation data used for calculating evaluation indexes.

Step 2: In the training stage, the SVR model is obtained after the training process by using history data and certain values of hyperparameter of N, d, K, γ, C.

Step 3: In the prediction and evaluation stage, prediction values are obtained based on the SVR model in step 2, and evaluation indexes (RMSE, MAPE, SMAPE, and MAE) between the prediction and validation values are calculated as follows equations [19-22, 27-32]:

$$RMSE = \sqrt{\frac{1}{h}\sum_{i=1}^{h}\left|y_{n-h+i} - \hat{y}_i\right|^2},\ MAPE = \frac{1}{h}\sum_{i=1}^{h}\left|\frac{y_{n-h+i} - \hat{y}_i}{y_{n-h+i}}\right| \times 100$$
$$SMAPE = \frac{1}{h}\sum_{i=1}^{h}\left|\frac{y_{n-h+i} - \hat{y}_i}{y_{n-h+i} + \hat{y}_i}\right| \times 200,\ MAE = \frac{1}{h}\sum_{i=1}^{h}\left|y_{n-h+i} - \hat{y}_i\right| \quad (13)$$

where: $[y_{n-h+1}, y_{n-h+2}, \ldots, y_n]$ is the validation values (real values), and $[\hat{y}_1, \hat{y}_2, ..., \hat{y}_h]$ is the prediction values.

In the paper, the scikit-learn library in Python was used to build the SVR model [26]. The pseudocode of the training and prediction & evaluation stages is shown in Figure 3.

Pseudocode of training stage

Input:
- History data $[y_1, y_2, \ldots, y_{n-h}]$
- cfg: combination of tuning hyperparameters (N, d, K, γ, C)

1: Differencing data:
If d > 0:
*History data = History data – History data [-**d**]*

2: Transform data into supervised format
*Transform History data into input X_train and output Y_train according the number of input data **N***

3: Define SVR model:
*model = svm.SVR(kernel=**K**, gamma = **γ**, C=**C**)*

4: Training model
model.fit(X_train,Y_train)

Output: **model**

(a)

Pseudocode of prediction & evaluation stage

Input:
- History data: $[y_1, y_2, \ldots, y_{n-h}]$
- Validation data: $[y_{n-h+1}, y_{n-h+2}, \ldots, y_n]$
- model: model from training stage

1: t = 1

Repeat

a: Difference History data and calculate offset
If d > 0:
*History data = History data – History data [-**d**]*
*Offset = History data [-**d**]*

b: Obtain the input X_test, the length of X_test is the number of input *i*.
*X_test = History data [-**N**:]*

c: Predict for X_test and add offset
$\hat{y}_1 = model.predict(X_{test})$
$\hat{y}_1 = \hat{y}_1 + Offset$

d: Add actual observation to history for the next prediction value
History data : $[y_1, y_2, \ldots, y_{n-h}, y_{n-h+1}]$
t = t+1
Until t = h

2: ***Calculate evaluation indexes***
Calculate evaluation indexes between the validation values $[y_{n-h+1}, y_{n-h+2}, \ldots, y_n]$ and the prediction values $[\hat{y}_1, \hat{y}_2, ..., \hat{y}_h]$

Output: **RMSE, MAPE, SMAPE, MAE**

(b)

Figure 3
The SVR pseudocode: training stage (a); prediction & evaluation stage

2.4 SVR Grid Search Methodology

Based on the hyperparameters tuning and the SVR model as earlier described, the methodology of the SVR Grid Search is proposed as shown in Figure 4. Each hyperparameters take a range of values, such as: N= {N_{min}, …,N_{max}}, …, C={C_{min}, …, C_{max}}. The combination for certain values of hyperparameter is $\mathbf{cfg_i}$={N_i, d_i, K_i, γ_i, C_i} and the total combination of hyperparameters is **CFG**={$\mathbf{cfg_i}$}. The training and the testing processes have the same combination of tuning hyperparameters **CFG** and the same length of validation data **h**. In the training and the testing processes, each component hyperparameter $\mathbf{cfg_i}$ of CFG is inputted into the SVR model (Section 2.3) and the evaluation indexes are calculated at the output layer. The **Min** stage in Figure 4 takes a role of selecting optimal hyperparameters ($\mathbf{cfg}_{RMSE}$, $\mathbf{cfg}_{MAPE}$, $\mathbf{cfg}_{SMAPE}$, $\mathbf{cfg}_{MAE}$) that satisfies a minimum of the evaluation indexes ($RMSE_{min}$, $MAPE_{min}$, $SMAPE_{min}$, and MAE_{min}) correspondingly. In the Evaluating stage, these optimal hyperparameter models are compared to all other ones according to their evaluation indexes that were obtained in the testing process.

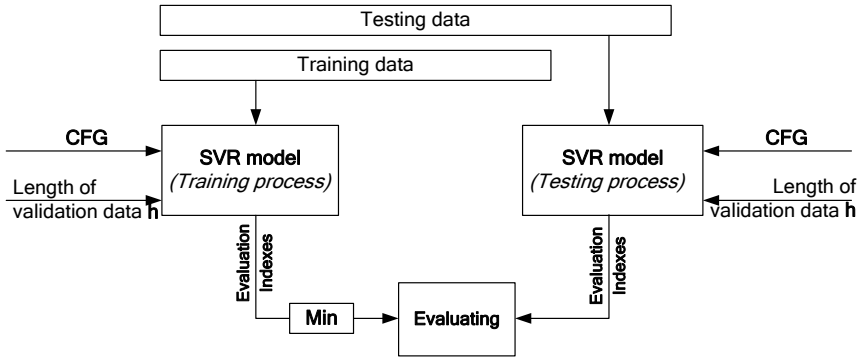


Figure 4
The SVR Grid Search methodology

3 Experimental Results and Analysis

3.1 Data Description and Hyperparameters Tuning

In order to enhance the reliability of results, load demand data of Tasmania State, Australia, and Ho Chi Minh City, Vietnam were studied in our experiments. Tasmania State's load demand dataset provides peak daily electricity demand in MW from 2013-03-10 to 2014-05-31, and so does Ho Chi Minh city load demand dataset - from 2017-10-09 to 2018-12-30. The characteristics of these load demand data, are presented in Table 2 and Figure 5.

Table 2
Characteristics of load demand data

Describe	Tasmania state	Ho Chi Minh City
mean	1304.67	3452.78
std	136.97	475.62
min	987.26	1594.10
max	1650.34	4138.50
count	448	448

Table 3
The values of tuning hyperparameters

Items	Values
Number of input data **N**	7, 28
Data differencing order **d**	0, 1, 7
Kernel functions **K**	linear, RBF, sigmoid
Kernel function parameter **γ**	0.01, 0.1, 1, 10, 100, 1000
Regularized constant **C**	0.01, 0.1, 1, 10
Number of combination **CFG**	432

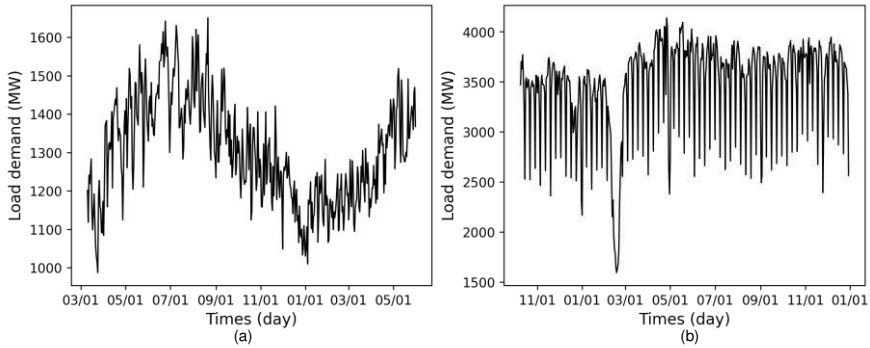


Figure 5
Load demand data: (a) Tasmania state, (b) Ho Chi Minh city

The setup of the value ranges of the hyperparameters tuning for Tasmania state and Ho Chi Minh city load demand data is listed in Table 3. Because of weekly seasonality data, there is a numeric value of 7 assigned to number of input data **N** and the value of differencing order **d**. With N=7, the SVR model used 7 days (one week) before to predict the data of one day ahead; with N=28, the SVR model used 28 days (one typical month) before to predict the data of one day ahead. Combining all tuned hyperparameters gives 432 cases corresponding to 432 possible models of SVR. The values of the length of validation data **h** is 28 (four weeks).

3.2 Experimental Results

Table 4 shows the results of training and testing processes using Tasmania state load demand data. For the training process, the optimal model was selected according to the minimum values of evaluation indexes of RMSE, MAPE, SMAPE, and MAE. Obviously, we have the same optimal models in the case of RMSE and MAE, as well as in the case of MAPE and SMAPE. For the testing process, the column 'Optimal' shows evaluation indexes for the optimal model which was obtained from the training process, and the columns 'Min', 'Average' and 'Max' - the min, the average, and the max values for all possible models that can be generated by the combination of tuned hyperparameters **CFG** (432 models). Analyzing Ho Chi Minh City load demand data also gave similar results shown in Table 5.

Table 4

The results of training and testing process in case of Tasmania state load demand data

Evaluation indexes	Optimal models of training process	Evaluation of testing process			
		Optimal	Min	Average	Max
RMSE (MW)	[7, 0, 'linear', 0.01, 10]	74.66	69.75	102.74	386.62
MAPE (%)	[28, 1, 'rbf', 0.01, 0.01]	4.33	4.03	6.05	24.32
SMAPE (%)	[28, 1, 'rbf', 0.01, 0.01]	4.33	4.02	6.14	26.02
MAE (MW)	[7, 0, 'linear', 0.01, 10]	60.87	55.72	81.99	334.50

Table 5

The results of training and testing process in case of Ho Chi Minh city load demand data

Evaluation indexes	Optimal models of training process	Evaluation of testing process			
		Optimal	Min	Average	Max
RMSE (MW)	[28, 7, 'linear', 0.01, 10]	115.25	111.81	283.59	632.74
MAPE (%)	[28, 7, 'linear', 0.01, 10]	2.47	2.43	6.67	18.72
SMAPE (%)	[28, 7, 'linear', 0.01, 10]	2.44	2.41	6.54	19.74
MAE (MW)	[28, 7, 'linear', 0.01, 10]	89.81	86.99	204.83	515.36

Figure 6 indicates the distribution of difference evaluation indexes for the testing process toward Tasmania State load demand data. Figure 6a presents the box plot for the RMSE component with the first column for the distribution of all possible models and the second column for the optimal model. The same distributed data are plotted in Figures 6b, 6c, and 6d. In the same manner, results in the case of Ho Chi Minh City load demand data are shown in Figure 7.

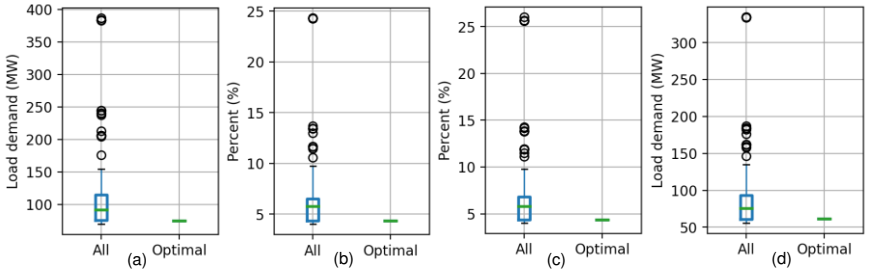


Figure 6

The box plot of evaluation indexes for testing process in case of Tasmania state load demand data: (a) RMSE, (b) MAPE, (c) SMAPE, (d) MAE

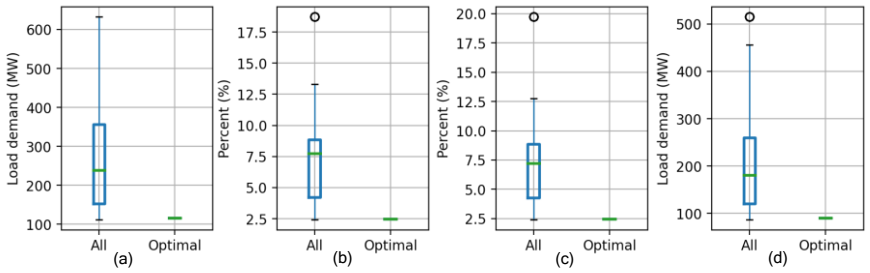


Figure 7

The box plot of evaluation index for testing process in case of Ho Chi Minh city load demand data: (a) RMSE, (b) MAPE, (c) SMAPE, (d) MAE

Figure 8 shows the prediction series and the validation series for Tasmania State load demand data. Figures 8a, 8b, 8c, and 8d give the prediction series of the optimal, minimum, and maximum models and the validation series for RMSE, MAPE, SMAPE, and MAE in the testing process, respectively. With regard to Ho Chi Minh City load demand data, similar results were also obtained as shown in Figure 9.

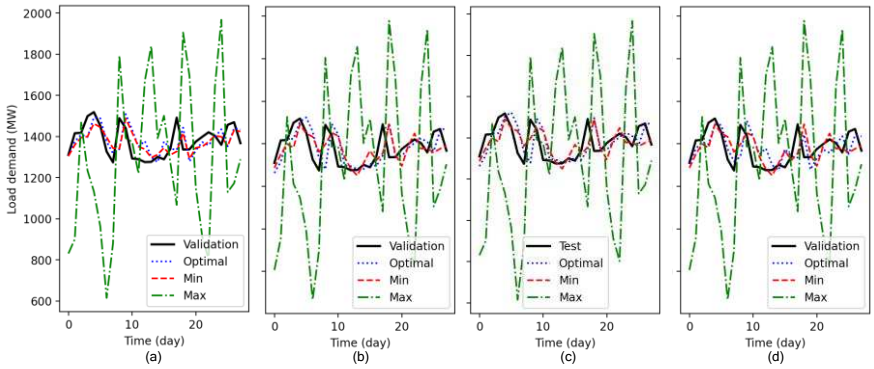


Figure 8

The prediction and validation series for testing process in case of Tasmania state load demand data: (a) RMSE, (b) MAPE, (c) SMAPE, (d) MAE

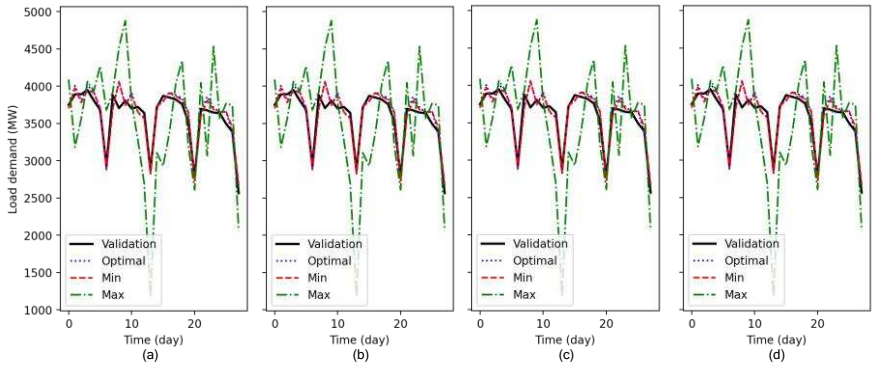


Figure 9

The prediction and validation series for testing process in case of Ho Chi Minh city load demand data: (a) RMSE, (b) MAPE, (c) SMAPE, (d) MAE

3.3 Evaluation and Discussion

As described above, the optimal models in the training process were determined by minimizing evaluation indexes such as RMSE, MAPE, SMAPE, and MAE. The analysis of the results listed in Table 4 and Table 5 shows the existence of the optimal model that satisfied the minimum criteria for evaluation indexes of RMSE, MAPE, SMAPE, and MAE. In the case of Tasmania state load demand data, there existed a model that satisfied all RMSE, MAE, and the other ones for MAPE and SMAPE. In the case of Ho Chi Minh City load demand data, there was a unique model that satisfied all RMSE, MAPE, SMAPE, and MAE.

The analysis of the data differencing order **d** is also shown in Tables 4, 5. The optimal value of **d** was 0 for RMSE and MAE, and the value of d was 1 for MAPE and SMAPE in the case of Tasmania. In the case of HCM, the optimal value of **d** was 7 for all evaluation indexes. Hence, transforming input data by representing the **d** hyperparameters can help to get better results than using original data (d=0).

An analysis of the number of input **N** hyperparameter can be extracted from Tables 4, 5. In the case of Tasmania, the optimal value of **N** was 7 for RMSE and MAE indexes and 28 for MAPE and SMAPE indexes. In the case of HCM, the optimal value of **N** was 28 for all evaluation indexes of RMSE, MAPE, SMAPE, and MAE. The results show that with extending the hyperparameters by using the input **N** hyperparameter, we achieved a better optimal model than without using the N hyperparameter (in case that the number of input data may be fixed at 7, 28, …)

It is worth noting, that the optimal model obtained in the training process does not guarantee the best results in the testing process. Let us analyze Table 4 in the case of Tasmania state load demand data. When using the optimal model in the testing process, evaluation indexes of RMSE, MAPE, SMAPE, and MAE were 74.66

MW, 4.33%, 4.33%, and 60.87 MW, respectively. Meanwhile, there were other models that gave better results in the testing process with the minimum values of 69.75 MW, 4.03%, 4.02%, and 55.72 MW for RMSE, MAPE, SMAPE, and MAE, respectively. However, compared to the average values of all models with the values of 102.74 MW, 6.05%, 6.14%, and 81.99 MW and to the maximum values of all models with the values of 386.62 MW, 24.32%, 26.02%, and 334.50 MW respectively, evaluation indexes of the optimal model was too small. In addition, analyzing the boxplot of the evaluation indexes shown in Figure 6 makes it clear that the evaluation indexes of the optimal models were close to the minimum value of all other models. Moreover, the prediction values of the optimal model shown in Figure 8 were very consistent with the validation values. Similar results were also obtained in the case of Ho Chi Minh City load demand data. These results clearly indicated that the optimal model received during training by applying the SVR Grid Search methodology can give good values in the testing process. Moreover, the SVR Grid Search methodology is thus suitable for most of the basic evaluation indexes such as RMSE, MAPE, SMAPE, and MAE.

Conclusions

An efficient SVR Grid Search methodology, based on the SVR model and their hyperparameters, was proposed, with reasonable analysis of Tasmania state and Ho Chi Minh City load demand data. In the training process, minimum evaluation indexes of RMSE, MAPE, SMAPE, and MAE were applied to specify the optimal model. In the testing process, evaluation indexes were used to compare the optimal model with all other ones. Both Tasmania State and Ho Chi Minh City load demands were used to verify the performance of the SVR Grid Search methodology. The results indicated the existence of an optimal model that satisfied the minimum requirement for evaluation indexes. Analyzing the obtained results in the testing process, showed that the evaluation indexes of these optimal models gave good results, close to the minimum and much smaller than the average of all models. The positive results obtained in this study suggest an improved and effective way to apply SVR in load forecasting.

References

[1] Raza MQ, Khosravi A. A review on artificial intelligence based load demand forecasting techniques for smart grid and buildings. Renew Sustain Energy Rev. 2015;50:1352-1372

[2] Din GMU, Mauthe AU, Marnerides AK. Appliance-level Short-Term Load Forecasting using Deep Neural Networks. 2018 Int Conf Comput Netw Commun ICNC 2018. 2018:53-57

[3] Tian L, Noore A. A novel approach for short-term load forecasting using support vector machines. Int J Neural Syst. 2004;14(5):329-335

[4] Bozic M, Stojanovic M. Application of SVM methods for mid-term load forecasting. Serbian J Electr Eng. 2011;8(1):73-83

[5] Hong WC. Electric load forecasting by support vector model. Appl Math Model. 2009;33(5):2444-2454

[6] De Cosmis S, De Leone R, Kropat E, Meyer-Nieberg S, Pickl S. Electric load forecasting using support vector machines for robust regression. Simul Ser. 2013;45(5):72-79

[7] Türkay BE, Demren D. Electrical load forecasting using support vector machines: A case study. Int Rev Electr Eng. 2011;6(5):2411-2418

[8] Sadli M, Fajriana, Fuadi W, Ermatita, Pahendra I. Electrical peak load forecasting using long short term memory and support vector machine. IOP Conf Ser Mater Sci Eng. 2020;725(1)

[9] Li X, Gong D, Li L, Sun C. Next day load forecasting using SVM. Lect Notes Comput Sci. 2005;3498(III):634-639

[10] Ostojin S, Kulic F, Svenda G, Bibic R. Short-Term Electrical Load Forecasting Using Support Vector Machines. Comput Simul Mod Sci. 2008;I:138-142

[11] Yang M, Li W, Zhang H, Wang H. Parameters optimization improvement of SVM on load forecasting. Proc - 2016 8th Int Conf Intell Human-Machine Syst Cybern IHMSC 2016

[12] Qiang S, Pu Y. Short-term power load forecasting based on support vector machine and particle swarm optimization. J Algorithms Comput Technol. 2018;13:1-8

[13] Matijaš M, Vukićević M, Krajcar S. Supplier short term load forecasting using support vector regression and exogenous input. J Electr Eng. 2011;62(5):280-285

[14] Lin S, Zhang S, Qiao J, Liu H, Yu G. A parameter choosing method of SVR for time series prediction. Proc 9th Int Conf Young Comput Sci ICYCS 2008. 2008:130-135

[15] Sano N, Higashinaka K, Suzuki T. Efficient parameter selection for support vector regression using orthogonal array. Conf Proc - IEEE Int Conf Syst Man Cybern. 2014;2014-Janua(January):2256-2261

[16] Hsia JY, Lin CJ. Parameter Selection for Linear Support Vector Regression. IEEE Trans Neural Networks Learn Syst. 2020:1-6

[17] Gonz A, Skarmeta AF, Mi˘ S. Machine Learning based Electric Load Forecasting for Short and Long-term Period. 2016-2018 IEEE 4th World Forum Internet Things. 2016:511-516

[18] Syarif I, Prugel-Bennett A, Wills G. SVM parameter optimization using grid search and genetic algorithm to improve classification performance.

Telkomnika (Telecommunication Comput Electron Control. 2016;14(4):1502-1509

[19] Zahid M, Ahmed F, Javaid N, et al. Electricity price and load forecasting using enhanced convolutional neural network and enhanced support vector regression in smart grids. Electron. 2019;8(2):1-32

[20] Smets K, Verdonk B, Jordaan EM. Evaluation of performance measures for SVR hyperparameter selection. IEEE Int Conf Neural Networks - Conf Proc. 2007:637-642

[21] Huang Q, Mao J, Liu Y. An improved grid search algorithm of SVR parameters optimization. Int Conf Commun Technol Proceedings, ICCT. 2012;(2):1022-1026

[22] Ma X, Zhang Y, Wang Y. Performance evaluation of kernel functions based on grid search for support vector regression. Proc 2015 7th IEEE Int Conf Cybern Intell Syst CIS 2015 Robot Autom Mechatronics, RAM 2015. 2015:283-288

[23] Lahiri SK, Ghanta KC. The support vector regression with the parameter tuning assisted by a differential evolution technique: Study of the critical velocity of a slurry flow in a pipeline. Chem Ind Chem Eng Q. 2008;14(3):191-203

[24] Zhang H, Chen L, Qu Y, Zhao G, Guo Z. Support vector regression based on grid-search method for short-term wind power forecasting. J Appl Math. 2014;2014

[25] Jason Brownlee. Deep Learning With Python. Machine Learning Mastery Pty. Ltd.: Vermont Victoria, Australia. 2019

[26] Andreas C. Müller and Sarah Guido. Introduction to Machine Learning with Python. In O'Reilly Media, Inc. 2016

[27] Grmanová G, Laurinec P, Rozinajová V, et al. Incremental ensemble learning for electricity load forecasting. Acta Polytech Hungarica. 2016;13(2):97-117

[28] Ngoc TT, Dai L Van. Grid search of exponential smoothing method: A case study of Ho Chi Minh City load demand. Indones J Electr Eng Comput Sci. 2020;19(3):1121-1130

[29] Hyndman RJ, Koehler AB, Ord JK, Snyder RD. Forecasting with Exponential Smoothing: The State Space Approach, 2008

[30] R. Precup, T. Teban, T. E. A. d. Oliveira and E. M. Petriu. Evolving fuzzy models for myoelectric-based control of a prosthetic hand. 2016 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Vancouver, BC. 2016; pp. 72-77

[31] Hedrea, E. L., Precup, R. E., & Bojan-Dragos, C. A. Results on tensor product-based model transformation of magnetic levitation systems. Acta Polytechnica Hungarica. 2019; 16(9): 93-111

[32] Juang, C. F., Lin, Y. Y., & Huang, R. B. Dynamic system modeling using a recurrent interval-valued fuzzy neural network and its hardware implementation. Fuzzy Sets and Systems. 2011; 179(1): 83-99

[33] Cheng, W. Y., & Juang, C. F. A fuzzy model with online incremental SVM and margin-selective gradient descent learning for classification problems. IEEE Transactions on Fuzzy Systems. 2014; 22(2): 324-337

Impact of Preprocessing Features on the Performance of Ultrasound Tongue Contour Tracking, via Dynamic Programming

László Czap

University of Miskolc, Egyetemváros, 3515 Miskolc, Hungary
czap@uni-miskolc.hu

Abstract: The automated assessment of ultrasound images for speech processing is a difficult process. The number of frames processed, amounts to several hundred thousand, this makes assessment nearly impossible to process manually. Tongue contour tracking is indispensable for the dynamic modelling of articulation. The difficulty of the task lies in the fact that the images have a noisy background and the contour curve is discontinuous. An algorithm based on dynamic programming has been developed to track the movement of the back of the tongue. With an extreme size edge enhancing and averaging construction, the procedure addresses the problems of break of discontinuity and noise, simultaneously. In the image obtained after smoothing, the brightest curve is sought, from the left to the right edges of each image. The points of the curve thus obtained, follow the uneven line of the tongue contour. To smooth the curve, filtering based on Discrete Cosine Transformation (DCT) is applied. With the appropriate selection of universal parameters and processing the signals of several speakers in an identical way, the accuracy of edge detection can be enhanced considerably. We have optimized and qualified the results, comparing them with manual contour tracking. The accuracy of contour tracking may be improved by applying speaker-specific adjustments. The results of this analysis define temporary data for articulation key frames for visual speech synthesis (a talking head). Beyond the static analysis, we also investigate the trajectories of articulation features over time. We refined our previously created dynamic model, in order to construct a full dataset for the articulation.

Keywords: ultrasound imaging; tongue contour tracking; dynamic programming; image preprocessing; visual speech synthesis

1 Introduction

Several studies reliably prove that the visual information obtained involving the physiological processes of human speech, greatly promotes the understanding of the complex mechanism of speech formation, and through this, the efficient development of speech synthesis methods [1]. Radiological and monitoring

processes currently available, like magnetic resonance imaging (MRI), computer tomography (CT), ultrasound, electropalatography (EPG), electromagnetic articulography (EMA) or electroglottography (EGG) are indispensable in getting to know the dynamic features of articulation. Using the morphological and geometric data obtained with the help of imaging techniques, it is possible to explore the articulatory movements belonging to a particular speech sign, which is of crucial importance in parametrizing a talking head, imitating articulation. In this research quantitative data from a series of MRI and ultrasound images have been derived. Thus, we provided appropriate parameters for our animation algorithm. The main feature of this application is to show the tongue movements in a transparent-faced talking head training to improve the speech production of deaf and hard of hearing children. Such a system can well be used in, for example, speech therapy, in the elaboration of non-native language learning training or in the construction of synthesizers necessary to convert articulation features into silent speech [2] [3] [4].

This paper is concerned with automated tongue contour tracking on the basis of the processing of ultrasound images. The ultrasound is a method comfortably and simply accessible as in contrast to the MRI and CT equipment, limitedly available in medical centers, an ultrasound head fixed on a portable helmet is sufficient for the tests so the images and sound materials necessary for the analyses can be made flexibly without the speaker being adversely affected by any harmful radiation.

The determination of the boundaries of objects may form the basis of the separation of objects or segmentation. Several image processing tasks are connected to segmentation, especially in medical imaging. Its use is widespread in the checking of blood vessels [5] [6] as well as in the measuring of bones [7]. The analysis of the changes in the brain [8], in the thyroid nodules [9], or the prostate gland [10] can be regarded as typical applications. The analysis of ultrasound image patches is also supported by universally applicable procedures [11] [12] [13].

With images taken for the purpose of speech processing, it is advantageous, that with ultrasound imaging, images of high resolution (almost a thousand pixels in a radial section) and high speed (80-85 images per second) can be made. Good spatial resolution is indispensable for the shape of the tongue to be displayed as sharply as possible while good temporal resolution supports the possibility of studying the rapid co-articulation changes occurring during continuous speech in a reliable way. It should not be left out of consideration, either, that ultrasound is particularly suitable for analyzing continuous speech as the time necessary for scanning the vocal tract is only a fragment of the time required by e.g. MRI imaging. However, work is made more difficult by the circumstance that in contrast to the MRI and CT images helping collect three-dimensional morphological information, ultrasound only provides information about the position of the tongue in the two-dimensional midsagittal plane so the contour of the palate and the tip of the tongue are not displayed in the image. A further

technical problem is that the surface contour of the tongue should be defined with the greatest possible accuracy during post-processing, which is not a trivial task.

During our work, the processing of the ultrasound images was carried out with the help of our software written in a MATLAB environment, in the course of which an auxiliary curve was fitted on the surface of the tongue, relying on dynamic programming. The verification of contour tracking results was performed on the basis of the article by Tamás Csapó and Steven Lulich [14]. During the movements of the tongue, the position of the auxiliary curve changes dynamically, therefore such a data set was obtained the elements of which varied in both space and time.

One type of procedures tracking tongue contour requires training with the contours manually marked in a large number of images, involving the application of artificial intelligence methods. The number of training images is e.g. 5,000 [15] or 700 radiographs and 400 ultrasound images [16]. Mozzafari et al. use 80% of the ultrasound frames for training [17] [18]. The accuracy of solutions not requiring any training usually falls behind of methods that requires machine learning. We have developed such a tongue contour tracking procedure not requiring training, the accuracy of which is competitive with that of the procedures requiring it.

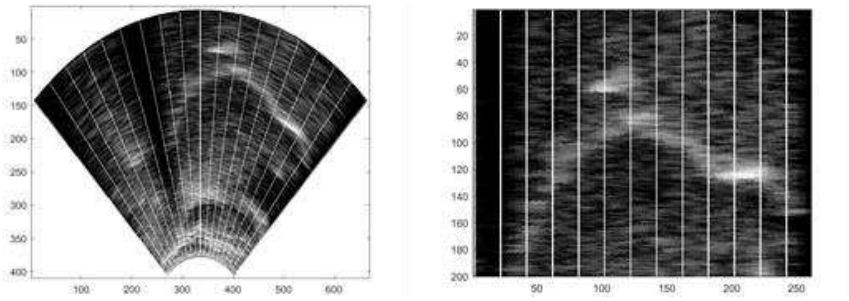
2 The Method of Tongue Contour Tracking

An algorithm based on dynamic programming, has been developed herein, to track the movement of the back of the tongue. In the ultrasound image, tongue contour is created by the radiation reflected at the boundary of the tongue and the air above it. The curve of the back of the tongue is detected at the lower boundary of the bright band, thus obtained. The analysis requires several steps. First, the preprocessing of the image is completed. The extreme size Prewitt kernel, addresses the problems of break of discontinuity and noise, simultaneously. In the image obtained after filtering, the curve which has a maximum accrued brightness from the left to the right edge of the image is identified. The points of the curve thus obtained, follow the uneven line of the tongue contour. To smooth the curve, filtering based on Discrete Cosine Transformation (DCT) is applied. The smoothing of the curve improves the continuity of the contour and makes comparison possible with the results of manual contour detection.

2.1 Preprocessing Steps

As a first step, the image is resampled forming radial sections starting from the center of a circle. By arranging the sections thus obtained in a Cartesian column graph, a matrix is gained. Sampling performed by quarter degree has been arrived

at through experience so that there should not be a bigger difference than two pixels between the neighboring columns in the contour. Figure 1 a) shows the detection of the center of the circle and the line of the radial sections. For the sake of clarity, sections are only represented by five degrees. The matrix obtained after sampling is shown in Figure 1 b).



a) b)

Figure 1

a) Radial ultrasound image b) Column graph after resampling

Moving top-down, in a column of the image, a falling edge is searched for, where brightness decreases. In image processing, search for edges is made through examining the variation of the brightness of pixels and developing differences. With noisy images, however, enhancing differences leads to the improvement of noise. Noise removal and search for edges may be performed in one step in the way that the difference in brightness is not developed pixel by pixel but brightness is averaged for a bigger patch – thus noise reduction is performed – and the difference is developed for another patch of similarly averaged brightness.

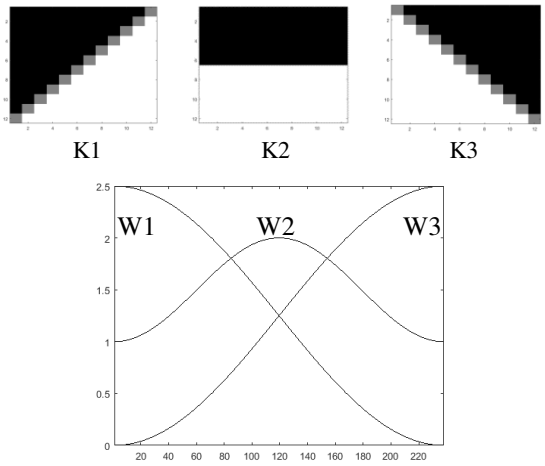


Figure 2

Prewitt kernels performing averaging and edge detecting for edges of different directions (above). Weighting functions of tri-directional edge enhancement (below).

In the top part of Figure 2, 12x12 pixel Prewitt kernels can be seen. Black stands for -1, white for +1 and grey for 0. The kernel performs averaging on the patch covered by the white area and then subtracts the mean of the patch marked with black from it. (The 1/144 multiplier to be applied for leaving the dynamic range unchanged is not included in the figure.) By applying the kernel (convolution), the difference between the averaged brightness of the two patches is obtained for a pixel of the image. Among the edge enhancement procedures, the Prewitt kernel proved to be the most effective in simultaneously handling noise and discontinuity. It can be observed in the ultrasound images, that on the left side of the image, the edges of the tongue contour are close to the direction of the minor diagonal of an imaginary square matrix, they are horizontal in character in the center of the image while on the right side of the image, they approximate the direction of the main diagonal. For each column, the result of the convolution performed with three kernels is weighted with the functions that can be seen in the bottom part of Figure 2. (W1: quarter-wave $\cos^2$, W2: full-wave raised -cos, W3: quarter-wave $\sin^2$. We have not examined any other weighting functions.) As a result, on the left side of the image, the edge enhancement performed with kernel K1, in the middle that performed with kernel K2 and on the right side that performed with kernel K3 is given greater weight. In the three weighted edge enhancement matrixes, the maximum is searched for each pixel, which is regarded to be the edge marker for each pixel. In comparison with W2, the weighting of W1 and W3 has been developed as a result of optimization.

After resampling, it is useful to apply vertical offset with the mean of the tongue contour measured in a lot of images in each column (Figure 3 a)). This step has a double role.

1) The slope range of the edges decreases and thus the efficiency of edge enhancement improves.
2) The area of the tendon, which might often lead to false edges, is shifted out of the image (see the thin white patch in the bottom third of image a) Figure 3).

The white band that can be seen at about row 350 of part a), Figure 3 is caused by the reflection of the tendon.

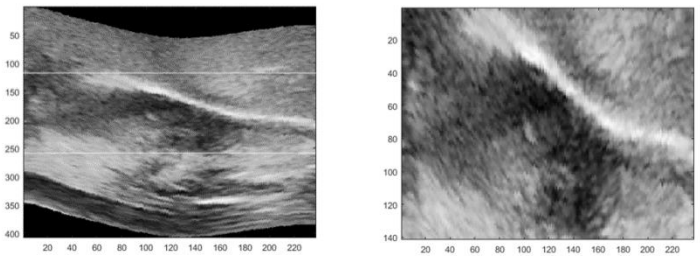


Figure 3

a) Offset column graph b) The area to be processed

After this, it becomes possible to detect the region of interest (ROI) (Figure 3 b). The axes of the figure indicate the row number of the pixels and the serial number of the column.

Performing convolution with the kernels in Figure 2 after the application of the relevant weighting, the edge enhancements distinguished by direction in Figure 4 are obtained. In Figure 4 a), weighting enhances the left side of the image suppressing the right side and reinforcing the edges close to the direction of the minor diagonal. In Figure 4 b), the center of the image is enhanced, keeping the edges of the horizontal direction at the edge of the image, as well. In Figure 4 c), the weighting reinforces the edges characteristic of the right side of the image, close to the direction of the main diagonal, attenuating the false edges that may be obtained on the left side of the image. Figure 4 d) shows the edge marker derived by forming the maximum pixel by pixel.

In part d) of Figure 4, especially in the third of the image on the left, the edge marker does not show continuity. We may improve continuity with a further averaging filter (11 x 11 matrix). Figure 5 shows the results.

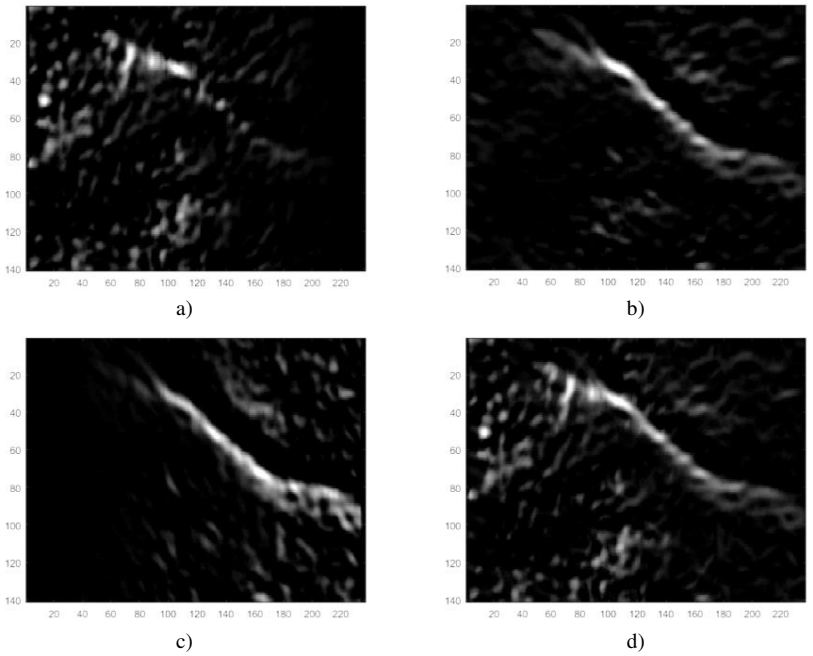


Figure 4
The result of edge enhancement after the convolution performed with kernels
a) K1
b) K2
c) K3
d) The unified edge marker

In the image thus obtained, the curve with the highest cumulated brightness is searched for from the left to the right edge of the image.

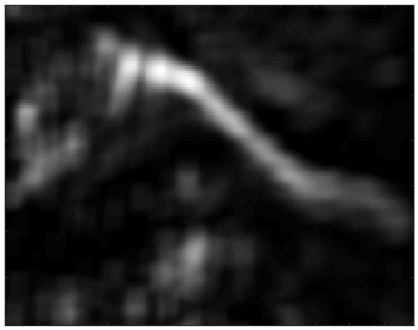


Figure 5
The image of edge enhancement with improved continuity, obtained after further averaging

The algorithm of dynamic programming has free end-to-end connectivity so it may start at any row of the first column and may end at any row of the last column. The cumulated sum should be defined for each pixel, moving from left to right. Cumulated brightness and the information from which pixel it has been accessed should be stored in each pixel. Therefore, it is examined for each pixel, which of the altogether five pixels among those in the preceding two rows and the following two rows in the previous column has the greatest cumulative brightness. You get the maximum brightness of the pixel being examined if the brightness of it is added to this sum. If you move on from the previous one or two rows of the previous column of the matrix representing the image, you go one or two rows downwards. If you obtain the maximum moving on from the following one or two rows of the preceding column, you go one or two rows upwards. You move on horizontally in the same row. If you find the maximum of the last column, the curve of the tongue contour may be reverse-engineered from this pixel. In Figure 6, the tongue contour detected in the column graph is indicated with white dots.

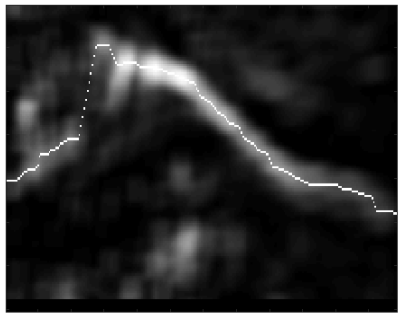


Figure 6
Uneven tongue contour obtained in the column graph

Figure 7 shows the contour projected back on the radial figure. The curve obtained follows the unevenness of the edge. The curve may be filtered with discrete cosine transformation. The smoothed curve is indicated with a line of white dots.

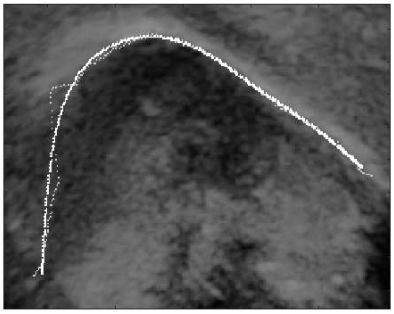


Figure 7
The uneven (thin grey) curve and the smoothed (thick, white) contour projected back on the radial image, enlarged

2.2 Parameter Initialization

In the ultrasound image, inaccuracy is not manifested in a little displacement of the edges but in some sections of the tongue contour, the search algorithm "gets lost" and finds an alien edge the brightest. Figure 8 gives examples for both correct and false edge detection, indicated the tongue contour found with a white curve.

a) b)

Figure 8
a) Correct b) False edge detection (< shift)

In our procedure, the success of edge detection is influenced by four parameters:

1) The size of the edge enhancing kernel.
2) The weighting of W1 for the edges parallel with the minor diagonal.

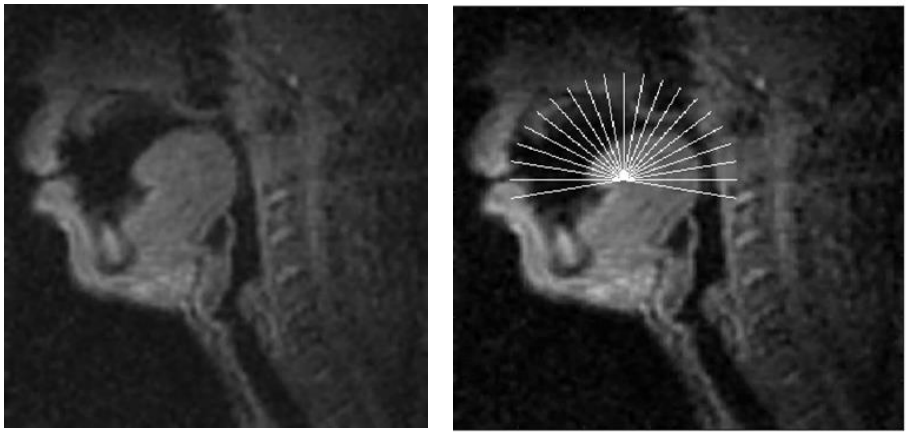
3) The weighting of W3 for the edges parallel with the main diagonal.

4) The size of the smoothing kernel.

These features can be changed independently. The right size kernel results in more spectacular weighted edges that yields the most highlighted edge after smoothing. The optimization has been performed with a comparison with manual contour detection.

2.3 Extending the Method to the Processing of MRI and CT Images

The procedure described is not only suitable for the processing of ultrasound images but the borderlines of the objects may be detected with it in images obtained with other imaging procedures, too. During the processing of the MRI and CT images, the difference is only that resampling is performed with a different center and radius, and moving upwards from the bottom, in contrast to ultrasound images it is not increasing (rising edge) but decreasing (falling edge) brightness transitions that are searched for. Part a) of Figure 9 shows the original MRI image while in Figure b), the radiuses of the radial resampling can be seen. (For the sake of traceability, radiuses are plotted by 10° while resampling is performed by 1°.)

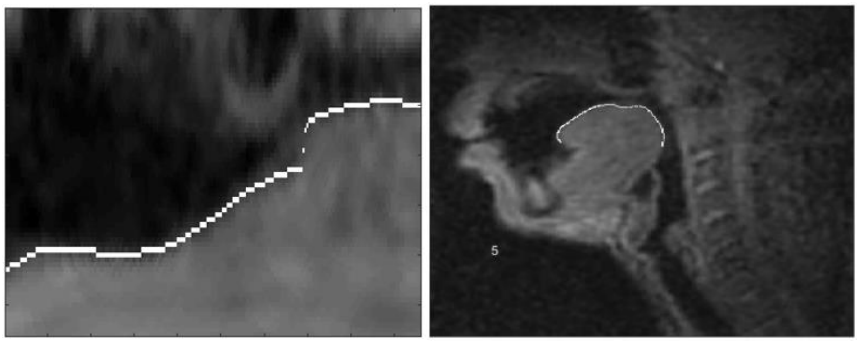


a) b)

Figure 9

a) The original MRI image b) Resampling radiuses

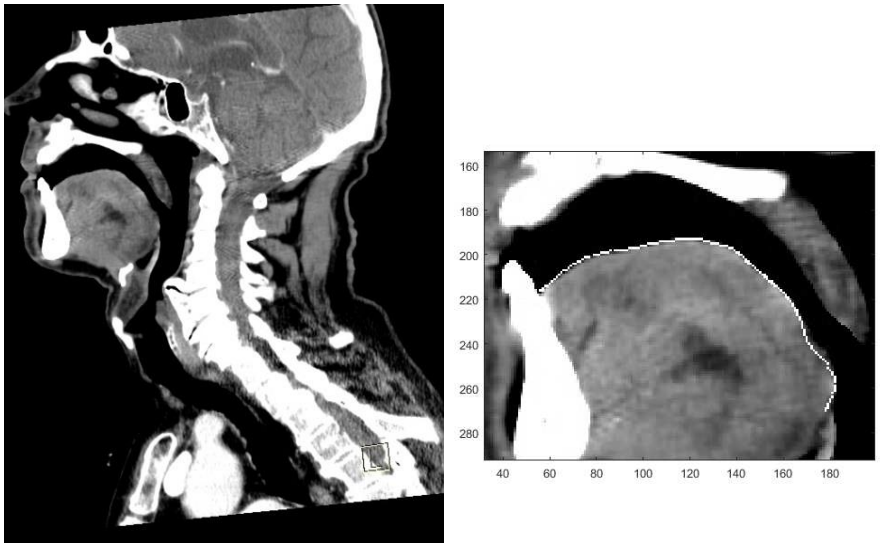
In image a), Figure 10, the resampled image is shown spread in the Cartesian coordinate system The detected contour is indicated with white dots. In Figure b), tongue contour can be traced projected back on the original image.



a) b)

Figure 10

a) The spread image with the white contour b) The tongue contour detected in the original image

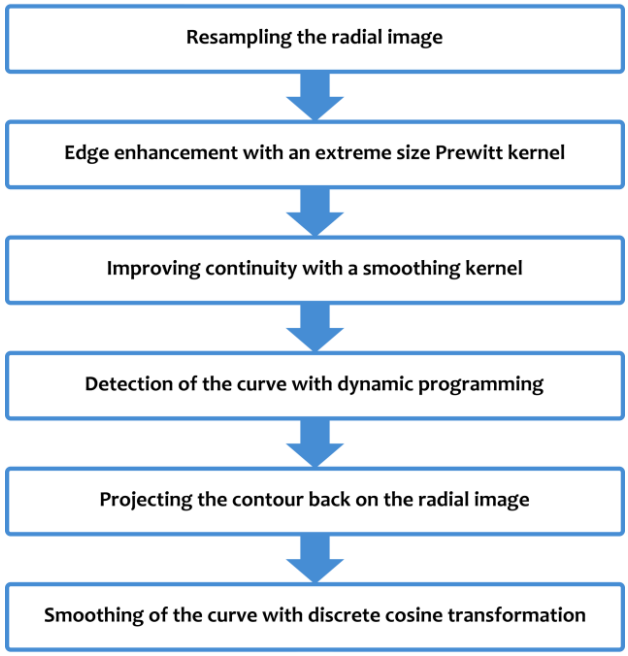


a) b)

Figure 11

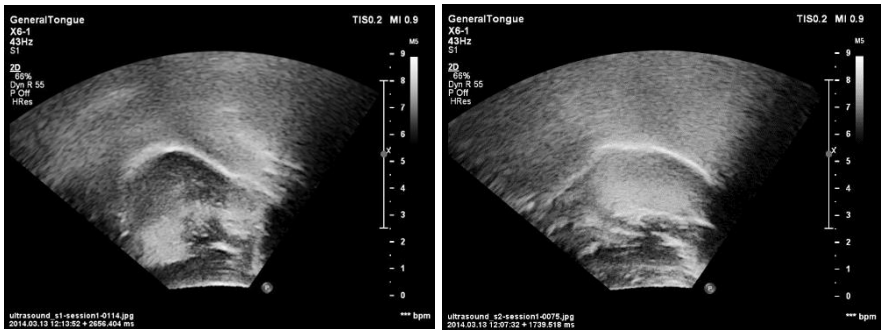
a) CT image b) The enlarged area of the tongue with the white contour

Steps of the applied contour tracking procedure:



3 Results

The verification of the results of tongue contour tracking was performed on the same set of ultrasound images on which Tamás Csapó and Steven Lulich [14] had compared contour tracking processes. Two female (F1, F2) and two male speakers (M1, M2) said the sentence 'I owe you a yoyo' twice, one after the other, in the recording. Figure 12 shows the variation in the tongue contour sharpness of the four speakers.



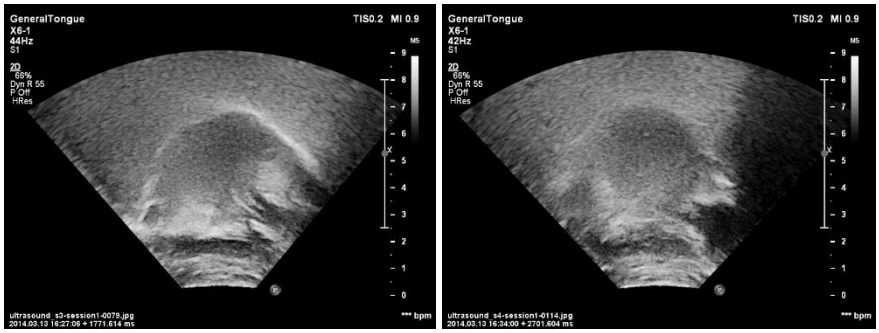


Figure 12
Ultrasound images of the four speakers in the middle of the first 'o' sound of the word 'yoyo' (From left to right: top: F1, F2, bottom: M1, M2)

It can clearly be seen that the sharpness of tongue contour is different for the four speakers. The success of manual and automatic contour tracking is strongly influenced by edge visibility. Csapó and Lulich [14] performed manual contour detection with seven volunteers. Mean Absolute Error was used to characterize manual contour detection (Table 1). The table confirms the visual qualification of the tongue contours in Figure 5. During the assessment of automatic tongue contour detection, the accuracy that can be expected depends on image quality, which can be characterized with the mean error of manual processing.

Table 1
Mean absolute error of manual contour detection (mm)

Speaker	**F1**	**F2**	**M1**	**M2**
Mean Absolute Error	0.95	1.09	1.17	2.11

Four free access methods were tested for automatic contour tracking. The best result was yielded by the AutoTrace3.5 setting. Images were divided into two parts, so that the sample sentence appeared once in every series of images. The two samples of the four speakers yield altogether eight series of images. In the case marked as AutoTrace3.5, training samples were represented by the average of the manual contour detections of seven image series and testing was performed on the eighth image series. When the speaker's own image series was not involved in the training (AutoTrace3 but six image series from the other three speakers were used for training and the speaker's own two image series were used for testing), the accuracy of contour tracking deteriorated drastically. Table 4 includes the Root Mean Square Error (RMSE) values for the different procedures. Averaging was performed on the logarithm of square error, and then the result was restored with an exponential function (logRMSE). Data are given in mm, in the enlargement applied in the images, 1 mm = 4.24 pixels.

In our approach, with optimizing the parameters of the proposed contour tracking algorithm, we strove for a universal setting: the four features listed in Section 2.2 are identical for all the four speakers. This is presented next.

Table 2
logRMS error in contour tracking with the universal setting (mm)

Speaker	F1	F2	M1	M2	Mean
logRMS error	0.66	0.88	1.10	2.13	1.19

As an example, Figure 14 shows the impact of the size of the smoothing filter, apparently influencing the accuracy of contour tracking considerably.

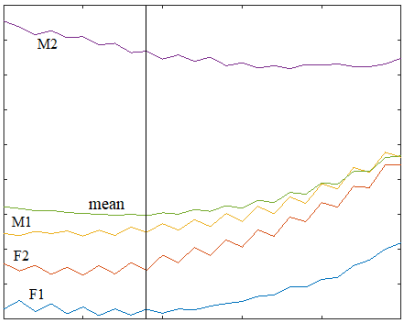


Figure 13
Mean error for each speaker and for the mean of the four speakers as a function of the size of the smoothing screen

With the setting yielding the smallest mean error, 11x11 pixels was the optimum size of the edge enhancing Prewitt kernel and 2.5 was the value of W1 and W2 weighting. As Figure 13 testifies, for the four speakers, the optimum size of the smoothing filter ensuring the smallest mean error, regarding the average of the four speakers, was 14x14 pixels (vertical line).

Performing the optimizing of parameters for each speaker after this, we obtained individual, speaker-specific settings with the speaker-specific selection of the edge enhancing kernel and the smoothing kernel. The result can be further improved by the individual setting of W1 and W2 weighting. Table 3 shows logRMS errors obtained with optimum settings for each speaker. The speaker selected for optimization is indicated in the 'Reference' column.

Table 3
logRMS error of contour tracking with the individual settings (mm)

Reference	F1	F2	M1	M2	Mean
F1	**0.55**	0.91	1.12	2.45	1.26
F2	0.91	**0.80**	1.05	2.65	1.35
M1	0.75	0.81	**1.02**	2.51	1.27
M2	0.79	1.17	1.31	**1.94**	1.30

As regards the optimum size of the edge enhancing kernel, there was no considerable difference between the speakers. W1 weight had to be increased for speaker F1 and W2 weight for speakers F2 and M2. For the size of the smoothing kernel, for speaker F1 the optimum proved to be 11x11 pixels, for speakers F2 and M1 10x10 pixels and for speaker M2 24x24 pixels. The optimum values of universal parameters lie between the individual optimum values.

Table 4
logRMS errors of automatic contour tracking (mm)

Speaker	**F1**	**F2**	**M1**	**M2**	**Mean**
AutoTrace3	5.85	7.06	5.59	9.94	7.11
EdgeTrak	1.95	3.46	1.89	5.15	3.11
TongueTrack	1.96	3.15	2.76	3.6	2.87
AutoTrace3.5	1.15	1.93	1.78	2.19	1.76
Proposed	**0.55**	**0.80**	**1.02**	**1.94**	**1.08**

Logarithm formation compresses the dynamic range with the weight of outstandingly high errors decreasing.

Figure 14 shows the values of Table 4 in graphic representation.

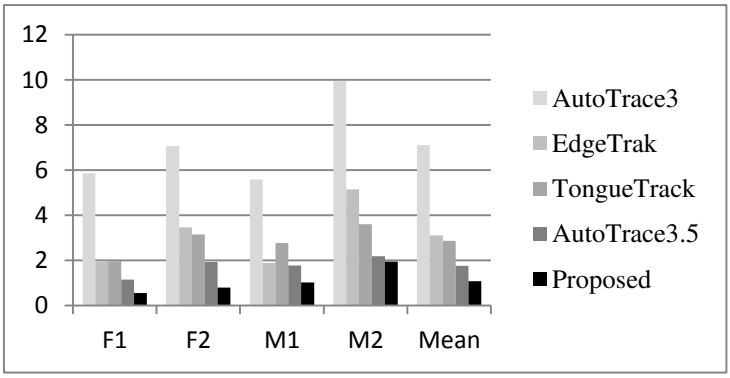


Figure 14
logRMS errors of the specific contour tracking procedures

Table 5 presents the different means of the errors in proposed contour tracking as compared with the mean of manual contour detection (logRMSE, linear RMSE, Mean Absolute Error).

Table 5
Different errors in proposed contour tracking (mm)

Speaker	**F1**	**F2**	**M1**	**M2**	**Mean**
logRMSE	0.55	0.80	1.02	1.94	1.08
linRMSE	0.63	0.99	1.24	2.36	1.31
Mean Absolute Error	0.33	0.41	0.45	0.64	0.46

It is a significant result that our tongue contour tracking algorithm based on dynamic programming yielded a smaller error than the other procedures tested by Csapó and Lulich [14]. The mean error calculated for the four speakers also proved to be the smallest with the method developed by us. In addition, with the AutoTrace3.5 application, having proved the best, contour detection requires training. Researchers have not examined the number of training samples necessary for a reliable result. Our method, based on dynamic programming, only requires the detection of the region of interest to avoid false edges.

As regards manual contour tracking, own logRMSE values for speakers F1 and F2 are better than that of each assessor. For speaker M1, 2 manual assessors out of the seven gave a better result and five worse than the ones designated as 'proposed'. With speaker M2, two assessors tracked tongue contour with a smaller while a third with identical error and four assessors achieved weaker tracking.

In lack of the set of images examined, we are unable to compare our proposed results with other published data, furthermore, the measures of accuracy are different. Mean Sum of Distance (MSD) is an often applied distance measure, especially for curve pairs with different indexing. For each point, the formula takes into account the nearest point in the other curve.

$$D(U,V) = \frac{1}{m}\sum_{i=1}^{m} \min_{j} \left|u_i - v_j\right| + \frac{1}{n}\sum_{i=1}^{n} \min_{j} \left|v_i - u_j\right| \tag{1}$$

In calculating the absolute error in Table 6, we considered radial distances but nothing guarantees that this is also the nearest point. This way, the absolute error calculated by us cannot be smaller than MSD.

In the relevant literature, Zhu et al. [15] specify the most favorable MSD error as 0.85 mm. Xu et al. [19] obtained 0.87 mm MSD error for the most precisely tracked speaker. For ultrasound contour tracking, [20] reported an absolute error of 0.5 mm. Without providing the distance measure, Tang et al. [20] tracked tongue contour with a 3 mm mean error. Mozaffari et al. [17] published 0.91 and [18] 0.61 mm MSD errors. Jaumard-Hakoun et al. [22] reported a 0.67 mm MSD error. Roussos et al. [16] gave the RMS error of contour tracking in a graphic form, which shows a minimum 1.5 mm as can be read in the relevant figure.

The description of tongue contour and the assessment of its data, cannot yet be regarded to be completely elaborated [23]. The results closest to the mean of manual detection were obtained by using the first seven coefficients of the discrete cosine transformation used for contour smoothing. Consequently, the complete tongue contour can be characterized with seven data but it is difficult to connect DCT coefficients with the geometric data. The detailed analysis of tongue contours requires further investigations.

Conclusions

In the field of speech processing, it is an immense advantage of the ultrasound imaging systems, of being suitable for tracking rapid movements, image and sound synchronization and it presents only a minimum inconvenience to the speaker, who is also not affected by any harmful radiation. Its disadvantage is that it does not provide a full three-dimensional image, but only shows either a longitudinal or transverse section and the tip of the tongue cannot be seen. The longitudinal (midsagittal) section is the most suitable for tracking tongue movements.

In the course of preprocessing, we simultaneously cope with the problems of edge enhancement and noise removal, which are two contradicting required goals. The parameters of the pre-processing steps are of decisive importance. With their appropriate selection, contour tracking accuracy, surpassed all the other procedures investigated. Performance can be improved further with the application of speaker-specific settings. The results show that the analysis of the articulation on the basis of ultrasound images not only makes it possible to define the static data of tongue position but also offers the opportunity to perform a dynamic description of tongue movements [24].

Ultrasound and MRI tongue contour analysis has paved the way for the designation of a new research direction. We explore the possibility of combining the benefits of the two imaging methods: Good spatial and temporal resolution of the ultrasound recordings and the three dimensional representations of the tongue, by MRI imaging.

Acknowledgements

The described study was carried out as part of the EFOP-3.6.1-16-00011 “Younger and Renewing University – Innovative Knowledge City – institutional development of the University of Miskolc aiming at intelligent specialization” project implemented in the framework of the Szechenyi 2020 program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

We would also like to thank the Lingual Articulation Research Group (Hungarian Academy of Sciences), for providing the recordings with the SonoSpeech system, and Tamás Gábor Csapó for the consultation on their method and providing the series of images and the data set they used.

References

[1] Barnaud, M-L., Schwartz, J-L., Bessière, P., Diard J. (2019) Computer simulations of coupled idiosyncrasies in speech perception and speech production with COSMO, a perceptuo-motor Bayesian model of speech communication. PLOS ONE pp. 1-34

[2] Csapó, T. G. (2020) Speaker dependent articulatory-to-acoustic mapping using real-time MRI of the vocal tract, In Proc. Interspeech 2020, 2722-2726, DOI: 10.21437/Interspeech.2020-0015

[3] Gábor Gosztolya, Tamás Grósz, László Tóth, Alexandra Markó, Tamás Gábor Csapó, (2020) Applying DNN Adaptation to Reduce the Session Dependency of Ultrasound Tongue Imaging-Based Silent Speech Interfaces', Acta Polytechnica Hungarica, Vol. 17, No. 7, pp. 109-124, 2020

[4] Douros, I. K., Kulkarni, A., Dourou, C., Xie, Y., Felblinger, J., Isaieva, K., Vuissoz, P., Laprie, Y. (2020) Using Silence MR Image to Synthesise Dynamic MRI Vocal Tract Data of CV. Proc. Interspeech 2020, 3730-3734, DOI: 10.21437/Interspeech.2020-1173

[5] Liang, Q; Wendelhag, I; Wikstrand, J; Gustavsson, T. (2000) A multiscale dynamic programming procedure for boundary detection in ultrasonic artery images. IEEE Trans Med Imaging 2000, 19, 127-142

[6] D. Cheng and X. Jiang, (2008) Detections of Arterial Wall in Sonographic Artery Images Using Dual Dynamic Programming, in IEEE Transactions on Information Technology in Biomedicine, Vol. 12, No. 6, pp. 792-799, Nov. 2008, doi: 10.1109/TITB.2008.926413

[7] Pezhman Foroughi, Emad Boctor, Michael J. Swartz, Russell H. Taylor, and Gabor Fichtinger (2007) Ultrasound Bone Segmentation Using Dynamic Programming. IEEE Ultrasonics Symposium. New York, NY, USA, 28-31 Oct. 2007, pp. 2523-2526

[8] Ahmad S, Wu Z, Li G, Wang L, Lin W, Yap PT, Shen D. (2019) Surface-constrained volumetric registration for the early developing brain. Med Image Anal. 2019 Dec; 58:101540. doi: 10.1016/j.media.2019.101540. Epub 2019 Aug 1. PMID: 31398617; PMCID: PMC6815721

[9] Liu T, Guo Q, Lian C, Ren X, Liang S, Yu J, Niu L, Sun W, Shen D. (2019) Automated detection and classification of thyroid nodules in ultrasound images using clinical-knowledge-guided convolutional neural networks. Med Image Anal. 2019 Dec; 58:101555. doi: 10.1016/j.media.2019.101555. Epub 2019 Sep 5. PMID: 31520984

[10] Ghavami N, Hu Y, Gibson E, Bonmati E, Emberton M, Moore CM, Barratt DC. (2019) Automatic segmentation of prostate MRI using convolutional neural networks: Investigating the impact of network architecture on the accuracy of volume measurement and MRI-ultrasound registration. Med Image Anal. 2019 Dec; 58:101558. doi: 10.1016/j.media.2019.101558. Epub 2019 Sep 11. PMID: 31526965

[11] T. McInerney and D. Terzopoulos, (1996) Deformable models in medical image analysis: a survey, Med. Image Anal., Vol. 1, No. 2, pp. 91-108

[12] Jingfeng Jiang and Timothy J. Hall (2009) A Generalized Speckle Tracking Algorithm for Ultrasonic Strain Imaging Using Dynamic Programming. Ultrasound Med Biol. 2009 November; 35(11): pp. 1863-1879

[13] Kathrin Ungru, Xiaoyi Jiang (2017) Dynamic Programming Based Segmentation in Biomedical Imaging. Computational and Structural Biotechnology Journal 15, pp. 255-264

[14] Csapó T. G., Lulich S. M. (2015) Error analysis of extracted tongue contours from 2D ultrasound images. Interspeech, pp. 2157-2161

[15] Jian Zhu, Will Styler, Ian C. Calloway (2019) A CNN-based tool for automatic tongue contour tracking in ultrasound images. ArXiv 2019, Vol. 1907.10210

[16] A. Roussos, A. Katsamanis and P. Maragos, (2009) Tongue tracking in Ultrasound images with Active Appearance Models, 16th IEEE International Conference on Image Processing (ICIP), Cairo, 2009, pp. 1733-1736, doi: 10.1109/ICIP.2009.5414520

[17] Mohammad Hamed Mozaffari, Shuangyue Wen, Nan Wang, Won-Sook Lee: (2019) Real-time Automatic Tongue Contour Tracking in Ultrasound Video for Guided Pronunciation Training, 14th International Conference on Computer Graphics Theory and Applications, Prague, Czech Republic

[18] M. Hamed Mozaffari, Md. Aminur Rab Ratul, Won-Sook Lee: IrisNet: Deep Learning for Automatic and Real-time Tongue Contour Tracking in Ultrasound Video Data using Peripheral Vision, arXiv preprint arXiv:1911.03972

[19] Xu K, Yang Y, Stone M, Jaumard-Hakoun A, Leboullenger C, Dreyfus G, Roussel P, Denby B. (2016) Robust contour tracking in ultrasound tongue image sequences. Clin Linguist Phon.; 30(3-5):313-27, doi: 10.3109/02699206.2015.1110714. Epub 2016 Jan 20. PMID: 26786063

[20] Changsheng Yang, Maureen Stone (2002) Dynamic programming method for temporal registration of three-dimensional tongue surface motion from multiple utterances. Speech Communication 38, pp. 201-209

[21] Tang, L., Bressmann, T. & Hamarneh, G. (2012) Tongue contour tracking in dynamic ultrasound via higher-order mrfs and efficient fusion moves. Medical Image Analysis, 16(8), pp. 1503-1520

[22] Aurore Jaumard-Hakoun, Kele Xu, Pierre Roussel-Ragot, Gérard Dreyfus, Maureen Stone, et al. (2015) Tongue contour extraction from ultrasound images based on deep neural network. The International Congress of Phonetic Sciences, Aug 2015, Glasgow, United Kingdom ⟨hal-01366237⟩

[23] Fabre, D., Hueber, T., Girin, L., Alameda-Pineda, X., Badin, P. (2017) Automatic animation of an articulatory tongue model from ultrasound images of the vocal tract. Speech Communication, Vol. 93, pp. 63-75S

[24] Zhao, Lu, Czap, László (2019) Visemes of Chinese Shaanxi Xi'an Dialect Talking Head, Acta Polytechnica Hungarica, Vol. 16, No. 5, pp. 173-193

Exploring the Relationship between Corporate Social Responsibility and Sales Growth of Small and Medium Enterprises: A Combined Case Study in the Light of a Literature Review

Jintao Lu[1,2,*], Dan Rong[1], Chong Zhang[1], Chunyan Wang[1], Parvaneh Saeidi[3], Justas Streimikis[4]

[1] Department of Business Administration, School of Economics and Management, Taiyuan University of Science and Technology, Taiyuan 030024, P. R. China, e-mail: lujintao@tyust.edu.cn (J. L.); S20190744@stu.tyust.edu.cn (D. R.); zhangchong@tyust.edu.cn (C. Z); S20190745@stu.tyust.edu.cn (C. W.)

[2] Research Center for Corporate Social Responsibility, Taiyuan University of Science and Technology, Taiyuan 030024, P. R. China

[3] Facultad de Negacios, Universidad del Pacifico, Ecuador, e-mail: Parvaneh.saeidi@upacifico.edu.ec

[4] Lithuanian Institute of Agrarian Economics, A. Vivulskio g. 4A-13, 03220 Vilnius, Lithuania; The University of Economics and Human Science in Warsaw, Okopowa 59, 01-043 Warsaw, Poland, justas.streimikis@laei.lt

Abstract: The purpose of this study is to analyze the influence of Corporate Social Responsibility (CSR) on a firms' sales growth and to assess the mediating role of competitive advantage and the moderating role of the employee's individual belief of social responsibility (SR) on the relationship between CSR and sales growth of small and medium enterprises. A survey of 107 small and medium enterprises (SMEs) in the consumption and manufacturing industry of a developing country was performed. Structural equation modeling based on AMOS path was employed to test the hypotheses linked to the relationship between CSR and sales growth of SMEs. Results indicate that the link between CSR and sales growth is mediated through competitive advantage and that the positive impact of CSR on sales growth is moderated by the employee's individual belief of social responsibility.

Keywords: corporate social responsibility; competitive advantage; employee's individual belief of social responsibility; small and medium enterprises

1 Introduction

Corporate Social Responsibility (CSR) has been acknowledged by companies, institutions, organizations and society, as the main trend of sustainable business development providing also for competitive advantage of the companies. It has therefore sparked an interest within academic communities, both locally and globally, to study corporate social responsibility initiatives from diverse angles covering strategic goals [13, 51, 55, 76] has been referred as a term in which the multi-faceted associations between companies and societies are represented [38, 39, 80, 68].

It is obvious that there are many relations between the economic, social and environmental issues of all business activities though traditionally companies were mainly concentrated on economic aspects in their actions. The scholars [29, 43, 51, 73, 76] in their studies showed that for generation of revenue or profits companies need to address consumers' behavior. Therefore, firms should not only be too obsessed with the profitability without giving any consideration to societies' needs and expectations. For instance, in the present ground reality of businesses, customers appear to have a certain level of awareness and concerns about environment, leading to increased demand in environmentally friendly products and services. Thinking along these lines, it can therefore be presumed that the asserted relationship between CSR and firm execution appear to be more muddled than what the related former analyses have reported. Therefore, there is a strong need to demystify the complexities of the link between environmental, economic, and social aspects by means of rigorous empirical investigations.

In this regard, this study attempts bridge some gaps identified in the preceding investigations and to extend extending some views developed by these studies by linking economic, social and environmental issue of CSR with profitability of companies. For this reason, a competitive advantage which is closely linked to firms' ability to increase satisfaction and loyalty of customers is being measured as the outcome of being environmentally friendly. In relation to this, a relevant question to address this aspect was asked in this study: 'Does being responsible toward the environment lead to firms' sales growth through the competitive advantage as a mediator?'.

It is worth noting, that most scholars investigated the benefits of CSR, by putting more attention on the financial issues linked to CSR and were not dealing the impacts on employees. However, considering the presently fast increment of CSR practices, an inquiry into the CSR, representatives' states of mind and firms' execution have jointly become essential. Scholars have therefore attempted to investigate how employees' perceived CSR may affect different aspects of firms' outcomes. Some studies analyzed the impacts of perceived CSR on employees' commitments [63, 69]. Other scholars examined the effect of CSR on employees' performance [25, 26, 30, 70]. Several studies analyzed the influence of CSR on

perceptions and disposition of potential employees and current workers of companies [2, 20, 33, 48]. In these studies, CSR was being considered as an independent factor and employees' outcomes were being analyzed as dependent factors. These studies found that CSR initiatives have positive impact on relationships between the organizations and its employees however the quality of these relationships and the main drivers of it are not fully addressed in these studies.

Therefore, the current study attempts to fill this gap identified in the literature by means of investigating the level and effect of employees' individual perceptions of social responsibilities as a moderator on CSR-sale growth relationship and to address the role of competitive advantage as mediator in relationship between CSR and sales growth of the company.

Considering the essential advances that have been made, thus far and moving to the center of CSR, one of the aspects which have received considerably less consideration within this wide research plan relates to a particular focus on small and medium enterprises (SMEs) in CSR among the developing countries. For these countries CSR issues are new but have very important impact on their sustainable development taking into account the important challenges addressed by Sustainable Development Goals (SDG). Scholars stressed that the collective grandness of small businesses has often have been underestimated in CSR studies [39, 59]. SMEs have therefore been fundamentally contributing to the creation of occupations and lightening poverty among developing nations. Estimated to represent about 90% of businesses internationally and half to 60% of occupations, SMEs have been depicted as the imperative spines of sound monetary developments and essentialness, as they help improve the livelihood, in support of the young entrepreneurial ability and significantly contribute to the systemic gainful limits that may in turn serve to encourage competitions and innovations of developing nations [40]. Additionally, SMEs are also found to be unequivocally established in their respective communities, and they are mostly nearer to their workers and group supporters [23, 39, 41, 61]. In this regard, a sample of SMEs drawn from a developing country in which, local firms are expected to actively assist their surrounding communities could be useful in relating CSR results to an overall setting [76]. Therefore, Iran has been selected for this case study as developing nation having important SMEs sector starting to implement CSR initiatives.

The rest of the paper is structured in the following way: Section 2 presents literature review and hypotheses development; Section 3 introduces methods, sampling and data; Section 4 discusses the results of study and the last, Section 5, concludes.

2 Literature Review and Hypotheses Development

The literature review performed in this section of paper aims to develop hypotheses for empirical study in Iranian SMEs. The studies dealing with CSR impacts on sales growth of the firm are discussed thereafter. The CSR is broadly defined as firm's commitment to avoid negative consequences and to maximise long-term benefit for the society [16, 20, 49, 56, 81, 82]. Authors [44, 80] stressed ethical responsibility of companies in development of CSR concept. Carroll's [14, 15] concept of CSR is one of the best known and accepted. It includes the main notion that the goal of the company in modern society is not only increase in profits but also its responsibility towards society. Many scholars [10, 20, 29, 76] used the same position and classification of social responsibilities of companies introduced by Caroll [14, 15]: cultural, economic, social, ethical, legal, environmental etc. The Carroll's dimension of CSR was revised by scholars [50, 51, 47, 48] in order to address the firm's acknowledgment of CSR.

As has been discussed in the foregoing, the main aim of the company is to produce more prosperity and profits for it's the shareholders. The revenues of companies mainly originate from their sales of products, and this is closely linked with consumer's satisfaction and loyalty. Therefore, the customer satisfaction was defined as the main driver of firm's long-term growth and profitability in several studies [29, 52, 67].

Conversely, some scholars [43, 80] also disputed that satisfaction of consumers itself is not directly linked with financial performance of company but it has influence on the reputation, image and brad of companies. Many studies analysed the impact of corporate reputation and consumer loyalty on competitive advantage of companies and confirmed the positive effects [7, 10, 18, 20, 33, 29]. Researchers [54, 46] pointed out that this can help to improve significantly the level of satisfaction among customers. So, shareholders may assess the level of success of the company growth not on financial performance indicators but also based on implementation of social responsibility programs as was confirmed by Barnett and Salomon [6]. Few other scholars [36, 62] highlighted that the competitive advantage is the main result of customer satisfaction due to implementation of CSR. To sum up, number of studies [46,76, 82] indicated that firms currently understand that CSR initiative is attractive for the buyers and society and provides a favourable image influencing positively consumers' attitudes toward the firms and increase in firms competitive advantage.

It is clear that increase in competitive advantage provides more financial benefits for companies and ensures their long-term growth. Many researchers [54, 62, 68, 75, 78] showed in their studies that firms are implementing different, new and possible marketing strategies to attract more and more satisfied customers every day with the intention increasing the competitive advantage, and that a company's success may depend mainly on that factor. These studies have concentrated on the

expectation of new customers about products and services of companies and proved that these are no longer linked with quality and price alone but also with environmental awareness level of the society members and their increasing demands for environmentally friendly products. The studies dealing with competitive advantage [7, 9, 18, 52, 66, 67] highlighted the following factors important for assessing comparative advantage of firms: strong brand, corporate image and reputation, innovations, market position and leadership and other intangible assets of growing importance. The comprehensive review of literature to date has revealed that most of the scholars examined the relationship between CSR and financial performance of companies by dealing with its main antecedents: customer satisfaction and corporate image, however there are no studies dealing with the role of competitive advantage in the relationship between CSR and sales growth. Therefore, the first hypothesis (H1) was developed to address this gap:

H1: *The competitive advantage of company is the mediator of the effect of CSR on its sales growth.*

The scholars [64, 65, 84] agree that employees are the most important drivers of the company's goal achievements. However, most studies focused on external stakeholders such as customer's environmental awareness. Of course, all stakeholders but especially internal such as employees are tightly involved in supporting and implementing main goals of the firm's strategy as highlighted by several studies [19, 24, 42]. Porter and Kramer [64] stressed the importance of employees in implementing CSR initiatives. It is possible to guess that awareness of the social responsibilities and acceptance by employees are necessary for delivering social and environmental objectives of companies as pointed by Bauman and Skitka [11]. Similarly, Renouard and Ezvan [71] and Greening and Turban [31] revealed that firms' positive attitudes and imagination are interrelated with job satisfaction and less willingness on the part of the employees to consider changing their current workplace. The positive CSR perceptions may directly influence the rate of job satisfaction of managers [21]. Carrol [14] explained that perceptions on CSR, in relation to the concentration of firms on improving their quality of products and services. This may make management teams and employees to get along better and therefore lead to a better relationship on one hand, and create a better working environment in which support for current staff members and an increase in employee retention rate which may eventually lead to higher job performance level on the other [67].

Some studies [45, 63] found that CSR affects CSR perceptions and, consequently, employees' performance, loyalty and organizational commitments. The work environment has also positive influence on employees' performance therefore employees prefer in socially responsible companies based on several works [2, 33].

Referring to the discussion in the foregoing along with a comprehensive review of literature, there were studies which have focused mainly on examining the employees' perceptions on companies' involvement in social and environmental issues and their effects on their work performance on one hand and investigating the influence of CSR on attracting more qualified employees on the other. Unlike the previous related studies, the present study reasons that the relationship between CSR and firms' sales growth are moderated positively by means of the relatively higher level of employees' individual beliefs of social responsibilities. Accordingly, the researcher hypothesizes the following:

H2: *Higher level of employees' individual beliefs of social responsibility makes the effect of CSR on sales growth stronger.*

Unlike the existing instruments reported in the literature which only focused on the employees' perceptions on companies' involvement in social and environmental issues [5, 45, 72, 79], a proper and relevant scale was therefore adapted from work by Jamali, Zanhour and Keshishian [37] for the present study. Respondents of the related previous studies were managers, whereas in this study, employees were recruited as respondents to provide their self-reported responses to the questions in the questionnaire. Therefore, questions were changed to employees' personal attitudes and perspectives. Accordingly, fourteen items were used to measure to what extent employees believe the true nature of SR. Opinions were indicated using a five-point scale indicating by ''1'' (strongly disagree) and by ''5'' (strongly agree). Figure 1 shows the study framework.

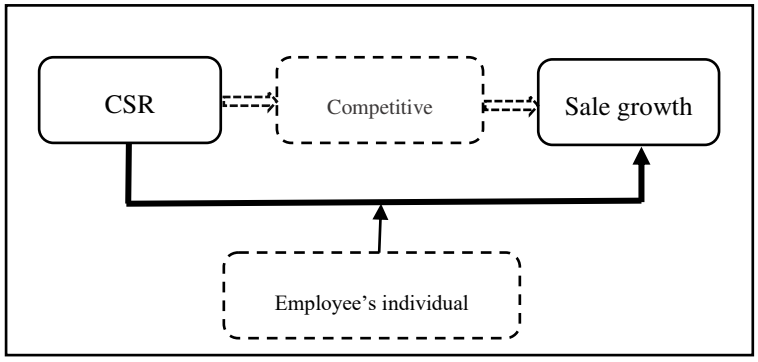


Figure 1
Conceptual Framework of the study

3 Research Method and Data

Academic research by and large, has paid most of their attention to large companies while small medium enterprises (SMEs) are left with more complicated challenges facing which, gaining a competitive advantage for relatively longer periods of time is therefore more complex. As described by Jenkins [38], when these small organizations are summed, their impact on societies and environment can be potentially great. Therefore, general assumptions about CSR should be adapted to SME contexts [10, 38, 57, 59, 76]. Notwithstanding the significance, related studies reported in the literature helped discover that there is still a gap identified in CSR for SMEs, and there is still a long way ahead to manage CSR-SMEs by means of a constructed model particularly in the contexts of developing countries [4, 27, 39, 74, 84]. Consequently, upon a comprehensive review of literature along with validating new hypotheses, this study therefore, has formulated the objective of carrying out a case study of CSR-SMEs in the context of Iran as a developing country in which, CSR has not been adequately addressed both in practical and theoretical terms in other conducted studies [18, 19, 55, 78].

3.1 Sampling

Survey was considered one of the most suitable ways to gather information for this study owing to the fact that there was no comprehensive database available for SMEs in the context of Iran. About 843 SMEs within consumer and manufacturing product sectors from four big cities in Iran were shortlisted for this study. It was assumed that at least 2 managers and 4 employees of all listed firms randomly answer their respective questionnaires. Three related parts: CSR, competitive advantage and sales growth were answered by top managers, because they were more familiar with their respective companies' affairs and had first-hand knowledge about the improvement processes, while employees' individual beliefs of social responsibilities were answered by employees.

Upon collecting the questionnaires, firms in which only managers responded or only employees responded were eliminated from the data of the study and only firms with both managers and employees have responded were considered for analysis purposes. The overall clear response rate was 28% (i.e., 107 out of 843 firms). Even though the return rate was considered lower, it was however not unusual, because the response rate among top managers within CSR contexts is reportedly lower in general. For example, [29, 55, 48, 76] reported that their response rate was between 6% to 17%. Another scholar i.e., [84] found that the response rate is an element of how imperative the idea of CSR is seen in every nation, so that higher response rate in developed nations may indicate that CSR is an issue in relation to their business plans, while lower response rates in less developed nations may suggest that it is not a significant issue among

entrepreneurs. Along these lines, in light of the all related evidences, a return rate of 28% ought to be adequate for a developing nation like Iran, in which CSR has not been essentially intended.

3.2 Measurement Model

Structural equation modelling was found to be the proper statistical analysis technique for this study and AMOS on the other hand as the appropriate analysis software to run tests. This is because; Rowley and Berman [75] and [3, 29] believed that SEM is deemed more fitting than the other conventional regression analysis in relation to CSR research. Therefore, it can be explained that the SEM is capable of simultaneously testing the causal relationships between independent variables and multiple dependent variables as opposed to the first-generation techniques which may not be able to do so. Furthermore, they also claimed that SEM is considered better because it can significantly reduce bias by taking measurement errors into account. Moreover, [37] demonstrated observationally that SEM approaches which in many cases are considered reliable, can be more capable of identifying an intercession results than the regression approach.

Confirmatory Factor Analysis CFA was employed to examine the fitness of the model in which, all variables were assigned to load on one single factor. Only items with a factor loading of greater than 0.6 were selected as belonging to a specific factor in this study. In addition to factor loading, convergent validity was likewise measured by means of Average Variance Extracted (AVE). It is considered adequate when the AVE value of each construct exceeding 0.5 [35]. Moreover, according to [34] that the value of a Cronbach's alpha being greater than 0.7 may indicate relatively a higher level of internal reliability. It is worth noting that all Cronbach's alpha values involved in this study were at acceptable levels. Table 1 delineates the final results of the convergent validity and reliability tests after deleting several items which were considered unnecessary.

Table 1

Convergent validity and reliability

Variable	Mean	SD	Internal consistency	Cronbach's alpha	AVE
CSR					
Ethical	3.28	0.55	0.89	0.79	0.61
Economic	3.97	0.71	0.87	0.83	0.73
Discretionary	4.01	0.52	0.77	0.81	0.55
Legal	3.67	0.61	0.93	0.92	0.59
Competitive advantage	3.92	0.55	0.80	0.86	0.67
Employees' individual beliefs of SR	3.52	0.73	0.83	0.77	0.71
Sale growth	4.06	0.59	0.74	0.94	0.82

In Table 2, the AVE values for all of the study's constructs were well over the limit, and the square base of the AVE esteem in the slanting for every construct was bigger than the relationship coefficients in the comparing lines and sections. Hence, a higher discriminant validity of the collected data existed as well [28]. All discriminant, convergent validities and reliability were found to be at significant levels in this study.

Table 2
Correlations and square root of AVE value

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1) Ethical dimension of CSR	**0.78**						
2) Economic dimension of CSR	0.21	**0.85**					
3) Discretionary dimension of CSR	0.08	0.03	**0.74**				
4) Legal dimension of CSR	0.11	0.10	0.09	**0.76**			
5) Competitive advantage	0.36	0.43	0.25	0.31	**0.81**		
6) Employee beliefs of SR	0.12	0.11	0.13	0.29	0.20	**0.84**	
7) Sale growth	0.41	0.34	0.46	0.58	0.38	0.39	**0.90**

The hypotheses in this study were tested by SEM. Structural Equation Modelling is the main technique to examine and the relationships among research constructs, to test hypotheses of studies in order to identify latent variables in the conceptual model designed by researchers as well as to define the direction and significance of these relationships [3, 12]. The moderating effects were tested in this study by conducting a multiple sample analysis in the SEM competing model [42]. In addition to moderating test i.e., the mediating effects were tested according to procedures established by [8]. The findings of the study are discussed in the following sections.

4 Discussion of Results

According to the four steps approach presented by [8], the collected results from the principal model (i.e., CSR-sale growth relationship) may demonstrate that there is a positive and significant relationship between CSR as the second order and also all measurements of CSR as the main order variables and sale growth. Before running the tests, the levels of root mean square (RMR), comparative fit index (CFI) and goodness of fit index (GFI), which should be less than 0.05 for RMR, and more than 0.9 for CFI and GFI were then tested. The basic model showed that GFI = 0.951, CFI = 0.921, RMR = 0.035, Chi Square = 55.949, which indicated that the model was considered suitable for the general model fit evaluation of path direct connections. Table 3 and Table 4 provide the summary of the results of the Path direction relationships of the study.

Table 3

Path direct relationship

Path			Path Co	P	Hypothesis
H1: CSR	✍	**Sale growth**	**0.58**	*******	**Supported**
Ethical dimension	✍	Sale growth	0.38	***	Supported
Economic dimension	✍	Sale growth	0.49	***	Supported
Discretionary dimension	✍	Sale growth	0.41	***	Supported
Legal dimension	✍	Sale growth	0.18	***	Supported
*** p<0.001					

The initial condition of building up the mediation was created with all significant effects of CSR components on sale growth. After including the mediator variable and running the second model to test H1, it was revealed that the CSR and sales growth relationships were fully mediated relationships by means of the influence of CSR to sales growth via gaining higher competitive advantage (see Table 4).

Table 4

Main effects of variables in mediating model (H1)

			Estimate	S.E.	C.R.	P
CSR	✍	Sale growth	0.014	0.065	0.215	0.52
CSR	✍	Ethical dimension of CSR	0.502	0.146	3.438	***
CSR	✍	Economic dimension of CSR	0.382	0.107	3.570	***
CSR	✍	Discretionary dimension of CSR	0.229	0.051	4.490	**
CSR	✍	Legal dimension of CSR	0.432	0.102	4.235	**
CSR	✍	Competitive advantage	0.686	0.176	3.897	***
Competitive advantage	✍	Sale growth	0.704	0.132	5.333	***

** p<0.01 *** p<0.001

By means of adhering to [8] steps to create a mediated association, it was discovered that there was a meaningful connection between CSR as the independent variable and competitive advantage as the hypothesized mediating variables (i.e., meeting second step). Competitive advantage is a predictor of the dependent variable (i.e., meeting third step). The last circumstance for establishing mediation also happened, because the relationship between CSR and sales growth in the revised model was no longer considered significant than the direct effect model. Accordingly, the gained outputs in Table 3 and Table 4 support the fully-mediated relationship and thus showed that all CSR dimensions and sales growth were connected through higher competitive advantage that may come after CSR.

In order to evaluate the moderating effects of employees' perception on CSR, the study compared the first model (original) against the competing model. It is worth noting that in addition to testing the moderating effects on the relationship between second order variable (CSR) and sales growth, the moderating effects of the moderator on all first order variables' relationships with sales growth were also tested.

The original model with second order variable showed that GFI = 0.951, CFI = 0.921, Chi-square = 55.949, $p < 0.001$. In the competing model of the second order variable, after introducing the moderating role of employee's individual perception of SR on CSR-sales growth relationship, the results showed that GFI = 0.913, CFI = 0.912, RMR = 0.028, Chi-square = 77.277, $p < 0.001$. Significant increase in Chi-square confirms the moderating effect of employee perception of CSR on the influence of CSR on sales growth (see Table 5).

Table 5
Main effects of variables in moderating model (second order variable on sale growth)

Path relationships		construct	Chi-square: Original model	Chi-square: Competing model	t-value >1.96	Results	Effect size $f2$
CSR×EB of SR	✍	Sale growth	55.949	77.277	2.549	**	0.279 (medium)

** p<0.01

EB of SR: Employee's individual beliefs of Social Responsibility

Furthermore, in the second model, with all first order variables, the original model showed that GFI = 0.911, CFI = 0.903, RMR = 0.042, Chi-square = 61.658, $p<0.001$. In the competing models, of all first order variables, which were tested separately, the moderating effect of employees' individual perceptions of CSR on the influences of all CSR components on sales growth was confirmed. The results showed that the moderator may therefore have a positive and significant effect on the relationship between all first order variables and sales growth (see Table 6). Notwithstanding, these results are not 100% clear without knowing the size of the moderator effects on such relationships. Therefore, in addition to examining the changes in Chi-square, the effect sizes of moderator were also examined through Cohen's f2.

$$\text{Cohen's } f^2 = \frac{\text{Rsq(competing model)} - \text{Rsq(original model)}}{1 - \text{Rsq(competing model)}} \quad (1)$$

Based on the Cohen's formula, if $f2$ is situated between 0.02 and 0.15, the effect of size can be smaller; if $f2$ is situated between 0.15 and 0.35, the effect of size can be medium, and if $f2$ is greater than 0.35, the effect of size can be huge [36].

Table 6
Main effects of variables in moderating model (All first order variables on sale growth)

Path relationships		construct	Chi-square: Original model	Chi-square: Competing model	t-value >1.96	results	Effect size f^2
$H2_a$: Ethical ×EB of SR	✍	Sale growth	61.658	84.242	8.921	***	0.372 (big)
$H2_b$: Economic ×EB of SR	✍	Sale growth	61.658	72.867	5.701	***	0.184 (medium)
$H2_c$: Discretionary ×EB of SR	✍	Sale growth	61.658	64.908	3.074	**	0.053 (small)
$H2_d$: Legal ×EB of SR	✍	Sale growth	61.658	69.007	3.611	**	0.121 (small)

** p<0.01 *** p<0.001

EB of SR: Employee's individual beliefs of Social Responsibility

During comparison of the results shown in Table 5 and Table 6, all Chi-squares of the competing models were found to be bigger than the original models. Moreover, all t-values were observed to be greater than 1.96. These results were used to conclude that the moderating effect of higher level of employees' individual beliefs of CSR was all significant. Thus, H2 and its all sub-hypotheses were supported.

The effect of size showed that higher level of employees' individual beliefs of SR as moderator may have the biggest positive effect on ethical dimension of CSR-sales growth relationship, followed by on economic dimension, then legal dimension, and at last, the smallest positive effect can be observed on the discretionary dimensions of CSR-sales growth relationship. Therefore, the findings of this study have confirmed and supported all previous studies indicating the positive influence of CSR on various indicators of financial performance of companies [1, 29, 46, 51, 76, 83]. Therefore, considering the reproach of some scholars [1, 29; 51, 73] against some studies in which the direct relationship between CSR and firm financial performance being examined along with CSR and sales growth respectively, the researcher of the present study similarly assumed that the engagement in CSR may affect the sales growth by improving the competitive advantage. Finally, the findings of this study have supported the hypothesis that the association between CSR and firms' performance is a fully mediated relationship by the competitive advantage among SMEs in the context of Iran. These findings have also supported the most recent findings reported by [76] which was carried out among large companies in the context of Iran and have discovered mediated relationship between CSR and the sampled firms' financial performance by means of the competitive advantage. In addition to considering

the effective roles of customers towards CSR and achieving a relatively higher level of sales growth, the researcher also examined the effects of employees' individual beliefs of social responsibilities on CSR-sale growth link.

The findings of the present study are also supported by Resource-Based Theory (RBT). The main dependent construct of RBT is sustainably competitive advantage and the main independent constructs are assets, capabilities, and resources as in studies [17, 22, 24]. A company's failure or success rate is substantially determined by means of the firms' resources and the competitive advantage under the RBT theory [60]. In this regard, [53] have considered CSR as a main resource which may lead to more sales and higher financial performance of firms. Therefore, RBT is the most suitable theory to support the findings of the present study. Although CSR has not been adequately addressed in the context of Iran both practically and academically [18, 19, 55, 78], these results are, however, consistent with those of other studies which were carried out mainly in developed countries and they have found positive effects of CSR on firms' financial performance in their respective contexts.

Conclusions

This case study was performed in the SME sector, of a developing country. It examined the moderating effects of the employees' individual beliefs about SR, in the relationship between implementation of CSR initiatives and sales growth. The study also assessed the moderating role of competitive advantage in the relationship between CSR and sales growth.

The results of this study have revealed that SMEs with more socially responsible employees found it is easier to implement their strategies and CSR initiatives and consequently to achieve relatively higher sales and better results, in financial performance and profits.

The main findings suggest that for SMEs, it is advisable to implement CSR initiatives, as currently, customers are taking into account CSR practices, in their decisions to purchase products and services and most employees desire to work in socially responsible firms.

The findings of the study are consistent with results of other studies which were performed, mainly in developed countries, and they have also obtained the positive effects of CSR on firms' financial performance in their respective contexts.

The study has significantly contributed to the CSR domain in developing countries. From the point of view of knowledge, it has contributed by means of overcoming some of the complexities surrounding the asserted connection between CSR and the performance of firms. This work has also extended the literature on CSR, for which, a framework which may potentially assist to clarify, how CSR might be related to sales growth.

In terms of the practical contributions, the study may increase the level of knowledge among firms' managers, concerning the significance of CSR, as an approach that may produce intangible benefits, such as, more experts and loyal personnel, better levels of customer satisfaction and an enhanced competitive advantage.

Funding

This work was supported by the Program for the Innovative Talents of Higher Education Institutions of Shanxi (PTIT) under Grant (20191043); Key R&D Program of Shanxi Province, China (Social Development) under Grant (201903D321004).

References

[1] Alafi, K., & Alsufy, F.: Corporate social responsibility associated with customer satisfaction and financial performance a case study with Housing banks in Jordan, International Journal of Humanities and Social Science, 2 (2012) No. 15, pp. 102-115

[2] Albinger, H. S., & Freeman, S. J.: Corporate social performance and attractiveness as an employer to different job seeking populations, Journal of Business Ethics, 28 (2000) pp. 243-253

[3] Anderson, J. C., & Gerbing, D. W.: Structural equation modeling in practice: a review and recommended two-step approach, Psychological Bulletin, 103 (1988) No. 3, pp. 411-423

[4] Baden, D., Harwood, I. A., & Woodward, D. G.: The effects of procurement policies on 'downstream' corporate social responsibility activity: content-analytic insights into the views and actions of SME owner-managers, International Small Business Journal, 29 (2011) No. 3, pp. 259-277

[5] Bagire, V. A., Tusiime, I., Nalweyiso, G., & Kakooza, J. B.: Contextual environment and stakeholder perception of corporate social responsibility practices in Uganda, Corporate Social Responsibility and Environmental Management, 18 (2011) No. 2, pp. 102-109. doi:10.1002/csr.252

[6] Barnett, M. I., & Salomon, R. M.: Beyond dichotomy: the curvilinear relationship between social responsibility and financial performance, Strategic Management Journal, 27 (2006) No. 11, pp. 1101-1122

[7] Barney, J.: Firm resources and sustainable competitive advantage, Journal of Management, 17 (1991) No. 1, pp. 99-120

[8] Baron, R. M., & Kenny, D. A.: The moderator-mediator variable distinction in social psychological research: conceptual, strategic and statistical considerations, Journal of Personality and Social Psychology, 51 (1986) No. 6, pp. 1173-1182

[9] Bataineh, M. T., & Zoabi, M. A.: The effect of intellectual capital on organizational competitive advantage, Jordanian commercial banks (Irbid district). An empirical study, International Bulletin of Business Administration 10 (2011) pp. 15-24

[10] Battaglia, M., Testa, F., Bianchi, L., Iraldo, F., & Frey, M.: Corporate Social Responsibility and competitiveness within SMEs of the fashion industry: Evidence from Italy and France, Sustainability, 6 (2014) No. 2, pp. 872-893

[11] Bauman, C. W., & Skitka, L. J.: Corporate social responsibility as a source of employee satisfaction, Research in Organizational Behavior, 32 (2012) pp. 63-86, doi:http://dx.doi.org/10.1016/j.riob.2012.11.002

[12] Baumgartner, H., & Homburg, C.: Applications of structural equation modeling in marketing and consumer research: a review, International Journal of Research in Marketing, 13 (1996) No. 2, pp. 139-161

[13] Carmeli, A., Gilat, G., & Waldman, D. A.: The role of perceived organizational performance in organizational identification, adjustment and job performance, Journal of Management Studies, 44 (2007) No. 6, pp. 972-992

[14] Carroll, A. B.: A Three-Dimensional conceptual model of corporate performance, The Academy of Management Review, 4 (1979) No. 4, pp. 497-550

[15] Carroll, A. B.: Managing ethically with global stakeholders: A present and future challenge, Academy of Management Executive, 18 (2004) No. 2, pp. 114-120

[16] Cavusgil, S. T., & Knight, G.: Born global firms: a new international enterprise, New York: Business Expert Press, 2009

[17] Chang, C. H.: The influence of corporate environmental ethics on competitive advantage: the mediation role of green innovation, Journal of Business Ethics, 104 (2011) No. 3, pp. 361-370

[18] Chapardar, H., & Khanlari, R.: Iranian corporations and Corporate Social Responsibility: an overview to adoption of CSR themes. 2011, SAGE Open, available in: http://sgo.sagepub.com/content/early/2011/11/18/2158244011430988

[19] Choi, Y., & Yu, Y.: The influence of perceived corporate sustainability practices on employees and organizational performance, Sustainability, 6 (2014) No. 1, pp. 348-364

[20] Crifo, P., & Forget, V. D.: The economics of Corporate Social Responsibility: a firm-level perspective survey, Journal of Economic Surveys, 29 (2015) No. 1, pp. 112-130

[21] Dana, L. P., Welpe, I. M., Han, M., & Ratten, V.: Handbook of research on european business and entrepreneurship: towards a theory of internationalization, Cheltenham, UK: Edward Elgar Publishing, 2008, pp. 800

[22] Demuijnck, G., & Ngnodjom, H.: Responsibility and informal CSR in formal Cameroonian SMEs, Journal of Business Ethics, 112 (2013) No. 4, pp. 653-665, doi:10.1007/s10551-012-1564-3

[23] Etemed, H.: International entrepreneurship in small and medium size enterprises: orientation, Environment and Strategy, Cheltenham, UK: Edward Elgar Publishing, 2004, p. 277

[24] Farooq, M., Farooq, O., & Jasimuddin, S. M.: 'Employees response to corporate social responsibility: exploring the role of employees' collectivist orientation', European Management Journal, 32 (2014) No. 6, pp. 916-927, doi:http://dx.doi.org/10.1016/j.emj.2014.03.002

[25] Farooq, O., Payaud, M., Merunka, D., & Valette-Florence, P.: The Impact of Corporate Social Responsibility on organizational commitment: exploring multiple mediation mechanisms, Journal of Business Ethics, 125 (2013) No. 4, pp. 563-580, doi:10.1007/s10551-013-1928-3

[26] Fassin, Y., Rossesn, A., & Buelens, M.: Small-business owner-managers' perceptions of business ethics and CSR-related concepts, Journal of Business Ethics, 98 (2011) No. 3, pp. 425-453

[27] Fornell, C., & Larcker, D. F.: Evaluating structural equation models with unobservable variables and measurement error, Journal of Marketing Research, 18 (1981) No. 1, pp. 39-50

[28] Glavas, A., & Godwin, L. N.: Is the perception of 'goodness' good enough? exploring the relationship between perceived Corporate Social Responsibility and employee organizational identification, Journal of Business Ethics, 114 (2013) No. 1, pp. 15-27, doi:10.1007/s10551-012-1323-5

[29] Grant, A. M.: The significance of task significance: Job performance effect, relational mechanisms, and boundary conditions, Journal of Applied Psychology, 93 (2008) No. 1, pp. 108-124

[30] Grant, A. M., Campbell, E. M., Chen, G., Cottone, K., Lapedis, D., & Lee, K.: Impact and the art of motivation maintenance: the effects of contact with beneficiaries on persistence behavior, Organizational Behavior and Human Decision Processes, 103 (2007) No. 1, pp. 53-67

[31] Greening, D. W., & Turban, D. B.: Corporate social performance as a competitive advantage in attracting a quality workforce, Business & Society, 39 (2000) No. 3, pp. 254-280, doi:10.1177/000765030003900302

[32] Hair, J., Black, W., Babin, B., Anderson, R., & Tatham, R.: Multivariate data analysis (6th edition ed.), NJ: Prentice-Hall, 2006

[33] Hair, J. F. J., Babin, B., Money, A. H., & Samouel, P.: Essentials of business research methods, New York:Wiley, 2003

[34] Hoivic, H. V. W., & Mele, D.: Can a SME become a global corporate citizen? Evidence from a case study, Journal of Business Ethics, 88 (2009) No. 3, pp. 551-563, 10.1007/s10551-009-0123-z

[35] Husted, B. W., & De Jesus Salazar, J.: Taking Friedman seriously: maximizing profits and social performance, Journal of Management Studies, 43 (2006) No. 1, pp. 75-91, doi:10.1111/j.1467-6486.2006.00583.x

[36] Iacobucci, D., Saldanha, N., & Deng, X.: A meditation on mediation: evidence that structural equations models perform better than regressions, Journal of Consumer Psychology, 17 (2007) No. 2, pp. 139-153, doi:http://dx.doi.org/10.1016/S1057-7408(07)70020-7

[37] Jamali, D., Zanhour, M., & Keshishian, T.: Peculiar strengths and relational attributes of SMEs in the context of CSR, Journal of Business Ethics, 87(2009) No. 3, pp. 355-377

[38] Jenkins, H.: Small business champions for Corporate Social Responsibility, Journal of Business Ethics, 67 (2006) No. 3, pp. 241-256, doi:10.1007/s10551-006-9182-6

[39] Jöreskog, K. G., & Sörbom, D.: PRELIS 2: User's reference guide, Lincolnwood, IL: Scientific Software International, Inc, 1999

[40] Kamasak, R., James, S. R., & Yavuz, M.: The interplay of corporate social responsibility and corporate political activity in emerging markets: The role of strategic flexibility in non-market strategies, Business Ethics-A European Review, 28 (2019) No. 3, pp. 305-320

[41] Kolodinsky, R. W., Madden, T. M., Zisk, D. S., & Henkel, E. T.: Attitudes about corporate social responsibility: business student predictors, Journal of Business Ethics, 91 (2010) No. 2, pp. 167-181

[42] Lee, E. M., Park, S. Y., & Lee, H. J.: Employee perception of CSR activities: Its antecedents and consequences, Journal of Business Research, 66 (2013) No. 10, pp. 1716-1724, doi:http://dx.doi.org/10.1016/ j.jbusres.2012.11.008

[43] Lu, J., Ren, L., He, Y., Lin, W., & Streimikis J.: Linking Corporate Social Responsibility with reputation and brand of the firm, Amfiteatru Economic, 21 (2019) No. 51, pp. 442-460

[44] Lu, J., Ren, L., Qiao, J., Lin, W., & He, Y.: Female executives and corporate social responsibility performance: a dual perspective of differences in institutional environment and heterogeneity of foreign

experience, Transformations in Business & Economics, 18 (2019) No. 2, pp. 174-196

[45] Luo, X., & Bhattacharya, C. B.: Corporate Social Responsibility, customer satisfaction, and market value, Journal of Marketing, 70 (2006), No. 4, pp. 1-18

[46] Maignan, I., & Ferrell, O. C.: Measuring corporate citizenship in two countries: the case of the United States and France, Journal of Business Ethics, 23(2000) pp. 283-297

[47] Maignan, I., & Ferrell, O. C.: Antecedents and benefits of corporate citizenship: An investigation of French businesses, Journal of Business Research, 51 (2001) No. 1, pp. 37-51

[48] Maignan, I., Ferrell, O. C., & Hult, G. T. M.: Corporate citizenship: cultural antecedents and business benefits, Journal of the Academy of Marketing Science, 27, (1999) No. 4, pp. 455-469

[49] Margolis, J. D., & Walsh, J. P.: Misery loves companies: rethinking social initiatives by business, Administrative Science Quarterly, 48 (2003) No. 2, pp. 268-305

[50] Matzler, K., & Hinterhuber, H. H.: How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment, Technovation, 18 (1998) No. 1, pp. 25-38

[51] McWilliams, A., & Siegel, D. S.: Creating and capturing value: strategic corporate social responsibility, resource-based theory and sustainable competitive advantage, Journal of Management, 37 (2010) No. 5, pp. 1480-1495

[52] Michelon, G., Boesso, G., & Kumar, K.: Examining the link between strategic Corporate Social Responsibility and company performance: an analysis of the best corporate citizens, Corporate Social Responsibility and Environmental Management, 20 (2013) No. 2, pp. 81-94, doi:10.1002/csr.1278

[53] Mohr, L. A., Webb, D. J., & Harris, K. E.: Do consumers expect companies to be socially responsible? The impact of corporate social responsibility on buying behavior, The Journal of Consumer Affairs, 35 (2011) No. 1, pp. 45-72

[54] Murillo, D., & Lozano, M.: SMEs and CSR: an approach to CSR in their own words, Journal of Business Ethics, 67 (2006) No. 3, pp. 227-240

[55] Nejati, M., & Ghasemi, S.: Corporate social responsibility in Iran from the perspective of employees, Social Responsibility Journal, 8 (2012) No. 4, pp. 578-588, doi:10.1108/17471111211272552

[56] Ogola, F. O., & Mària, J.F.: Mechanisms for development in corporate citizenship: a multi-level review, International Journal of Corporate Social Responsibility, 5 (2020) p. 7, https://doi.org/10.1186/s40991-020-00051-5

[57] Pastrana, N. A., & Sriramesh, K.: Corporate Social Responsibility: perceptions and practices among SMEs in Colombia, Public Relations Review, 40 (2014) No. 1, 14-24

[58] Peng, M. W.: Global business.Cincinnati: South-Western Cengage Learning, 2010

[59] Perez, A., de los Salmones, M. D. G., Liu, M. T.: Maximising business returns to corporate social responsibility communication: An empirical test, Business Ethics-A European Review, 28 (2019) No. 3, pp. 275-289

[60] Perrini, F.: SMEs and CSR theory: evidence and implications from an Italian perspective, Journal of Business Ethics, 67 (2006) No. 3, pp. 305-316

[61] Perrini, F., Russo, A., Tencati, A., & Vurro, C.: Deconstructing the relationship between corporate social and financial performance, Journal of Business Ethics, 102 (2011) No. 1, pp. 59-76

[62] Peterson, D. K.: The relationship between perceptions of corporate citizenship and organizational commitment, Business & Society, 43(2004) No. 3, pp. 296-319, doi:10.1177/0007650304268065

[63] Pornchokchai, S.: Housing finance mechanism in Thailand: Nairobi, Kenya: UN-Habitat, 2008

[64] Porter, M. E., & Kramer, M. R.: Creating shared value, Harvard Business Review 89 (2011) (January-February) pp. 62-77

[65] Porter, M. E., & van der Linde, C.: Toward a new conception of the environmental competitiveness relationship, Journal of Economic Perspectives, 9 (1995) No. 4, pp. 97-118

[66] Psomas, E. L., & Fotopoulos, C. V.: Total quality management practices and results in food companies, International Journal of Productivity and Performance Management, 59 (2010) No. 7, pp. 668-687

[67] Pucheta-Martinez, M. C., Bel-Oms, I., & Olcina-Sempere, G.: Commitment of independent and institutional women directors to corporate social responsibility reporting, Business Ethics-A European Review, 28 (2019) No. 3, pp. 290-304

[68] Rao-Nicholson, R., Khan, Z., & Marinova, S. T.: Balancing social and political strategies in emerging markets: evidence from India, Business Ethics-A European Review, 28 (2019) No. 1, pp. 56-70

[69] Raszkowski, A., Bartniczak, B.: Towards sustainable regional development: economy, society, environment, good governance based on

the example of Polish regions, Transformations in Business & Economics, 17 (2018) No. 2, pp. 225-245

[70] Rego, A., Leal, S., Cunha, M. P., Faria, J., & Pinho, C.: How the perceptions of five dimensions of corporate citizenship and their inter-inconsistencies predict affective commitment, Journal of Business Ethics, 94 (2010) No. 1, pp. 107-127, doi:10.1007/s10551-009-0252-4

[71] Renouard, C., & Ezvan, C.: Corporate social responsibility towards human development: acapabilities framework, Business Ethics-A European Review, 27 (2018) No. 2, pp. 144-155

[72] Riketta, M.: Organizational identification: A meta-analysis, Journal of Vocational Behavior, 66 (2005) No. 2, pp. 358-384, doi:http://dx.doi.org/10.1016/j.jvb.2004.05.005

[73] Rothenhoefer, L. M.: The impact of CSR on corporate reputation perceptions of the public-A configurational multi-time, multi-source perspective, Business Ethics-A European Review, 28 (2019) No. 2, pp. 141-155

[74] Rodrigo, P., & Arenas, D.: Do employees care about CSR programs? A typology of employees according to their attitudes, Journal of Business Ethics, 83 (2008) No. 2, pp. 265-283, doi:10.1007/s10551-007-9618-7

[75] Rowley, T., & Berman, S.: A brand new brand of corporate social performance, Business & Society, 39 (2000) No. 4, pp. 397-418, doi:10.1177/000765030003900404

[76] Russo, A., & Perrini, F.: Investigating stakeholder theory and social capital: CSR in large firms and SMEs, Journal of Business Ethics, 91 (2010) No. 2, pp. 207-221

[77] Russo, F.: What is the CSR's focus in healthcare? Journal of Business Ethics, 124 (2016) pp. 323-334, doi:10.1007/s10551-014-2430-2

[78] Salehi, M., & Azary, Z. H.: Stakeholders' perceptions of Corporate Social Responsibility: empirical evidences from Iran, International Business Research, 2 (2009) No. 1, pp. 63-72

[79] Samy, M., Odemilin, G., & Bampton, R.: Corporate Social Responsibility: a strategy for sustainable business success. An analysis of 20 selected British companies, Corporate Governance, 10 (2010) No. 2, pp. 203-217

[80] Sangle, S.: Critical success factors for corporate social responsibility: a public sector perspective, Corporate Social Responsibility and Environmental Management, 17 (2009) No. 4, pp. 205-214

[81] Scherer, A. G., & Palazzo, G.: Toward a political conception of corporate responsibility: business and society seen from a Habermasian Perspective, Academy of Management Review, 32 (2007) No. 4, pp. 1096-1120

[82] Sen, S., & Bhattacharya, C. B.: Does doing good always lead to doing better? consumer reactions to corporate social responsibility, Journal of Marketing Research, 38 (2001) No. 2, pp. 225-243

[83] Shen, C. H., & Chang, Y.: Does Corporate Social Responsibility improve financial performance? Evidence from FTSE4GOOD UK Index, Academia Economic Papers, 36 (2008) No. 3, pp. 341-385

[84] Smith, D., & Rhiney, E.: CSR commitments, perceptions of hypocrisy, and recovery, International Journal of Corporate Social Responsibility, 5(2020) No. 1, pp. 1-12, https://doi.org/10.1186/s40991-019-0046-7

Bending Fatigue Tests of Carbon Fiber Reinforced Epoxy Resin Composite Plates

Péter Szuchy, Tamás Molnár, István Bíró, Sándor Csikós, László Gogolák, József Sárosi

Department of Technology, Faculty of Engineering, University of Szeged,
Mars tér 7, 6724 Szeged, Hungary
e-mail: szpeter@mk.u-szeged.hu, molnart@mk.u-szeged.hu,
dekan@mk.u-szeged.hu, csikos-s@mk.u-szeged.hu, gogolak@mk.u-szeged.hu,
sarosi@mk.u-szeged.hu

Abstract: This paper introduces the results of the bending fatigue tests of composite materials manufactured with different numbers of carbon fiber layers, embedded in an epoxy resin. The novel fatigue test machine, with crank mechanism, is presented and was optimized for partial dynamic loads. During the tests, half of the specimens were examined only for tensile strength, the other half were tested first, by fatigue tests, with at least 10 million bending cycles and afterwards using tensile tests. We studied the differences between the tensile strengths of the two groups and the influence of the number of reinforcing material layers in the results. Different kinds of ruptures were detected and categorized as Grip ruptures, Neck ruptures, Whiskers ruptures and Double ruptures. Results of an unplanned excess load is also presented, where cracks appeared along the reinforcing fibers and the tensile strength decreased significantly.

Keywords: composite; carbon fiber; epoxy resin; fatigue; tensile test; crank mechanism; optimization for partly dynamic load

1 Introduction

In the 21st Century, the development of technology requires increase of capability of artificial engineering materials. The continuously developing composite materials are significantly enlarging the toolbox of engineers, and with the application of them some of the engineering structures and equipment can operate with higher efficiency and longer lifetime [1]. From this point of view, the polymer structural materials have outstandingly important role and combining them with other polymers, metals or ceramics heavy-duty composite structures can be produced [2]. Polymer composites are complex systems, typically, one of the components, called the reinforcement, takes the mechanical loads, the other is the bedding material, called the matrix. The main objective of the latter, is proper

load distribution and protection of the reinforcing materials, against external influences. The adhesive connection between the two composites needs to be strong, so that the material can withstand high loads without failure, even in case of large number of repetitive loads. These materials are characterized by relatively low density, alongside their excellent mechanical properties, so their usage can bring lower tare weight of a given structure. This reduction of weight can go hand in hand with significant energy- and cost-savings, in almost every sector of transport [3].

A significant part of the polymer components are subjected to a permanent load and this load, is often cyclical. Therefore, the viscoelastic behavior of polymers is especially important because, as a result of this, their response for the long term load is not static. In engineer practice the design for stress is an accepted and widespread practice, but in the case of polymers, it is not enough, the change of deformation in time has to be considered as well, especially for the case of permanent loads. The deformation of thermoplastic polymers can be divided into three deformations, regardless of the maximum load [4]:

- Instantaneous
- Delayed elastic
- Permanent deformation

The creep and stress-relaxation tests of polymers are widespread, however, all the effects of the different reinforcing materials are not revealed yet that is especially true in case of the nano- and hybrid-composites. The traditional microfibers and the nano-scale reinforcing materials can have a possible impact on the creep as well. The rate of creep and stress-relaxation can be lower as the reinforcing materials take a part of the load and reduce the deformation of the composites, pushing its viscoelastic behavior in the shade. Besides that, the reinforcing materials usually do not have creep [5].

There are many factors influencing the behavior of material during fatigue test, so the proper choice of testing parameters is essential. It is particularly true in case of the thermoplastic polymers where significant warming of specimen can be observed many times during the tests due to the higher deformation and inner friction. So the EN ISO 13003 standard prescribes that the temperature has to be registered continuously or at the examination such a frequency has to be chosen which does not increase more than 10% the temperature of the specimen. It can happen at composites that the rise of temperature enlarges the lifetime, as the temperature of the specimen can overstep the glass transition, due to which the polymer becomes tougher. The presence of the fibers also influences the fatigue, these effects are mostly known nowadays, but in case of hybrid composites only moderate knowledge is available [6].

In the case of fiber-reinforced polyamide 6 matrix composites, initially, Horst and Spoormaker described the failure process. Based on the fatigue test the failure

process was divided into the following parts. During the fatigue, the binding between the fiber and the matrix always break up, first at the ends of the fibers, because these are stress collecting points where locally high shearing stress appears. In certain cases, hollowing can occur at the middle section of fiber, because of the buckling of the fiber, when the matrix cannot distribute it flexibly [7]. The fracture of the fiber is less prevalent during the fatigue tests. The micro-cracks in the matrix grow along the fibers, after their emergence, thus, the matrix increasingly, assumes the load. In the surroundings of the fiber, the matrix deforms plastically, while the cracks become larger and the ends link to each other, creating a growing surface which is bonded by polymer chains or fibers. When the linked cracks reach a critical dimension, the stress reaches the tensile strength in the cross section of the polymer and a brittle fracture occurs.

In the professional literature, different constructions can be found to fatigue composite materials. Ueki developed the methodology for high-speed fatigue testing, especially for resin materials, including fiber-reinforced composites [8]. The temperature of specimen was controlled by external cooling. To confirm the validity of the devised high-speed-testing method, a completely reversed bending test at 1 Hz was also performed with identical specimens. There are agreement between the obtained results for this reason the fatigue tests in high cycle region of resin and composites can be evaluated in a very short time.

Kulkarni et al. in [9] presented the development of a plane bending fatigue testing machine for composite material. The proposed machine is simple in design and economical. An eccentric cam and connecting rod arrangement is done for the fully reserve bending motion of the work piece.

Van Paepegem and Degrieck developed an experimental setup for bending fatigue [10]. A numerical method is presented as well, which allows one to describe the degradation of the composite specimen during its fatigue life. Authors noted that these bending tests yield important additional information that cannot be recovered from conventional tension fatigue tests. Landge et al. also developed an experimental setup for bending fatigue [11]. The setup is inexpensive, efficient and does not requires a lot of space, like the conventional fatigue testing machines available in the market.

2 The Fatigue Test Machine

The first step of the project was developing and manufacturing a fatigue test machine that can produce 10 million load cycles per specimen in a reasonable time. In the beginning of the development, an extant Brüel & Kjaer shaker had the key role, but at the end a crank mechanism was executed (Fig. 1). At this point in the construction, the linear guideway, at relative high speed and the dynamic balancing, caused the main problems. For the linear guideway, sinter-bronze

bearing bushes were choosen. Due to the lubricant pressed into its porous material, during production, the maximum sliding speed of this kind of sliding bearing is 10 m/s, which exceeded our needs.

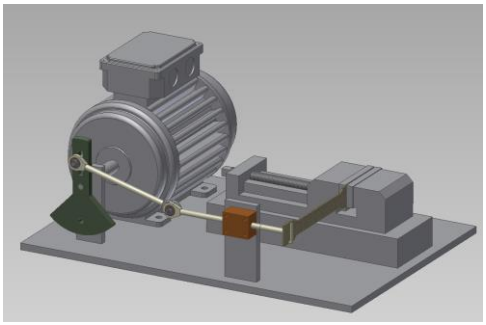


Figure 1
3D model of the bending fatigue test machine with crank mechanism

Two pieces of 08.12.20 (8 mm inner diameter, 12 mm outer diameter, 20 mm length) bushing was applied for the horizontal support, and the housing was manufactured at the Faculty. The highest surface pressure (q_f) of the bushings was calculated by the loading model of Fig. 2.

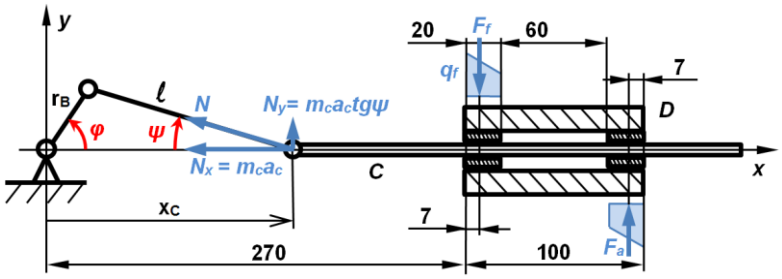


Figure 2
Loading model of the bushes

The moments of rod C are written to the intersection of shaft *x* and line of action of force F_a, where F_f and F_a are the apparent concentrated forces of the bushings:

$$0.086\text{m}\, F_f - (0{,}363\text{m} - x_c) m_c a_c tg\psi = 0 \tag{1}$$

The maximum load F_f can be overestimated by the longest arm of the force, the maximum angle of the crank arm (ψ) and the highest angular velocity:

$$F_{fmax} = \frac{0.357\text{m} * 0.1614\text{kg} * 0.05\text{m} * (2\pi 10\text{Hz})^2 * tg15^0}{0.086\text{m}} = 35.5\text{N} \tag{2}$$

So the maximum surface pressure on the 8 mm inner diameter, 20 mm long bushing:

$$q_f = \frac{4*F_{fmax}}{3*160\text{mm}^2} = 0.3\text{MPa} \tag{3}$$

At the first model with crank mechanism the previously used disk was taken over, in which there was only one radial slot for setting the bending deflection's size of the specimen. But the accelerations of the crank mechanism were so high that a partly dynamic balancing of the masses was necessary, and the best location of it was on the disc (Fig. 3).

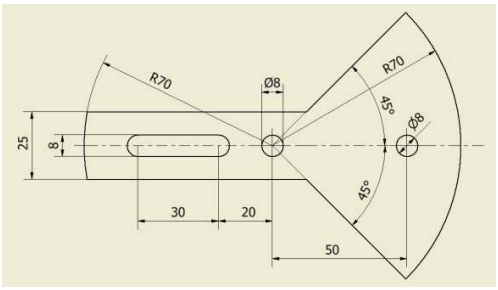


Figure 3
Disk of the crank mechanism optimized for partly dynamic load

The disk can be divided to two parts (see Fig. 3): the right one consists of a circular sector with 90° central angle, the other part is the rest of the disc, named stick. The sector's center of mass, measured from the middle point of the circle in case of r=70mm, α=90° (without the hole):

$$r_e = \frac{2}{3}\frac{r\,sin^{\alpha}/_2}{{}^{\alpha}/_2} = \frac{2}{3}\frac{70mm\frac{\sqrt{2}}{2}}{\frac{\pi}{4}} = \frac{4}{3}\frac{70mm\,\sqrt{2}}{\pi} = 42\ mm \tag{4}$$

The mass of the quarter circle if the width of the disc is v=10 mm:

$$m_e = \frac{r^2\pi}{4}v\rho = \frac{(0.07m)^2\pi}{4}0.01m\ 7850\frac{kg}{m^3} = 0.30\ kg \tag{5}$$

The kinetic model of the crank mechanism with point-like masses without extension is introduced by Fig. 4:

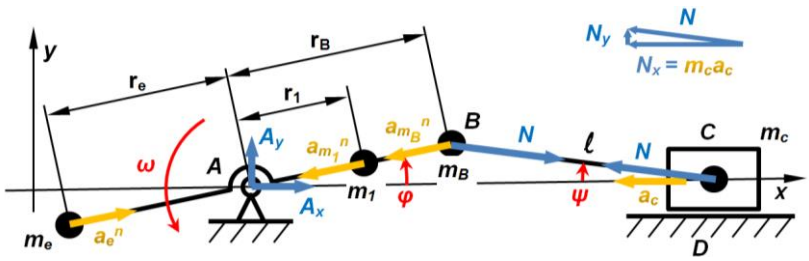


Figure 4
Kinetic model of crank mechanism

At the kinetic model of crank mechanism the masses are considered without extension: m_e is the mass of the circle section part, m_1 is the mass of the stick, m_B is the mass of pin, bearing and housing connected to the disc, together with the half of the crank-arm, m_C is the mass of the coupling rod with the connected bearing, housing and the other half of the crank-arm. As an engineering approximation the angular velocity of disc ω is considered constant. Accordingly, the relationships are as follows:

$$r_B sin\,\varphi = l\,sin\psi \tag{6}$$

$$\psi = arc\,sin\frac{r_B}{l}\,sin\varphi \tag{7}$$

$$N = \frac{m_C\,a_C}{\cos\psi} \tag{8}$$

The kinetic equations of movement written to x and y direction according to D'Alembert:

$$-m_e\,r_e\omega^2 cos\varphi + m_1\,r_1\omega^2 cos\varphi + m_B\,r_B\omega^2 cos\varphi - m_C a_C + A_x = 0 \tag{9}$$

$$-m_e\,r_e\omega^2 sin\varphi + m_1\,r_1\omega^2 sin\varphi + m_B\,r_B\omega^2 sin\varphi - m_C a_C tg\psi + A_y = 0 \tag{10}$$

and so the x and y directional force components awakening in the point A:

$$A_x = m_C a_C + \omega^2\,(m_e\,r_e cos\varphi - m_1\,r_1 cos\varphi - m_B\,r_B cos\varphi) \tag{11}$$

$$A_y = m_C a_C + \omega^2\,(m_e\,r_e sin\varphi - m_1\,r_1 sin\varphi - m_B\,r_B sin\varphi) \tag{12}$$

According to (14) and (15) equations a numerical analysis was executed, on which base an optimization was implemented. The goal of the optimization was bringing to the same level the maximum value of the A_x and A_y bearing force components. Fig. 5 presents the changes of the bearing force components during a whole rotation beside optimized parameters. B_y increasing the mass me of the counterweight, the maximum value of the force component A_x decreases, and the maximum value of A_y increases. As the counterweight decreases, the consequence is converse.

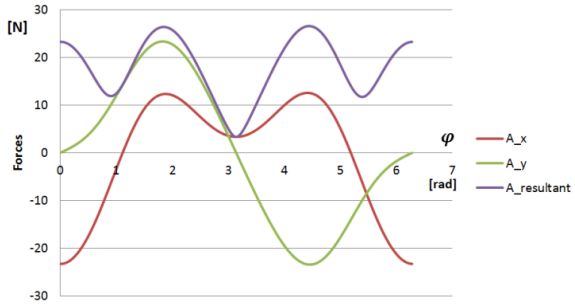


Figure 5

Changes of force A and x, y components of it during a whole rotation

The working test of the fatigue test machine with the partly dynamic balanced crank mechanism was successful. For rotation control of the electric motor a frequency converter was applied. For counting the number of bending an optical sensor with a CPU was installed.

3 Fatigue and Tensile Tests

The tests were determined as bending fatigue and tensile tests of composite materials with different number of reinforcing laminates. Since the required 10 million bending movements for one specimen could be accomplished in about two weeks by the fatigue test machine, we could not aim to achieve statistical quantity of tests, we rather tried to find orientations for latter research that cover the following:

- Effects of bending fatiguing for the tensile strengths
- Effects of the number of reinforcing laminates for the tensile strength without fatiguing
- Effects of the number of reinforcing laminates for the tensile strength after fatiguing

The composite material plates with four different thicknesses were manufactured with vacuum-infusion technology. The fiber reinforcement was ensured by 3, 4, 5 or 6 laminations of twill of carbon fiber (each lamination had the same 200 g/m2), embedded into epoxy resin. The standard flat tensile test specimens were cut out of the plates by milling machine. The thickness of the specimen was measured at three points of each: at the both neck and in the middle, then probe tensile tests were executed. Finally, half of the specimens were examined by fatigue test then tensile tests, the rest of them were tested only by tensile test as a control group.

3.1 Tensile Tests without Fatiguing

The first probe tensile test was executed on specimens with three different thicknesses (1^{st}: 3 layers, 2^{nd}: 4 layers, 3^{rd}: 6 layers.) and these presented immediately some interesting findings which also occurred later in the examinations (Fig. 6):

1) **Grip rupture** (Fig. 6b): at one of the tests the rupture proceeded from the grip jaws.
2) **Neck rupture**: the normal rupture (not Grip rupture) always appeared at the neck section (and only once at the long narrow section).
3) **Whiskers rupture** (Fig. 6c),: at neck ruptures long fiber whiskers remain on both brinks of the specimen.

4) **Double rupture**: in case of the thick, 6 reinforcing laminated composite a double rupture happened: the specimen broke at once at both neck.

The most important observation was the Grip rupture which was induced by the crunch of the gripping jaws, destroying the specimen and the examination in most cases. We used several gripping methods in order to avoid this failure (aluminum or composite plates between the specimen and the jaws) but the attempts were barren of results, so this problem brought many annoyances during the subsequent examinations. The second observation, the Neck rupture derives probably from the fiber damage made by the milling that could impair the longitudinal fibers at the neck, just like a "crack on the texture" effect.

Figure 6
First probe tensile tests (6a: left), Neck rupture (6b: middle), Whiskers rupture (6c: right)

The Whiskers rupture appears as longitudinal fibers ripped out of the twill, the best chance the peripheral fibers have, is where the cross fibers cannot keep them in the texture. The fourth phenomenon is the double rupture that occurred later, in all of the 6 layer composites specimens' tensile tests, without fatiguing. We have not tried to find the explanation for it, but it may have a correlation to the phenomenon of spaghetti break into three parts (Feynman's puzzle).

For examining the effects of the number of reinforcing laminates in the tensile strength, without fatiguing, the best is comparing the result of the tensile tests of the 3 and 6-layer composite specimens (Table 1).

Table 1
Tensile test results of 3 and 6-layer composite specimens without fatigue tests

Without fatig. test	**Code**	**Fm** [N]	**Rm** [MPa]	**Without** fatig. test	**Code**	**Fm** [N]	**Rm** [MPa]
3 layer	1A	3 921,5	248,98	6 layer	4A	14 031,5	359,23
	1B	3 817,0	242,35		4B	11 523,5	295,02
	1C	3 995,5	253,68				
	Komp1	5 691,5	361,37		Komp3	9 322,0	238,66

The tensile tests of Komp1 and Komp3 specimens were executed previously during the probes and the results of them are exceptionally different from the others, and just counter as it should have been waited based on the other tensile

strength data. Without them it should be considered that the double reinforcing material supports higher load on unit surface area of cross section, but the two probe data give way to doubt. The diagrams of tensile tests have the same shape (Figs. 7, 8), after the opening convex and concave sections a long almost linear part follows until the fracture. It is interesting that the 3 layer specimens 1B and Komp1 suffered Grip rupture while neither of the 6 layer specimens did it. But all of the 6-layer composite specimens broke into three parts (Double rupture).

For substantive findings, further examinations are necessary.

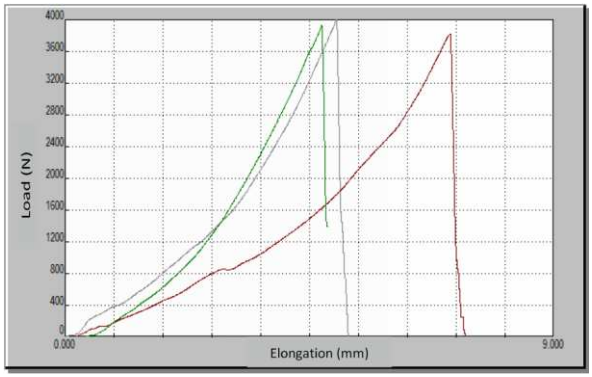


Figure 7
Tensile test diagrams of 3-layer composite specimens without fatiguing

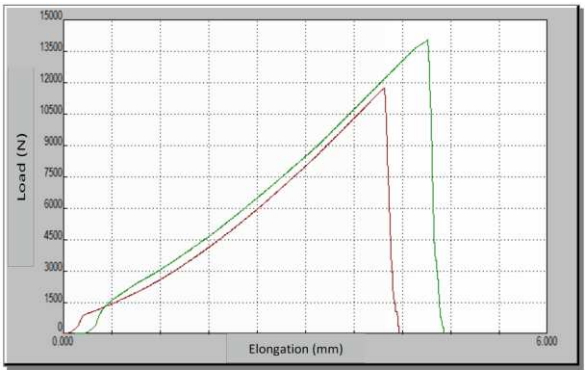


Figure 8
Tensile test diagrams of 6-layer composite specimens without fatiguing

3.2 Tensile Tests after Fatigue

During the fatigue tests at least 10 million bends were executed on each specimen with different stress values what the tensile tests followed. The beginning stress value was set by bending the specimen with increasing the amplitude (r_B) till the resin broke then the amplitude was decreased.

The 6-layer specimens were not useable for examining the effects of the number of reinforcing laminates for the tensile strength after fatiguing because of their specific case (see it later), so the data of the 4- and 5-layer composite specimens were compared (Table 2). There were 35 mm and 40 mm bending amplitudes in both cases and the highest tensile strengths always came from the fatigue tests with lower bending stress. But neither this, nor the number of the layers influenced significantly the tensile strength of the composites.

Table 2

Tensile test results of 4 and 5 layer specimens after fatigue tests

After fatigue test	**Code**	**Fm** [N]	**Rm** [MPa]	**Amplitude** [mm]	**Bending cycles** (ps)
4 layer	2A	7 050,0	294	35	10 384 260
	2C	5 985,5	252	40	13 248 110
5 layer	3A	6 914,5	258	40	11 401 760
	3B	6 869,0	251	40	12 286 140
	3C	6 985,0	268	35	12 096 790
	3D	6 799,5	248	35	13 110 910

The highest tensile strength was achieved by the specimen 2A which was broken with Grip rupture, alone out of the six specimens. However, this Grip rupture happened along not a straight line, but a curve connecting the neck and the gripped head of the specimen with strongly stringy rupture surface. Only one more curved Grip rupture happened during the probe tests, in case of specimen Komp1 (Fig. 6b). In both cases outstandingly high tensile strength was observed, significantly excessing their own group averages. So the Grip ruptures had to be divided into two parts: the traditional straight grip rupture (Fig. 9a) appears with average or lower tensile strength, and the curved grip rupture (Fig. 9b) brings outstanding tensile strength.

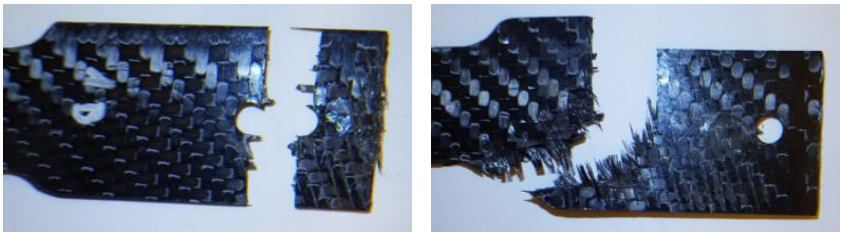


Figure 9

Straight grip rupture (9a. left), curved grip rupture (9b. right) on specimen 2A

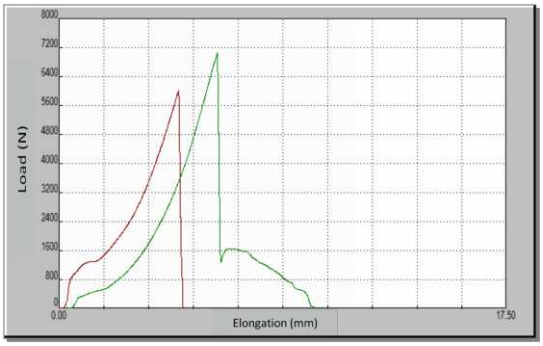


Figure 10
Tensile test diagrams of 4-layer composite specimens after fatiguing

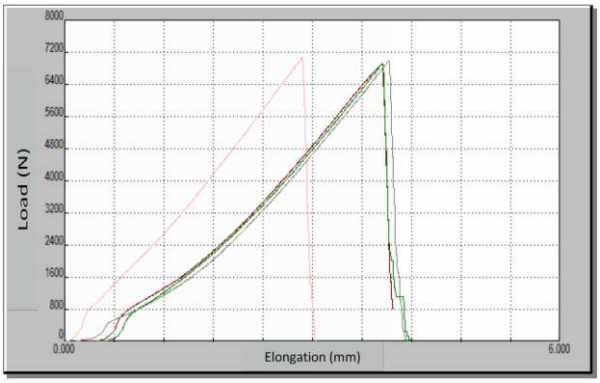


Figure 11
Tensile test diagrams of 5-layer composite specimens after fatiguing

There was no significant difference between the tensile test diagrams of the 4- and 5-layer composites (Figs. 10, 11). In both cases parallel moved diagrams are visible along the X axis.

Interesting result was achieved at fatigue tests of the thickest 6-layer composite specimens due to a design mistake: the reciprocating fork that bended the specimen at the opposite end to the gripped one, was too narrow and wide, so it did not let the moving end of the specimen turn accordingly to the camber of the bending. Therefore, a local bending with small radius happened at the moved neck that resulted higher stress than it occurred at the gripped neck. At this moved neck the damages were much stronger than at the other fewer layer composite specimens, which external appearances were the followings (Fig. 12):

- The wearing effect of the moving fork was clearly visible on both sides
- Cracking appeared in the resin along the reinforcing fibers on both sides
- Looking to the side it was visible that the layers partly separated

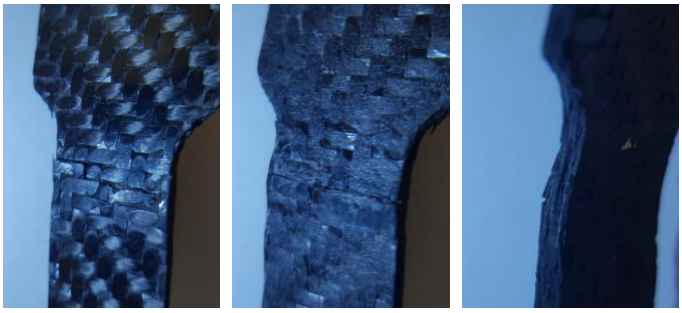


Figure 12
Fatigue damages of 6-layer composite specimen due to unplanned local load

Due to the local load the resin broke out from the fibers in small particles that led to decreased moment of second degree which is essential for bending, as there remained not enough material between the fibers that could ensure the former distance among them. The reinforcing fibers did not suffer visible damages, but during the tensile tests the specimens broke at this place one by one and at a much lower tensile strength as it would have been waited based on the results of the other tests (Figs. 13, 14).

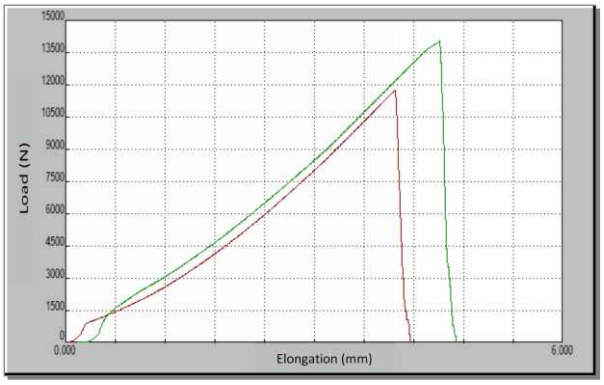


Figure 13
Tensile test diagrams of 6-layer composite specimens without fatiguing

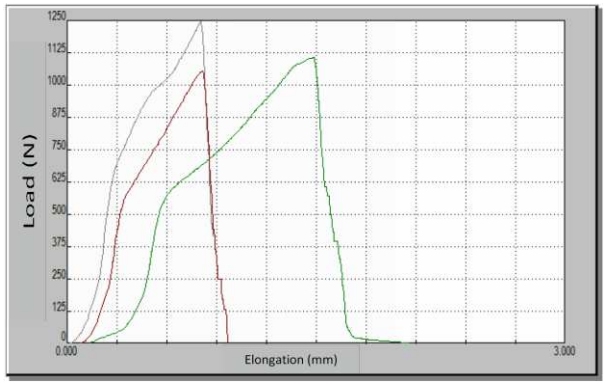


Figure 14
Tensile test diagrams of 6-layer composite specimens after fatiguing

It is visible well that the tensile strength of the damaged 6-layer composite specimen decreased to the tenth (Table 3) and there is a change in the diagram as well. The diagram of without fatiguing can be described after a short convex and concave section as a long almost linear curve, while on the diagram of after fatiguing can be observed the initial convex-concave section either (even though at lower stress and longer elongation), but this curve does not continue.

Table 3
Tensile strength of 6-layer composite specimens without and after fatiguing

Without fatig. test	**Code**	**Fm** [N]	**Rm** [MPa]	**After** fatig. test	**Code**	**Fm** [N]	**Rm** [MPa]
6 layer	4A	14 031,5	359,23	6 layer	4A	1 105,0	28,29
	4B	11 523,5	295,02		4B	1 052,0	26,91
	Komp3	9 322,0	238,66		4C	1 244,0	31,85

On the magnifications of the photos of 6-layer specimen 4B is visible (Fig. 15) that the carbon fiber fabric did not break along one edge and the longitudinal fibers turn a bit away of the parallel direction. This presumably means that the reinforcing fibers did not break uniformly at once, but separately one after the other. On the right, optically filtered picture it can be observed that far from the fracture (on the right side of the photo) the black spots (adhesions to the form by vacuum-infusion) shows coherent appearance (they are all in one plane), but approaching the fracture this order is loosened, the planes are deforming.

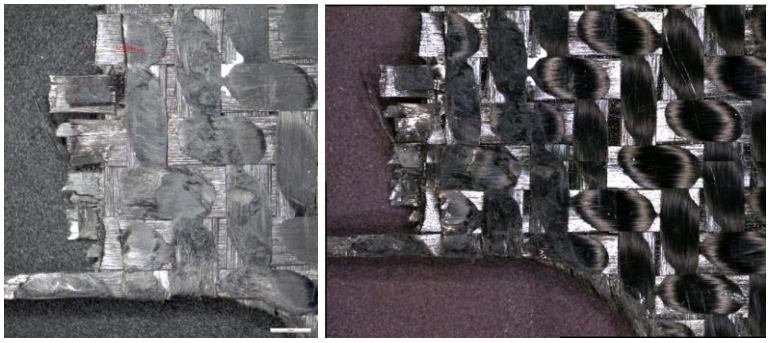


Figure 15
Tensile fracture of a 6-layer specimen after fatiguing, by diffused light (left), optically filtered (right)

If it is still considered on the basis of adequate bibliography that the carbon fibers are resistant to fatigue, the lower tensile strength had to be caused by the resin fracture. Either the resin particles damaged the carbon fibers (by wearing or sharp edges), or the carbon fibers each other, or the load-share of the resin was missing, or two or more worked together causing the very low tensile strength.

Conclusions

In this project, the aim was to fatigue test carbon fiber composite materials with differing numbers of reinforcing laminates embedded in epoxy resin. First, a bending fatigue test machine, with a crank mechanism was developed and manufactured. The devise was also optimized for partly dynamic loads. Afterwards, half of the in-house produced specimens, were examined by fatigue and tensile tests, the other half, only tensile tests. Interesting ruptures were detected, categorized and named as Grip ruptures, Neck ruptures, Whiskers ruptures and Double ruptures. Grip ruptures were divided into two groups: straight rupture with normal tensile strength and curved rupture with higher strength. Within the control group, without fatiguing, all of the thickest (6-layer) specimens broke into three parts, during the tensile tests. In accordance with the literature, the fatigue limit was undetectable in cases of the 3-5 reinforcing layers, the thickness did not influence, significantly, the tensile strength per unit surface. In the 6-layer composite material's fatigue tests, the bending fork caused an unplanned excess load, that produced an interesting result: Cracks appeared in the resin along the reinforcing fibers, the cross section of the specimen reduced and the tensile strength (counted with the original cross-section) decreased to a tenth.

Acknowledgement

This work has been supported by the European Union, co-financed by the European Social Fund. EFOP-3.6.1-16-2016-00014. Authors are thankful for it.

References

[1] Friedrich K., Fakirov S., Zhang Z.: Polymer Composites. Springer US, Boston (2005)

[2] Trewin E.: The advanced composites industry - Global markets, technology trends and applications. Materials Technology Publications, Watford, UK (2003)

[3] Forsdyke K. L., Starr T. F.: Thermoset resins- Market Report. , Shawbury, (2002)

[4] Shaw T. M., MacKnight J. W.: Introduction to Polymer Viscoelasticity. Wiley, New York (2005)

[5] Starkova O., Buschhorn S. T., Mannov E., Schulte K., Aniskevich A.: Creep and recovery of epoxy/MWCNT nanocomposites. Composites Part A: Applied Science and Manufacturing, 43, 1212-1218 (2012)

[6] Harris B.: Fatigue in composites. Woodhead Publishing, Cambridge (2003)

[7] Horst J. J., Spoormaker J. L.: Fatigue fracture mechanisms and fractography of shortglassfibre-reinforced polyamide 6. Journal of Materials Science, 32, 3641-3651 (1997)

[8] Ueki Y.: High-speed bending-fatigue testing of composite materials, IOP Publishing, IOP Conf. Series: Materials Science and Engineering **388,** 012008 (2018)

[9] P. V. Kulkarni, P. J. Sawant, V. V. Kulkarni: Design and Development of Plane Bending Fatigue Testing Machine for Composite MaterialMaterials Today: Proceedings 5, 11563-11568 (2018)

[10] W. Van Paepegem, J. Degrieck: Experimental setup for and numerical modelling of bending fatigue experiments on plain woven glass/epoxy composites, Composite Structures, 51(1), 1-8, (2001)

[11] S. M. Landge, Patil D. N., Talekar A. V., Ghosh A. A., Prof. Mr. Mainak Bhaumik M.: Design & Development of Bending Fatigue testing Machine for Composite Materials, International Research Journal of Engineering and Technology (IRJET) 05, 04 (2018)

Institutional Settings and their Impact on the IPO Activity: An Exploratory Study Based on Qualitative Modelling

Tomáš Meluzín, Marek Zinecker, Adam P. Balcerzak, Michał B. Pietrzak, Karel Doubravský

Brno University of Technology, Faculty of Business and Management, Antonínská 548/1, 610 90 Brno, Czech Republic, meluzint@fbm.vutbr.cz, zinecker@fbm.vutbr.cz, doubravsky@fbm.vutbr.cz

University of Warmia and Mazury in Olsztyn, Faculty of Economic Sciences, ul. pl. Cieszyński 1/327; 10-720 Olsztyn, Poland; Brno University of Technology, Kolejní 2906/4, 612 00 Brno, Czech Republic, a.balcerzak@uwm.edu.pl

Nicolaus Copernicus University, Faculty of Economic Sciences and Management, ul. Gagarina 13a, 87-100 Toruń, Poland, michal.pietrzak@umk.pl

Abstract: This article deals with the propagation of rumours about the introduction of institutional settings, which are intended to make the going public strategy in a country more attractive. Rumours significantly affect the level of uncertainty and can be both positive – if the market responds by increasing the initial public offering activity – or negative – if the market responds by a drop of primary issues. We document how the going public activity in a country might be promoted if both positive and negative rumours occur. The rumour spreading model called SIRaRu and qualitative trend-based modelling are applied. There are no quantifiers such as numbers or fuzzy sets needed. Altogether 17 variables are used to capture two dimensions of general institutional quality and internal state of the company. The numerical calculations result in a set S of 9 scenarios, which are complemented by a set T of 46 transitions. Hence, any past and future behaviour of the qualitative model QS can be reconstructed as a sequence of obtained scenarios. Moreover, a graphic solution was derived to study the behaviour of selected variables on the timeline.

Keywords: institutional economics; rumours; IPO; qualitative trend models; scenarios

1 Introduction

An initial public offering (IPO) represents a procedure within which a firm sells common stocks to the investment public for the first time since its establishment. It is a milestone in the business life cycle providing shareholders and investors

interested in buying shares a unique opportunity of making a profit on their investment (Certo et al. 2009). Going public activity in a country is in general interpreted as a favourable dimension of overall-economic development supporting investments, growth, and job creation (Lewellyn and Bao 2014). Many academic studies emphasize the essential role of a well-developed financial system, where such institutions are established, which mobilise savings, accelerate the capital flow, and optimise capital allocation (Olgic Draženovic and Kusanovic 2016).

Lewellyn and Bao (2014) suggest that the parties involved in the going public procedure require a certain degree of certainty in achieving their individual interests. There are two categories of institutions lowering the level of uncertainty, i.e. affecting the belief of market participants that the valuation of the corporate stocks will be well-balanced and that any profits will be secured from "wrongful misappropriation" (Lewellyn and Bao 2014). Firstly, formal institutions have to be established, i.e. laws and regulations protecting minority shareholders from oppressive or unfairly prejudicial behaviour by controlling shareholders, stable and in its operations efficient and transparent government, stable political regime, zero corruption, public access to information, and integrity of the judiciary (e.g. La Porta et al. 2006, 1997). Moreover, as Lewellyn and Bao (2014) note, the institutional environments taking impact on the IPO activity in a country are also "composed of informal institutions". These institutions include local (often religious) norms, taboos, traditions, customs, and the perception of humility, patience, curiosity, openness, and independent thinking (Boetke et al. 2008). Recent empirical research delivered evidence that national or local culture could play a significant role in encouraging or impeding IPO activity" (Lewellyn and Bao 2014).

In this paper, we build on our previous works devoted to the spreading of rumours related to political or macroeconomic instability and their impact on going public activity in a country (Meluzín et al. 2018). More specifically, we study the link between rumours about the introduction of institutional settings, which might reduce political uncertainty and boost the IPO activity in an emerging capital market. Empirical evidence suggests a positive correlation between the institutional quality on local stock markets and IPO volumes (Lewellyn and Bao 2014, La Porta et al. 1997, King and Levine 1993). We use an explorative research approach based on qualitative modelling and the rumour spreading model SIRaRu introduced by Wang et al. (2014). This model investigates the dynamics of rumours which are spread in complex social networks. We study how the going public volumes in a country might be promoted if positive rumours in regard to the introduction of institutional settings occur. This might happen during election campaigns or if a new government is appointed into office. The SIRaRu model is designed on a qualitative basis; this means that there is information shortage in relation to the impact of institutions on the IPO activity and this is obtainable only as a verbal description based on prior knowledge of the trend. We define specific

stock market conditions on prior rumour spreading models and derive a new qualitative model based on heuristics. A transitional graph is used as a tool to cover all possible past and future behaviour of the variables under study. Furthermore, a graphic solution was derived to study the behaviour of selected variables on the timeline. To our knowledge, this study contributes to the existing body of the going public literature as the relationship between the various aspects of formal institutions and going public volumes has not yet been studied on a qualitative basis. This research approach is used because a shortage of data makes an application of conventional statistical methods not possible. We believe that the results represent a tool supporting IPO companies, investors, and public authorities in their decision making if rumours occur and thus conceivable scenarios of the subsequent developments have to be analysed and evaluated.

The remainder of this article is structured as follows. Section 2 deals with the literature on institutional settings and their impact on the IPO activity with a focus on emerging markets. In Section 3, data and methods are discussed. Section 4 presents the main research results. The discussion and conclusions are outlined in the last section.

2 Theoretical Background

The question to what extent expansion of the financial system contributes to overall-economic growth has been investigated extensively in financial academic literature for decades (Skare and Porada-Rochoń 2019, Karkowska and Kravchuk 2019, Olbryś 2019). King and Levine (1993) report that countries with market-based financial systems can achieve higher economic growth in the long run. While banks as financial intermediaries lose importance, an increasing number of empirical studies have provided evidence that institutional investors and capital markets are becoming key elements accelerating capital raising and securities trading (Olgic Drazenovic and Kusanovic 2016; Meluzín et al. 2018; Bonaventura and Giudici 2017). This transformation is mainly driven by the globalisation and liberalisation facilitating capital inflows and outflows and accelerating capital market interconnections (Balcerzak and Pietrzak 2017). The volume of IPOs has accelerated during the last two decades in emerging markets and stock exchanges belong to essential elements that form the external business environment (Kiseľáková et al. 2019).

The academic theory dealing with IPOs has identified many factors that are relevant in terms of the going public activities. A significant number of studies are focused on microeconomic issues, such as making a decision on where to obtain financial resources and how to optimize a capital structure (Gombola et al. 2019, Pieloch-Babiarz, 2020, Kliestik, et al., 2020, Myers 1984), information disclosure (Hlel et al. 2020, Maksimovic and Pichler 2001, Chemmanur and Fulghiery 1999),

broadening the ownership structure (Foley and Greenwood 2010, Boot et al. 2006) or fear of IPO failure (Fontinelle 2015). Approximately the same amount of literature documents, how different external factors affect the demand and supply-side on primary markets with public issues. The qualitative aspects of the institutional background is a crucial factor determining capital market efficiency (Olgic Drazenovic and Kusanovic 2016, Lewellyn and Bao 2014, La Porta et al. 2006, 1997, King and Levine 1993). The risk of external investors in terms of investments into primary shares arises from a lack of information about issuing firms and zero history of market pricing (Certo et al. 2009). There is also high uncertainty on the side of issuers who might be exposed to disinterest of investors resulting in the IPO failure. Doidge et al. (2012) and North (2003, 1990) argue that uncertainty can be reduced by an appropriate institutional framework pushing involved parties to keep on the rules of the game. In their groundbreaking studies, La Porta et al. (2006, 1997) document how the ownership structure, the quality of the protection of property rights, and the law enforcement quality affect local capital market developments and the volumes of IPOs. The authors show that common law countries provide investors with better protection of property rights than civil law countries, which is supported by the development of the local financial market institutions. From more recent studies delivering empirical evidence on the role of the institutional framework, we recall Lewellyn and Bao (2014) who analysed IPOs in 45 countries in the period between 2001 and 2011. They found that the level of IPO activity is positively influenced by the quality of formal institutions work in the country and the culture, which should be performance, oriented. Many other studies on emerging capital markets also reveal that volumes of primary issues is driven by changes in political and economic ecosystem in particular because more efficient general economic institutions lower the transaction cost, risk, and uncertainty and boost returns on investment (Doidge et al. 2012, Kaufman et al. 2009).

The institutional theory distinguishes between formal and informal institutions (North 2003, 1990). Helmke and Levitsky (2004) define formal institutions as "rules and procedures that are created, communicated, and enforced through channels widely accepted as official". By contrast, informal institutions are "socially shared rules, usually unwritten, that are created, communicated, and enforced outside of officially sanctioned channels". The theory suggests that formal and informal institutions within a country interact in various forms and both affect economic performance (Lewellyn and Bao 2014, Helmke and Levitsky 2004). However, while formal institutions can be modified depending on political preferences and overall economic conditions, informal institutions are rather resistant in terms of radical changes (Balcerzak, 2020). Helmke and Levitsky (2004) believe that informal institutions play an essential role in enforcing the formal rules. Therefore, establishing formal institutions is not a guarantee of their effective functioning as long as these institutions are not accepted by economic actors (Lizińska et al. 2016).

The political system in a country and the state government are essential elements in shaping the formal institutional environment that is intended to define what rules in economic transactions will be followed and how the behaviour of economic actors – firms going public and investors – will be regulated (North 2003, 1990). Prior studies have shown that the ability of formal institutions to protect minority shareholders has a strong and positive impact on the IPO volumes, as these regulations define barriers to insiders or majority shareholders to expropriate profits or assets from companies (Djankov et al. 2008, La Porta et al. 2006, 1997). As noted by Lewellyn and Bao (2014), law enforcement is as important as legal protection because investors evaluate both the "level of law" and "order," generally known as the "rule of law," which will take influence on systematic risk in a country and ultimately perceived risk of investments in primary shares.

The investors as well as the intra-firm decision-makers are very sensitive in terms of both formal and informal institutions and their development reflected, e.g. in government policies and campaigns as well as in terms of opinions, estimations or predictions evaluating such policies. Private analysts, columnists, or financial experts use countless information channels to convey information about governments, industries, and enterprises. Such estimations and opinions can be sometimes interpreted as rumours – "purely speculative and unreliable" information of all kinds with the potential to affect behaviours of economic actors substantially (Spiegel et al. 2010). The character of rumours can vary from a simple gossip to well-developed marketing propaganda. Nekovee et al. (2007) interpret rumours as an "infection of the mind" meaning that their transmitting documents a close similarity to that of epidemics. Chen and Kutan (2016), Spiegel et al. (2010), or Kosfeld (2005) document that rumours unambiguously have a psychological impact on the intra-firm decision-makers and external investors. The authors conclude that in particular high-tech information sources such as websites, social networks and blogs represent a kind of the "intellectual epidemic". Studying the transmission of "intelectual epidemics" has a long tradition. Goffman and Newill (1964) defined the "epidemic" process" as "transition from one state (susceptible) to another (infective) where the transition is caused by exposure to some phenomenon (infectious material)". Daley and Kendall (1964), who developed the very first rumour-spreading model, divided the closed and homogenously mixed population into three groups. The first group are spreaders (S), who attempt actively to "infect" the other individual with the rumours by pair-wise contacts. If the other individual is ignorant of the rumour (I), it turns into a spreader. The third group are those who already know the rumour and decide not to spread it anymore, hence they turn into stiflers (R). Wang et al. (2014) argue that rumour spreading differs from the transmission of infectious disease. While an infected patient is unable to take influence whether to spread the disease to others or not, an individual has the autonomy to perform an action, whether to accept the rumour and spread it or not. They accept enlarged classification of stiflers proposed by Huang and Jin (2011). "Ra" stands for

individual "who accept the rumour but lose interest to spread it". "Ru" are people who do not accept the rumour at all. Furthermore, Wang et al. (2014) attempted to overcome a traditional shortcoming of the above class of models that assume a homogeneously mixing population. The SIRaRu rumour-spreading model extends the research while describing the dynamics of rumours in "complex networks" and delivers evidence that "the spreading threshold exists in both homogenous and inhomogeneous networks".

Summing up, we believe that the phenomenon of rumour propagation offer a unique opportunity for studying the variability in the number of IPOs across countries. Rumours significantly affect the level of uncertainty and can be both positive – if the market responds by increasing the initial public offering activity – or negative – if the market responds by a drop of primary issues. Hence, to better understand the impact of rumours on the IPO activity, we hypothesize that rumours about the introduction of stronger institutional settings driven by political and economic changes will help to foster IPO activity in a country, however, the success of an individual firm might be seriously jeopardized by misinformation and rumours related to a range of intra-firm issues. We adopt the SIRaRu rumour-spreading model introduced by Wang et al. (2014) and tools of qualitative modelling to examine the above hypothesis with a focus on emerging primary stock markets.

3 Methodology

Qualitative Trend Models and Transitional Graphs

Studying the impact of rumours on the IPO activity is a task that can be described as unique, non-linear, (partially) subjective, and vague. Generally, the key problem of realistic and complex tasks is a serious lack of information (Doubravsky and Dohnal 2018). This limits the straightforward application of traditional statistical methods assuming the existence of complex data sets. Therefore, both objective and subjective information require synthesis to obtain the obvious benefits of objective accuracy (deep knowledge) and semi-subjective common sense capabilities (shallow knowledge) see, e.g. Jiang et al. (2014).

A shallow knowledge item is represented by heuristics or statistical data sets. It is usually characterized by a number of exceptions. Shallow knowledge/data sets items have forms of equations as well. Exponential or polynomial relations are typical examples. The larger part of shallow knowledge items takes the form of a mere verbal description based on pairwise trends, decreasing, constant and increasing (Yan et al. 2013). The most common examples of such pairwise trend relations can be seen in Figure 1. All pair-wise relations X, Y are based on trends. It means no quantifiers are used. The pairwise trend relations are marked as 21,

22, 23, 24, 25, and 26 and represent just an expression of the first quadrant of a coordinated system, for more details see (Doubravsky and Dohnal 2018). To design the trend model, deep knowledge, shallow knowledge, or both are applied. The trend model based on deep knowledge is denoted QR, the trend model based on shallow knowledge is denoted QH, and the trend model based on both knowledge is denoted QS. Qualitative variables and constants are used in all of the mentioned models.

The trend model based on deep knowledge is defined as a set of differential equations. This model is denoted:

$$QR(X) \tag{1}$$

Where X = (X1, X2,..., Xn) is a vector of monitored variables of qualitative type.

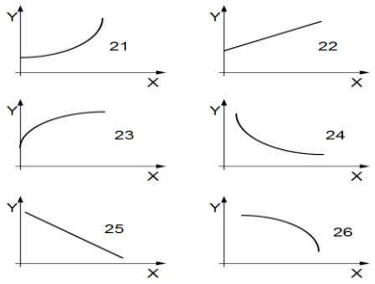


Figure 1
Qualitative pair wise relations – the most common examples

The trend model (1) is identified when all monitored variables X1, X2,..., Xn are specified by triplets:

$$(Xi, DXi, DDXi),\ i = 1, 2,\ldots, n \tag{2}$$

Where DX is the first qualitative time derivative of X and DDX is the second qualitative time derivative of the variable X.

Let give the following example: the triplet (+ + +) means that the variable X takes only positive values (X = (+)), is growing over time (DX = (+)) and this growth is of an accelerating nature (DDX = (+)). Hence, the solution of the model QR is a set MR comprising the triplets (2) which are in accordance with all equations of the model QR. An element S of the set MR is written as follows:

$$[(X1, DX1, DDX1), (X2, DX2, DDX2),\ldots, (Xn, DXn, DDXn)]. \tag{3}$$

Thus, each element of MR represents one particular solution of the model QR. This solution is called a scenario. The process of finding the solution MR of the model QR is called trend analysis, for more details see Doubravsky and Dohnal (2018). Each element of the triplet (2) can be substituted only by a finite volume of qualitative values. The set MR comprises only a finite volume of scenarios.

Hence, within a trend analysis, a finite set of solutions can be obtained. In many real-world situations, equations are not available to describe the model. In such cases, the experience and knowledge of experts are used. The trend model based on shallow knowledge is provided by statements as follows:

$$QH(H1, H2,\ldots, Hw) \tag{4}$$

Where w is the number of statements.

In order to work with the model, it is necessary to convert the statement into mathematical language. The easiest way how to conduct the conversion is the application of pairwise trends, see Figure 1. Each statement can be transferred to a pairwise trend:

$$Pv(Xi, Xj) \tag{5}$$

Where v = 1, 2,..., w and i, j = 1, 2,..., n, $i \neq j$.

The trend model (4) can be written using a pairwise trend:

$$QH(P1, P2,\ldots, Pw) \tag{6}$$

In respect to (5) the model (6) can be written:

$$QH(X) \tag{7}$$

Where X = (X1, X2,..., Xn) is an expression of the vector of variables under study.

The output of the model QH is a set MH containing the triplets (2) which meet all pairwise trends (5). An element of the set MH is scenario (3). The mixed trend model QS is the model based on deep and shallow knowledge. The mixed trend model is created by merging (used the symbol ⁀) of equations with pairwise trends.

$$QS(X) = QR(X) \frown QH(X) \tag{8}$$

The output of the model QS is a set MS of scenarios (3) which is the intersection of the set MR and MH.

$$MS = MR \cap MH. \tag{9}$$

From a set M of scenarios S, transitions between these scenarios can be generated. The scenarios and the transitions between them can be represented by a transitional graph. An elementary common-sense analysis of an oscillator suggests that a spring that is rolling in one single way must be stopped in the first stage; in the second stage, it can be redirected. We can conclude that the next transition between two triplets which are one-dimensional is ruled out:

$$(+ + +) \rightarrow (+ - -). \tag{10}$$

The transitional graph "G" consists of nodes representing the scenarios S. The set of the ordered pairs can be expressed as $T \subseteq (S \times S)$.

$$G(S, T) \tag{11}$$

A sequence of transitions T of the transitional graph G between two nodes (scenarios) s_1 and s_m is called a directed path (shortly a path). The path starts in s_1 and ends in s_m. If $s_1 = s_m$, the path is closed, otherwise the path is open. In this paper, closed paths are not the subject of our interest. The transitional graph is coherent if there is at least one path between its nodes. For more details about the graph theory see Gallier (2011). Any path of the transitional graph G represents a description of the trend and a prediction or past behaviour. This suggests that the transitional graph is a visualisation of all potential future or past events within the model. Hence, any prediction is equal to a choice of any path displayed within the transitional graph.

In this paper, the choice of a suitable path is based on the common sense heuristic: the more variables to change, the less probable this change becomes. Therefore, the paths with the least number of changed variables are searched.

Data Description

We adopt the case study approach, which is systematically interpreted as a way how qualitative research might be carried out when an in-depth investigation of complex phenomena is required (Harrison et al. 2017). The object of the case study is represented by two kinds of rumours. Both of them are spread through the web and other information channels. The first rumour concerns the institutional quality and we term this (F1). The second rumour is related to the internal state of the company and we term this (F2).

As noted above, (F1) is represented by a confounding amount of opinions, estimations and predictions concerning changes in macroeconomic policy in country A: The previous government left office and the new political leader repeatedly claimed during the pre-election political campaigns that institutional settings will be introduced to reduce risk and uncertainty to lead the economy to growth; positive effect on innovation and productivity are expected. Measures to favour the listing of young and innovative firms should be implemented to foster economic growth. This announcement has been extensively discussed and analysed by experts, market analysts and columnists in countless websites, chat rooms and forums as well as in economic sections of business journals. As reported by Spiegel et al. (2010) some rumours – accurate or fake – emerge and vanish very quickly, but other rumours become "multi-rumours" by being reproduced time and again.

If institutional improvements were introduced in the country's economy, it can be assumed that significant growth in investment will boost its economic output. An IPO strategy is more attractive as IPO candidates and investors are exposed to a lower degree of risk and uncertainty. A drop in transaction costs and an increase in returns on investment are likely to happen in relation to future developments. The volume of IPOs in the country "A" will increase because institutional and retail investors as well as firms' decision-makers will change their sentiment towards investments in newly issued shares and thus going public strategy.

Contextual variables under study include two dimensions of institutional quality: 1) effectiveness of general economic institutions lowering the transaction cost, risk, and uncertainty (TC) and boosting returns on investment (r) (Kaufman et al. 2009) and 2) effectiveness of financial market institutions improving market liquidity (ML) and increasing IPO volumes (NIPO) in the country (La Porta et al. 2006, 1997). Four indices of governance proposed by Kaufman et al. (2009) are used to capture the following dimensions of general institutional quality: the government effectiveness (GEff), regulatory quality (Reg), rule of law (RoL), and control of corruption (Corr). Furthermore, two variables concentrated on the evaluation of institutional background in the local capital market are considered: regulatory and fiscal incentives to encourage institutional investors to enter the local capital market (IncInv) and regulatory incentives to attract emerging growth companies to conduct an IPO (IncIPO). All variables are *lottery* variables, i.e. both the investors and enterprises cannot take any action to influence them. For details see Table 1.

Table 1

Institutional settings affecting IPO market development – a description of the variables used

General Economic Institutions to Lower the Level of Transaction Costs (*TC*) and to Boost Returns on Investment (*r*)		
Government effectiveness (Kaufman *et al.* 2009)	*GEff*	Qualitative aspects of public services and the extent of their independence from political interests, the quality of policy conceptualization and implementation, and the integrity of the government's allegiance to such policies.
Regulatory quality (Kaufman *et al.* 2009)	*Reg*	The capability of the government to propose and apply such a kind of policies and rules, which are favourable to the development of non-public sector.
Rule of law (Kaufman *et al.* 2009)	*RoL*	The scope to which market participants trust that contracts and property rights are enforceable. The economic agents also trust that the police as well as the courts perform their functions. The likelihood of crime and violence is also considered.
Control of corruption (Kaufman *et al.* 2009)	*Corr*	Perceptions of the degree to which public power is misused for private benefit, including various forms of corruption.
Financial Market Institutions to Improve Market Liquidity (*ML*) and Increase the IPO Activity (*NIPO*)		
Regulatory and fiscal incentives to support the local capital market (La Porta *et al.* 1997, Olgic Drazenovic and Kusanovic (2016)	*IncInv*	Incentives that aim in particular at the protection of minority shareholders and the expansion of the institutional investors' base.

Regulatory incentives to attract enterprises to conduct an IPO (Wilson 2015)	*IncIPO*	Incentives that aim at reducing regulatory and reporting requirements to reduce compliance costs.

Source: Kaufman *et al.* (2009), Olgic Drazenovic and Kusanovic (2016), Wilson (2015), La Porta *et al.* (1997)

On the basis of the previous knowledge on the institutional determinants of the IPO activity in a country, the following variables and their relations, recorded by means of the pair relations from Figure 1, have been identified: P1(GEff, TC) = 24; P2(Reg, TC) = 24; P3(RoL, TC) = 24; P4(Corr, TC) = 24; P5(TC, r) = 24; P6(IncInv, ML) = 21; P7(IncInv, TC) = 24; P8(IncInv, NIPO) = M+; P9(IncIPO, TC) = 24; P10(ML, NIPO) = M+; P11(IncIPO, NIPO) = M+; P12(ML, TC) = 24.

→ Model QH1 (12)

The M+ label is used if it cannot be said whether the speed of changes between the relevant variables is constant, increasing, or decreasing. Thus, M+ stands for the relations 21, 22 and 23 given in Figure 1.

Moreover, in our case study rumours related to internal state of the company are considered (F2). These rumours are of a negative nature; hence, their spreading increases the uncertainty on the side of investors.

F2: There are misinformation and rumours about the firm's technology that is said not to be fully mature. Some experts, analysts, and stakeholders doubt the company would be able to achieve its full-year revenue targets and is actually not well prepared for the fund-raising process via IPO. These rumours seriously jeopardize the success of the primary issue which means "window of opportunity" might not remain open. Here, we define the "window of opportunity" as the most propitious time for launching an IPO. Here, it is a function of the firm's performance or exogenous factors (Loughran et al., 1994).

Ritter (1984) suggests that high profitability in previous periods is a significant factor encouraging managers to launch an IPO to gain from the window of opportunity. Pagano et al. (1998) contradicts this theory and believes that a negative relationship between profitability and the probability of going public (IPOP) exists as only firms that are incapable to produce sufficient internal resources prefer external capital. Alternative theories seem to attach little importance to the IPO timing hypothesis. The pecking-order theory assumes that firms prioritize internal to external financing because the cost of capital increases with information asymmetry (IA) between managers and external investors; this makes it extremely complicated to assess the prospects, risks, and value of a particular company (Myers 1984). Accordingly, retained profits (RP) are used first. When internal funds are depleted, bank loans (BL) represent the second financial choice. Issuing equity views the pecking-order theory as the last option. Other theories deal with the issue of how the information disclosure influences the decision to go public. Maksimovic and Pichler (2001) argue that a negative

relationship exists between sensitivity to information disclosure, especially in R&D issues, and the probability of going public. Rajan (1992) suggests that raising capital via IPO can lower the price of bank loans, probably because firms improve the dissemination of information to stakeholders and consequently improve their bargaining power with banks. Chemmanur and Fulghiery (1999) notice that when an adequate amount of information about firms is publicly accesible, the costs of producing information (CPI) decrease. In sum, in the case of mature and well-established companies is the probability of an IPO higher. Investors may also assess an IPO as risky because insufficient historical public data on the issuing company is available. With the less predictable future cash flows and the lower liquidity, there is the higher underpricing (UP) of the issued shares. Investors have to be compensated for their risk related to information asymmetry.

On the basis of the previous knowledge, the following firm-specific variables have been identified: IA, RP, BL, IPOP, CPI, and UP. We suggest that all these variables are decision variables, i.e. both the investors and enterprises can take any action to influence their quality. Their relations recorded by means of the pair relations from Figure 1 are as follows: P13(IA, RP) = 22; P14(IA, BL) = M+; P15(IA, UP) = 21; P16(IA, CPI) = 22; P17(IPOP, CPI) = 24.

→ Model QH2 (13)

Qualitative Heuristics-Based Model

We use the pair relations to formulate the qualitative models QH1 and QH2. Both of them are based on heuristics. Propagating the rumours F1 and F2 is described by the qualitative model QR. This is derived from the SIRaRu rumour spreading model by Wang et al. (2014) and extended with the infection rate of the population by the rumour PP.

$$DI = -I \cdot S$$

$$DS = +I \cdot S - S\,(S + Ra + Ru) - S$$

$$DRa = I \cdot S + S\,(S + Ra + Ru) + S \quad (14)$$

$$DRu = I \cdot S$$

$$P\_P=(S+R\_a)/(S+R\_a+R\_u+I)$$

The impact of the rumour propagation onto the IPO may be described by suitably interconnecting the model QR (14) with the models QH1 (12) and QH2 (13). Interconnecting both models QH(1,2) and QR may be performed by means of introducing the additional pair relations, i.e. by introducing another on heuristics-based qualitative model QH3. The coupling of the two rumours (F1 and F2) may cause contradictory reactions on the side of investors. Their decision to invest in newly issued stocks is either positive or negative and ultimately affect the success of the IPO. Accordingly, the heuristics H2 and H3 are as follows:

(H2) The growing knowledge of the rumour F1, i.e. the growing infection rate of the population PP, will lower transaction cost (TC). This will increase the IPO activity (NIPO) in the country and thus the probability of going public (IPOP). (H3) The growing knowledge of the rumour F2, i.e. the growing infection rate of the population PP, will increase the cost of producing information (CPI). This will dampen the probability of going public (IPOP).

The heuristics H2 does not conclusively indicate the changes in the speed of the transaction cost (TC) as the population infection rate PP grows. This means that the relation 24 or 25 or 26 (see Figure 1) may be used to describe the relationship between the TC and PP. These possible potential links will be marked by the label M–. Similarly, the heuristics H3 formulation does not conclusively indicate the changes in the speed of the cost of producing information (CPI) as the population infection rate PP grows. This means that the relation 21 or 22 or 23 (see Figure 1) may be used for the purposes of expressing the relation between the CPI and PP. These possible mutual links will be represented by the label M+. In such a case, the heuristics H2 and H3 may be recorded by the pair relations as follows: P14(PP, TC) = M–; P15(PP, CPI) = M+. These pair relations are represented by the qualitative model QH2, which is derived from heuristics H2 and H3.

The model characterizing the rumour spreading and its impact onto the IPO is an outcome of combining the models QH1, QR and QH2. The resulting model is a mixed qualitative model QS.

$$QS = QH1 \vee QR \vee QH2 \tag{15}$$

4 Research Results

A total of 46 possible transitions between all 9 scenarios could be identified (Table 2). These scenarios and their transitions are shown in the graph G (Figure 2). The initial node is denoted as 1 and the terminal node is denoted as 9. Each edge of the transitional graph represents the transition from one node to another. This transition is associated with a certain amount of time expressed in certain time units. The graph represents an overview of all possible oriented paths between the individual nodes/scenarios. These oriented paths are of a qualitative nature and describe the past and future behaviour of the model or variables under study. Therefore, any forecast concerning institutional determinants or the internal state of the company is equivalent equal to a path through a transitional graph. This means that any efforts to predict the future behaviours, which belong to the most common tasks of decision-makers, might be solved while using the graph. These predictions are done by rationally thinking participants assessing individual going public and investment strategies (decision-makers, such as the CFOs of issuing company, investors, columnists, social media contributors, etc.).

Table 2
A list of all one-dimensional transition

	GEFF	*REG*	*ROL*	*CORR*	*TC*	*RN*	*INCINV*	*ML*	*NIPO*	*INCIPO*	*IA*	*RP*	*BL*	*CPI*	*UP*	*IPOP*
1	+ + +	+ + +	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
2	+ + +	+ + 0	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
3	+ + +	+ + −	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
4	+ + 0	+ + +	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
5	+ + 0	+ + 0	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
6	+ + 0	+ + −	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
7	+ + −	+ + +	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
8	+ + −	+ + 0	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0
9	+ + −	+ + −	+ + −	+ + 0	+ − +	+ + 0	+ + −	+ + −	+ + −	+ + −	+ − +	+ − +	+ − +	+ − +	+ − +	+ + 0

Source: created by the authors

In sum, we identified 235 paths; an example of them is shown in Table 3. Each transition between scenarios is associated with changing at least one variable. Based on the number of variables to be changed, the paths with the least number of variables are selected from 235 paths. There were 13 paths selected (Table 4). Four variables were changed on these paths. Analogously, it is also possible to derive a trend graph for the other variables. Based on Table 3, it is possible to forecast the development of individual variables over time. For instance, Figure 3 shows the development of the variable *REG* over time *t*.

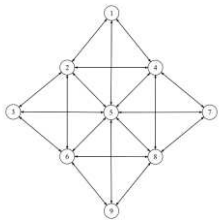


Figure 2
Transitional graph G

Source: created by the authors.

Table 3
A non-comprehensive list of paths

No	Path	No	Path
1	1→2→3→5→4→7→8→6→9	⋮	…⋮
2	1→2→3→5→4→7→8→9	220	1→5→7→4→2→3→6→9
3	1→2→3→5→4→8→6→9	221	1→5→7→4→2→6→8→9
4	1→2→3→5→4→8→9	222	1→5→7→4→2→6→9
5	1→2→3→5→6→8→9	223	1→5→7→4→8→6→9

6	1→2→3→5→6→9	224	1→5→7→4→8→9
7	1→2→3→5→7→4→8→6→9	225	1→5→7→8→4→2→3→6→9
8	1→2→3→5→7→4→8→9	226	1→5→7→8→4→2→6→9
9	1→2→3→5→7→8→6→9	227	1→5→7→8→6→9
10	1→2→3→5→7→8→9	228	1→5→7→8→9
11	1→2→3→5→8→6→9	229	1→5→8→4→2→3→6→9
12	1→2→3→5→8→9	230	1→5→8→4→2→6→9
13	1→2→3→5→9	231	1→5→8→6→9
14	1→2→3→6→5→4→7→8→9	232	1→5→8→7→4→2→3→6→9
15	1→2→3→6→5→4→8→9	233	1→5→8→7→4→2→6→9
16	1→2→3→6→5→7→4→8→9	234	1→5→8→9
⋮	…⋮	235	1→5→9

Source: own calculations.

Table 4

Paths with the least number of variables to be changed

No	Path	No	Path
1	1→2→3→6→9	8	1→4→5→9
2	1→2→5→6→9	9	1→4→7→8→9
3	1→2→5→8→9	10	1→4→8→9
4	1→2→5→9	11	1→5→6→9
5	1→2→6→9	12	1→5→8→9
6	1→4→5→6→9	13	1→5→9
7	1→4→5→8→9		

Source: own calculations.

Figure 3 is not a conventional graph, but a trend graph. The following inequalities represent the only restrictions:

$$0 < a < b < c \tag{16}$$

The numerical values of intervals are not relevant.

Conclusions

In this paper, we investigated the propagation of rumours in complex social networks and their impact on going public activity in a country while using the SIRaRu rumour propagation model and qualitative trend-based techniques. The qualitative research concept has been applied to study the propagation of rumours (Meluzín et al. 2018). Rumours might be described as unique, partially subjective, inconsistent, vague and multidimensional. Oversimplified and/or exact quantitative models can deliver misleading results. The main explanation of this phenomenon is a serious lack of data (Doubravsky et al. 2020).

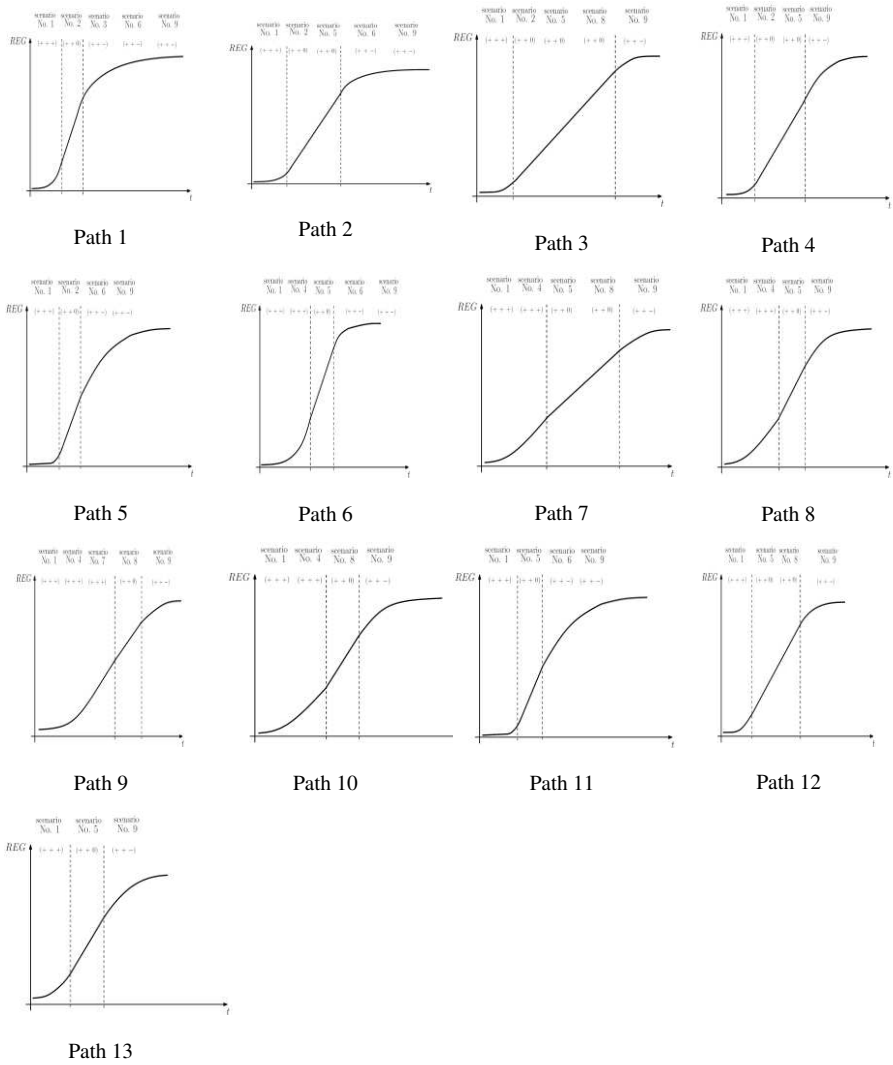


Figure 3
Qualitative description of the function REG(t)

Source: created by the authors.

Here, we document for the first time how two kinds of rumours – the first one is positive, the second one negative – might be spread and consequently support or dampen the development of the IPO market in a country. The positive rumour is out of control of decision-makers (we call this a lottery), while the negative rumour might be controlled by market participants. The main research outputs consist in a qualitative heuristics-based model and in a transitional graph.

Furthermore, we derived a graphical solution to investigate the evolution of the investigated variables over time. The set of scenarios, the transitional graph and the visualization of the development of variables represent a comprehensive tool allowing managers of issuing companies, investors, and other market participants to better understand the relationship between monitored variables. Based on the results, the whole variety of past or future developments of the variables under study can be analysed. Hence, the users of the model can derive how an individual variable can be affected by changing other variables. For instance, how law enforcement in the country will change if government effectiveness and corruption control will increase, but the growth of these variables will slow down.

There are five main benefits of the qualitative approach in the research of rumour propagation. Firstly, no numerical inputs about levels of measurements are required and the set of qualitative solutions represents a superset of all relevant solutions. This means that no significant forecast can be excluded. Secondly, all available time transitions among the obtained set of scenarios are specified. Thirdly, the very nature of the model enables studying its inner dynamics. Alternative variables can be integrated into the model. This feature makes it very flexible in performing any union or intersection of different models. Finally, the approach results are based on expert estimates and common sense, which makes them comprehensible from the perspective of practitioners. Corporate managers, investors, and other stakeholders are provided with a flexible tool to support effective decision-making without the knowledge of sophisticated mathematical and statistical methods. On the other hand, the disadvantages of qualitative models cannot be neglected. The most important of them consists in the linearity assumption (Doubravsky a Dohnal 2018, Doubravsky et al. 2020).

In the follow-up research, efforts will be made to improve the stability and accuracy of the model under study. Furthermore, probabilities of future forecasts and scenarios will be quantified while using the topology of the transitional graphs.

Funding

This work was supported by the Institute of Economic Research, Poland, and Brno University of Technology, Faculty of Business and Management, Czech Republic (grant number 2019/1). The title of the project is “Public and Private Equity in CEE countries”.

References

[1] Balcerzak, A. P. (2020) Quality of institutions in the European Union countries. Application of TOPSIS based on entropy measure for objective weighting. Acta Polytechnica Hungarica, 17(1), 101-122, doi: https://doi.org/10.12700/APH.17.1.2020.1.6

[2] Balcerzak, A. P., Pietrzak, M. B. (2017) Digital Economy in Visegrad Coutnries. Multiple-criteria decision analysis at Regional Level in the Years 2012 and 2015. Journal of Competitiveness, 9(2), 5-18

[3] Bonaventura, M., & Giudici, G. (2017) IPO valuation and profitability expectations: evidence from the Italian exchange. Eurasian Business Review, 7(2), 247-266

[4] Boot, A. W. A., Gopalan, R., & Thakor, A. V. (2006) The Entrepreneur's Choice between Private and Public Ownership . Journal of Finance, 61(2), 803-836, https://doi.org/10.1111/j.1540-6261.2006.00855.x

[5] Chemmanur, T. J., & Fulghieri, P. (1999) A Theory of the Going-Public Decision. Review of Financial Studies, 12(2), 249-279, https://doi.org/10.1093/rfs/12.2.249

[6] Chen, C. -Da, & Kutan, A. M. (2016) Information Transmission Through Rumors in Stock Markets: A New Evidence. The Journal Of Behavioral Finance, 17(4), 365-381, https://doi.org/10.1080/15427560.2016.1238373

[7] Certo, S., Holcomb, T. R., & Holmes, R. M. (2009) IPO research in management and entrepreneurship: Moving the agenda forward. Journal of Management, 35(6), 1340-1378, https://doi.org/10.1177/0149206309347375

[8] Daley, D. J., Kendall, D. G. (1964) Epidemics and Rumours. Nature, 204(1118), 42-55

[9] Djankov, S., La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (2008) The law and economics of self-dealing . Journal of Financial Economics, 88(3), 430-465, https://doi.org/10.1016/j.jfineco.2007.02.007

[10] Doidge, C., Karolyi, G., & Stulz, R. (2012) Financial Globalization and the Rise of IPOs outside the U.S. *Ideas Working Paper Series From Repec*. http://search.proquest.com/docview/1698269929/

[11] Doubravsky, K., & Dohnal, M. (2018) Qualitative equationless macroeconomic models as generators of all possible forecasts based on three trend values – Increasing, constant, decreasing. Structural Change and Economic Dynamics, 45, 30-36, https://doi.org/10.1016/j.strueco.2018.01.001

[12] Doubravsky, K., Doskocil, R., & Dohnal, M. (2020) A Dynamic Knowledge Model of Project Time-Cost Analysis Based on Trend Modelling. Periodica Polytechnica Social and Management Sciences, 28(1), 18-28, https://doi.org/10.3311/PPso.13318

[13] Foley, C. F., & Greenwood, R. (2010) The Evolution of Corporate Ownership after IPO: The Impact of Investor Protection. The Review Of Financial Studies, 23(3), 1231-1260. https://doi.org/10.1093/rfs/hhp069

[14] Fontinelle, A. (2015) IPO vs. Staying Private: Pros & Cons of Each Model. Investopedia, September 1

[15] Gallier, J. (2011) Discrete Mathematics. New York: Springer Science+Business Media. https:/doi.org/10.1007/978-1-4419-8047-2

[16] Goffman, W., & Newill, V. A. (1964) Generalization of Epidemic Theory. An Application to the Transmission of Ideas. Nature, 17, 225-228

[17] Gombola, M., Liu, F. -Ying, & Chou, D. -Wai. (2019) Capital structure dynamics with restricted equity issuance: Evidence from Chinese post-IPO firms. Asia Pacific Management Review, 24(1), 72-85, https://doi.org/10.1016/j.apmrv.2018.07.002

[18] Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017) Case Study Research: Foundations and Methodological Orientations. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 18(1), doi:http://dx.doi.org/10.17169/fqs-18.1.2655

[19] Helmke, G., & Levitsky, S. (2004) Informal Institutions and Comparative Politics: A Research Agenda. Perspectives on Politics, 2(4), 725-740

[20] Hlel, K., Kahloul, I., & Bouzgarrou, H. (2020) IFRS adoption, corporate governance and management earnings forecasts. Journal of Financial Reporting & Accounting, 18(2), 325-342, https://doi.org/10.1108/JFRA-01-2019-0007

[21] Huang, J., & Jin, X. (2011) Preventing rumor spreading on small-world networks. Journal of Systems Science and Complexity, 24(3), 449-456, https://doi.org/10.1007/s11424-011-8303-1

[22] Jiang, P., Zhou, Q., Jiang, H., & Yao, D. (2014) An Optimized Forecasting Approach Based on Grey Theory and Cuckoo Search Algorithm: A Case Study for Electricity Consumption in New South Wales. Abstract and Applied Analysis, 2014 (2014) https://doi.org/10.1155/2014/183095

[23] Karkowska, R., & Kravchuk, I. (2019) Identification of global systemically important stock exchanges. Equilibrium. Quarterly Journal of Economics and Economic Policy, 14(1), 31-51, https://doi.org/10.24136/eq.2019.002

[24] King, R., G., & Levine, R. (1993) Finance and growth: Schumpeter might be right (English). Policy, Research working papers; no. WPS 1083, Financial policy and systems. Washington, DC: World Bank

[25] Kiseľáková, D., Šofranková, B., Onuferová, E., & Čabinová, V. (2019) The evaluation of competitive position of EU-28 economies with using global multi-criteria indices. Equilibrium. Quarterly Journal of Economics and Economic Policy, 14(3), 441-462, https://doi.org/10.24136/eq.2019.021

[26] Kliestik, T., Valaskova, K., Nica, E., Kovacova, M., & Lazaroiu, G. (2020) Advanced methods of earnings management: monotonic trends and change-

points under spotlight in the Visegrad countries. Oeconomia Copernicana, 11(2), 371-400, https://doi.org/10.24136/oc.2020.016

[27] Kosfeld, M. (2005) Rumours and markets . Journal of Mathematical Economics, 41(6), 646-664, https://doi.org/10.1016/j.jmateco.2004.05.001

[28] La Porta, R., Lopez-de-Silanes, F., Shleifer, A., & Vishny, R. W. (1997) Legal Determinants of External Finance, Journal of Finance, 52(3), https://doi.org/10.1111/j.1540-6261.1997.tb02727.x

[29] La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (2006) What Works in Securities Laws? Journal Of Finance, 61(1), 1-32, https://doi.org/10.1111/j.1540-6261.2006.00828.x

[30] Lewellyn, K. B., & Bao, S. 'Rosey'. (2014) A cross-national investigation of IPO activity: The role of formal institutions and national culture. International Business Review, 23(6), 1167-1178, https://doi.org/10.1016/j.ibusrev.2014.03.010

[31] Lizińska, W., Marks-Bielska, R., Babuchowska, K., & Wojarska, M. (2016) Institutional efficiency of local government in issuing administrative decisions, exemplified by the performance of the local government appeal board in Olsztyn. Oeconomia Copernicana, 7(2), 285-296, https://doi.org/10.12775/OeC.2016.017

[32] Loughran, T., Ritter, J. R., & Rydqvist, K. (1994) Initial public offerings: International insights. Pacific-Basin Finance Journal, 2(2), 165-199, https://doi.org/10.1016/0927-538X(94)90016-7

[33] Meluzín, T., Balcerzak, A., Pietrzak, M., Zinecker, M., & Doubravsky, K. (2018) The Impact of Rumours Related to Political and Macroeconomic Uncertainty on IPO Success: Evidence from a Qualitative Model. Transformations in Business & Economics, 17 2(44), 148-169

[34] Maksimovic, V., & Pichler, P. (2001) Technological Innovation and Initial Public Offerings. Review of Financial Studies, 14(2), 459-494, https://doi.org/10.1093/rfs/14.2.459

[35] Myers, S. C. (1984) The Capital Structure Puzzle. Journal of Finance, 39(3), 575-592, https://doi.org/10.1111/j.1540-6261.1984.tb03646.x

[36] Nekovee, M., Moreno, Y., Bianconi, G., & Marsili, M. (2007) Theory of rumour spreading in complex social networks. Physica A: Statistical Mechanics and Its Applications, 374(1), 457-470, https://doi.org/10.1016/j.physa.2006.07.017

[37] North, D. (2003) The Role of Institutions in Economic Development. Ideas Working Paper Series From Repec. Retrieved from http://search.proquest.com/docview/1698318593/

[38] North, D. C. (1990) *Institutions, institutional change and economic performance*. New York: Cambridge University Press, https:/doi.org/ 10.1017/CBO9780511808678

[39] Olbryś, J. (2019) Intra-market commonality in liquidity: new evidence from the Polish stock exchange. Equilibrium. Quarterly Journal of Economics and Economic Policy, 14(2), 251-275, https://doi.org/10.24136/eq.2019.01

[40] Olgic Drazenovic, B., & Kusanovic, T. (2016) Determinants of capital market in the new member EU countries. Ekonomska Istrazivanja, 29(1), 758-769, https://doi.org/10.1080/1331677X.2016.1197551

[41] Pagano, M., Panetta, F., & Zingales, L. (1998) Why Do Companies Go Public? An Empirical Analysis. Journal of Finance, 53(1), 27-64, https://doi.org/10.1111/0022-1082.25448

[42] Pieloch-Babiarz, A. (2020) Managerial ownership and catering to investor sentiment for dividends: evidence from the electromechanical industry sector on the Warsaw Stock Exchange. Oeconomia Copernicana, 11(3), 467-483, https://doi.org/10.24136/oc.2020.019

[43] Rajan, R. G. (1992) Insiders and Outsiders: The Choice between Informed and Arm's-Length Debt. Journal of Finance, 47(4), 1367-1400, https://doi.org/10.1111/j.1540-6261.1992.tb04662.x

[44] Ritter, J. (1984) The "Hot Issue" Market of 1980. The Journal of Business, 57(2), 215, https://doi.org/10.1086/296260

[45] Skare, M., & Porada-Rochoń, M. (2019) Tracking financial cycles in ten transitional economies 2005–2018 using singular spectrum analysis (SSA) techniques. Equilibrium. Quarterly Journal of Economics and Economic Policy, 14(1), 7-29, https://doi.org/10.24136/eq.2019.001

[46] Spiegel, U., Tavor, T., & Templeman, J. (2010) The effects of rumours on financial market efficiency. Applied Economics Letters, 17(15), 1461-1464, https://doi.org/10.1080/13504850903035873

[47] Wang, J., Zhao, L., & Huang, R. (2014) SIRaRu rumor spreading model in complex networks . Physica A: Statistical Mechanics and its Applications, 398, 43-55, https://doi.org/10.1016/j.physa.2013.12.004

[48] Yan, X., Zhou, Y., Wen, Y., & Chai, X. (2013) Qualitative and Quantitative Integrated Modeling for Stochastic Simulation and Optimization. Journal Of Applied Mathematics, 2013 (2013) https://doi.org/10.1155/2013/831273

Laser-assisted Joining of Steel and Cellulose Fiber-reinforced PMMA

Tamás Csiszér[1], Tamás Temesi [2], Lajos Borbás[3], László Molnár[3]

[1] Óbuda University, Rejtő Sándor Faculty of Light Industry and Environmental Protection Engineering, Doberdó út 6, H-1034 Budapest, Hungary csiszer.tamas@rkk.uni-obuda.hu

[2] Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Polymer Engineering, Műegyetem rakpart 3, H-1111 Budapest, Hungary, temesit@pt.bme.hu

[3] EDUTUS University, Engineering Institute, Stúdium tér 1, H-2800 Tatabánya, Hungary, borbas.lajos@edutus.hu; molnar.laszlo@edutus.hu

Abstract: Laser Assisted Metal-Polymer Joining Technologies (LAMP) are widely used to create hybrid structures for different purposes. If the laser beam is transported to the connected surfaces from the polymer's side, the polymer has to be adequately transparent on the wavelength of the applied radiation to avoid degradation and to ensure effective and efficient adhesion. The transparency can be affected by the components and the structure of the polymer. The long-term goal of our research is to identify, assess and quantify the connection between the type and the amount of reinforcing fibers and the quality of metal-polymer joining. In this paper, we introduce the key findings of the first experiments aimed at joining steel and poly(methyl-methacrylate) reinforced with different amounts of cellulose fibers. We identified the optimal values of some laser technology parameters (e.g. power, velocity) that affect the strength and the visual appearance of joining.

Keywords: laser welding; hybrid joints; steel; PMMA

1 Introduction

An important aim in the vehicle industry, including companies from the automobile, railway and aerospace industries, is to reduce both the manufacturing and the operating costs of their vehicles. A possible way to achieve this is to use lighter materials, for example, polymers and polymer composites and combine them with metal parts into integrated structures using fast and reliable joining techniques. These integrated structures must have comparable mechanical properties to single-material components that are currently used in the vehicles. With lighter, less dense materials, the weight of the vehicle can be reduced, fuel

can be saved, and emissions can be lowered. Furthermore, the processing and forming of polymers and polymer composites can be achieved with less energy input, compared to metal and glass products [2, 16, 23, 32, 35].

The techniques and methods, with which metal and polymer structures can be joined have been a hot topic in recent years. Particular attention is paid to technologies that make it possible to form joints between metal and polymer materials without the use of an intermediate element (for example adhesive or standard fasteners), within the framework of mass production (with short cycle time, in an automated manner). Welding techniques that are widely used to join plastics (for example friction, ultrasonic, and laser welding) can also be used to manufacture joints between materials with dissimilar chemical structures [1, 3-5, 10, 12, 14, 20-22, 24, 28, 33, 34].

Laser welding stands out from these techniques, as it is an easily automatable, non-contact joining method, with which two or more structures can be joined simultaneously, and the realized joint is solid, watertight, and stress-free. Furthermore, heat is only generated near the seam, thus the thermal degradation of the welded structures can be avoided. Laser beam welding can only be used if one of the materials can absorb the energy of the laser radiation [5, 30, 33, 34].

When a laser beam is used to create a joint between metals and polymers the technique is usually called Laser-Assisted Metal-Polymer, or LAMP joining technology. In addition to joining process parameters, the surface preparation of the metal part and the degree of compatibility between metal and polymer also have a significant effect on the joint strength [6, 10, 13, 20, 21, 28, 30], since plastics and metals differ significantly in both physical and chemical structures. For this reason, the joint is usually based on adhesion. In this case, secondary chemical bonds are formed between the molten polymer and the surface oxide layer of the metal during the joining process [5]. The load-bearing capacity of the joint is further influenced significantly by the structure and conformation of the polymer chains [11], by the type and amount of monomer residues and additives in the polymer, and by the surface structure of the metal [6-9]. However, when optimal joining process parameters are chosen, the adhesion between metal and polymer can be even stronger than the cohesion of the polymer material [27].

Metals and polymers can be joined using laser radiation in two ways: the first is the so-called transmission joining method, while the second is the so-called direct laser joining process (Figure 1). The essence of the transmission joining (indirect fusion) process is that the polymer component is transparent to laser radiation, i.e. it transmits most of the energy (without bending or scattering) of the laser beam. When a metal part is placed under such a transparent polymer structure, the laser radiation is absorbed in the metal part and is converted into heat. The generated heat reaches the polymer part through heat conduction in the metal and heat transfer on the interface between the metal and polymer parts. If enough heat is

produced, the polymer melts and flows into the surface structures on the surface of the metal part [5, 33, 34].

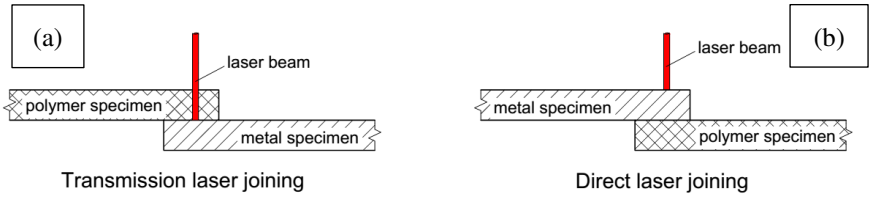


Figure 1
Schematic of the transmission laser joining (a) and the direct laser joining (b) joining techniques

The so-called direct laser joining process is mainly used to join metal and polymer materials if the polymer is not transparent enough on the wavelength of the laser radiation. This may be caused by the use of fillers, additives or reinforcing materials, or due to the microstructure of the polymer), or if it is prone to thermal degradation. During direct laser joining, the laser radiation directly heats the metal part and does not pass through the polymer material [5, 33, 34].

Polymethyl-methacrylate (PMMA) is a polymer material widely used in medicine (in dentistry, in implants, and other medical devices) as bone cement and in the vehicle industry, mainly as headlight and dashboard equipment covers [5, 26, 29]. In the latter cases, PMMA covers must be joined to other elements or even to the structural elements of the vehicle itself. Until recently, this was done using adhesives most of the time, as the joint must be watertight and solid. In recent years, however, laser welding gained traction as a joining technique for PMMA-metal structures [10, 13, 20, 21, 26, 28].

There are relatively few publications specifically dealing with the joining of PMMA and steel plates with laser joining. Bauernhuber et al. manufactured overlapped and pin-to-plate joints between structural steel (1.0038) and PMMA using the same welding equipment. In the case of overlapped joints, they investigated the effect of surface preparation (rolled and sandblasted surfaces), power and duration of pulses emitted by the pulsed-mode laser welding machine, different joining speeds, and focal spot diameters on the properties of the formed joints. They confirmed that surface preparation significantly increases the strength of the formed joints. Increasing the focal spot diameter and the joining speed, however, reduces the strength of the joints because in these cases, less laser energy is absorbed and less heat is formed in the metal specimen. Thus, the polymer also melts less thoroughly. With the applied parameters, no correlation could be proven between the laser power and the strength of the joints. In pin-to-plate joints, the effect of irradiation time, as well as the surface roughness of the steel pin was investigated. They found that increasing the irradiation time increased joint strength. There was a similar effect when the surface roughness of the pins was increased, which was explained by the formation of undercuts and better absorption of laser radiation energy [7-9]. Markovits and Berczeli [25]

investigated the effect of different laser beam power, feed rate and clamping pressure values and the effect of sandblasting on the strength of structural steel (1.0038) - PMMA joints manufactured using a CO_2 laser and the direct laser joining method. They found that increasing the clamping pressure and using sandblasted steel specimens both increased the shear strength of the joints, and also influenced the size and amount of bubbles that formed near the seam in the PMMA material. They explained the increase in shear strength with better laser absorption and better adhesion between steel and PMMA when sandblasted specimens were used. In their publication, Hussein et al. used the one-factor-at-a-time method and response surface methodology to search for the optimal joining process parameters when they joined PMMA and stainless steel (1.4301) using both the transmission laser joining and the direct laser joining techniques. They found that by increasing the thermal input, the strength of the joint also increased. However, there was an optimal thermal input value, over which the polymer material started to degrade, and the joint strength decreased with both joining techniques. They also found that joint strength was the highest when the top hat-type beam shape was used [18]. In a later article, Hussein et al. built a finite element model based on their results and findings to be able to predict and calculate the thermal distribution and the thermal history of seams manufactured between steel-PMMA samples with both laser joining techniques [19]. Huang et al. used the same 1.4301-type stainless steel and PMMA to manufacture joints, and they examined the effect of the joining process control parameters and the flow rate of argon shielding gas on the strength of the joints. They found trends consistent with the observations published by Bauernhuber et al., and Hussein et al. [17].

In recent years, reducing the amount of plastic waste became a hot topic and generated action plans both on a governmental level and in the industry. For example, Directive 2000/53/EC of the European Council describes the amount of polymer-based structures to be reused and/or recycled when a road vehicle is scrapped. Beyond recycling, special attention is given to prolong the life expectancy of polymer-based parts by modifying their mechanical properties. One such possible method is to use fiber reinforcement. Several publications showed results on the joining of fiber-reinforced thermoplastic composites and metal sheets with laser joining, in which glass or carbon fibers were mixed to varying degrees into polyamide, a material frequently used in the automotive industry [15, 31]. However, no research so far has been published on the applicability and use of fibrous reinforcements from renewable resources, specifically cellulose fibers.

The subject of our research is the joining of plastic reinforced with a bio-based reinforcing agent (PMMA filled with cellulose fibers) and structural steel (1.0038) with the transmission joining and direct laser joining techniques and the mechanical and optical examination of the joints. In this publication, we present the optical properties and weldability of PMMA material reinforced to different degrees with cellulose fibers and the possibilities and parameters of creating

hybrid joints between steel and cellulose fiber-reinforced PMMA sheets. We also present our experimental design, the methods used in the creation and testing of the joints, the optimal values of the technological parameters, and other results obtained during the mechanical and optical testing of the joints.

2 Materials and Methods

2.1 Raw Materials

The most important parameters of the raw materials used to manufacture the test specimens for our investigations are summarized below.

The steel specimens used to create the joints were cut from a 0.8 mm thick structural steel (S235JR/1.0038) sheet using a high-power laser cutting device. The specimens were 30 mm long and 10 mm wide.

We used two PMMA raw materials from two different manufacturers: the first type of PMMA we used is sold as Sitramac HW55, a PMMA-polystyrene copolymer made by Sitraplas GmbH, Germany. This material had a distinct grey tone even when no reinforcing agent was added to it. The second type of PMMA is called Altuglas VS-UVT, which is manufactured by the Arkema group. This PMMA is highly transparent in the visible and near-infrared spectrum.

For the reinforced composite specimens, we added 1 to 10 weight percent (whole numbers only) of Arbocel B600 cellulose fibers, a product of J. Rettenmeier & Söhne GmbH, to the PMMA raw materials.

2.2 Test Specimen Manufacturing

We manufactured the polymer test specimens for our experiments with compounding and injection molding. For the unreinforced PMMA specimens, we dried the material at 80° C for 8 hours (as recommended by the manufacturers), then used a twin-screw extruder (LTE 26-44, Labtech Engineering Company Ltd., Thailand) with an ascending temperature profile to manufacture an endless filament. This was then pelletized for injection molding on an Arburg Allrounder 270S 400-170-type injection molding machine. The compounding procedure was done so that the thermal history of the unreinforced material is as close to the reinforced materials as possible.

For the cellulose fiber-reinforced PMMA specimens, we followed the same steps: besides the PMMA raw material, we also dried the cellulose fibers at 80° C for 8 hours. Then, we made dry mixtures using neat PMMA pellets and different amounts of cellulose fibers, which we compounded using the same parameters on

the same LTE 26-44 twin-screw extruder. Filaments containing the cellulose fibers were again pelletized and injection molded using the same Arburg IM machine.

For the optical tests, standard, dog bone-shaped specimens were manufactured from both raw materials, both with and without reinforcement. For the joining tests, 2 mm thick, flat, rectangular specimens of the size of 80x80 mm were manufactured from the compounded, reinforced, and unreinforced pellets. 10 mm wide specimens were cut from them using a VersaLaser VLS 2.30-type CO_2 laser for the joining processes.

2.3 Specimen Testing

The wavelength-dependent transparency of the unreinforced and cellulose fiber-reinforced specimens was determined by using a Perkin-Elmer Lambda 1050 spectrophotometer. It can be stated that even with the incorporation of 1 wt% of cellulose fibers, the transparency of the specimens significantly decreases (from about 80% to about 30% in the case of the Sitramac material, and from about 90% to about 20% in the case of the Altuglas material) (Figure 2). This causes significant problems during transmission joining: less transparent specimens absorb more of the energy of the laser radiation, which can cause the degradation of the polymer material as well as prevent the formation of the joint itself. With this in mind, we performed the transmission joining experiments by setting lower laser power values, which also allowed us to determine the minimum laser power value required to create a durable, solid joint. More than 1 wt% of reinforcement also prevented joint formation in the case of transmission laser joining. As our aim was to manufacture and compare joints using the two different joining techniques (transmission joining and direct laser joining), we only used specimens containing 0 wt% and 1 wt% cellulose fiber.

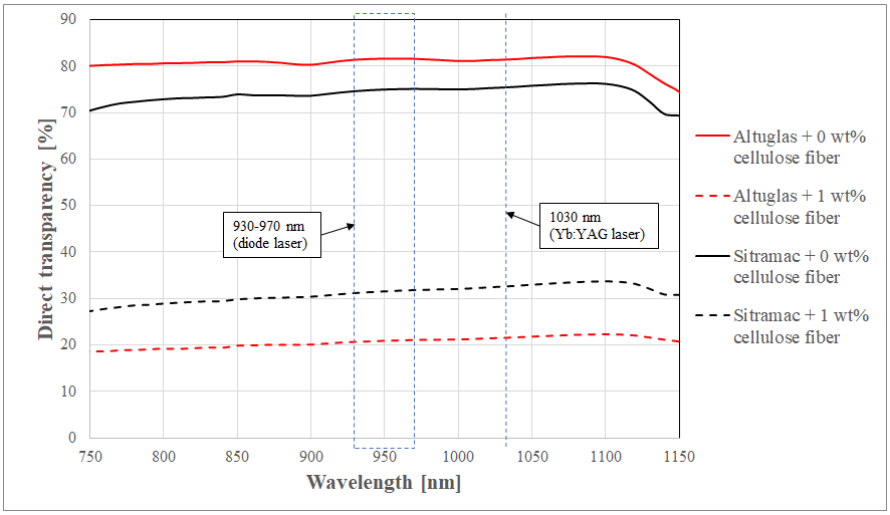


Figure 2
Transparency of unreinforced and reinforced (with 1 wt% cellulose fiber) PMMA specimens

2.4 Manufacturing and Testing of Steel-Polymer Joints

Two types of laser joining methods (transmission laser joining and direct laser joining, Figure 1) and two types of laser welding machines were used to create the overlapped joints. Before joining, the surfaces of both steel and polymer specimens were wiped with a cloth soaked in methanol, to degrease their surfaces. In our experiments, we did not change the surface structure of the metal specimens.

During transmission laser joining, the polymer specimen was placed on top of the steel specimen. The transmission joining was performed on a Trumpf TruDiode 151 diode laser, with a laser wavelength range of 930-970 nm. The laser power was set to 110, 130 & 150 W (Figure 3).

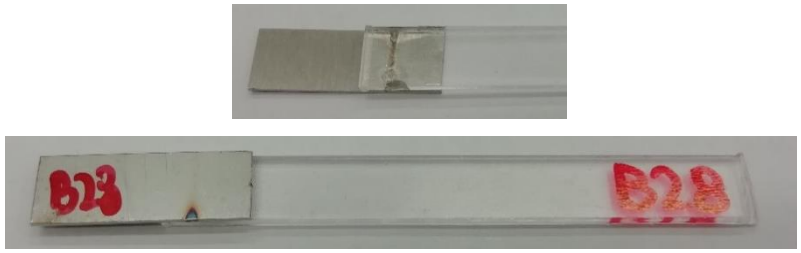


Figure 3
Overlapped specimens manufactured with the transmission laser joining technique using unreinforced Altuglas PMMA and steel

During direct laser joining, the steel specimens were placed on top of the polymer specimens. These joints were made using a Trumpf TruDisk 4001 Yb: YAG solid-state laser (with a wavelength of 1030 nm) housed in a Trump TruLaser Cell 7020 CNC cell. The laser power was set to 210, 230 & 250 W (Figure 4).

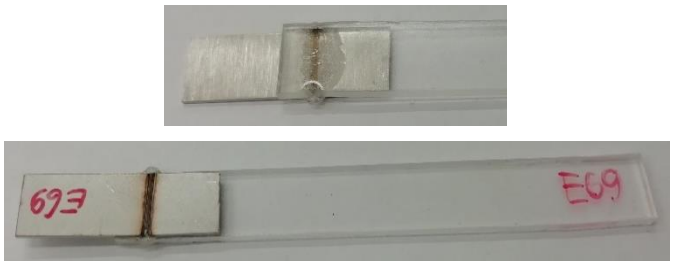


Figure 4
Overlapped specimens manufactured with the direct laser joining techniques using unreinforced Altuglas PMMA and steel

The joints were formed by linear joining with both techniques: the laser beam irradiated the specimens three times along the same line. The joining speed for both methods was set to 1 $m \cdot min^{-1}$ so that the joints were as comparable as possible. The strength and durability of the joints were evaluated using a Zwick Z005 universal material testing machine by compressive (shear) tests (Figure 5a). As the steel-PMMA joints behave in a rather brittle manner based on our preliminary experiments, the test speed was set to 1 $mm \cdot min^{-1}$. The joints were loaded to failure. The joint surface of the polymer specimens was investigated, and the size of the joined surfaces was quantified using a Keyence VHX-5000 optical microscope (an example is shown in Figure 5b).

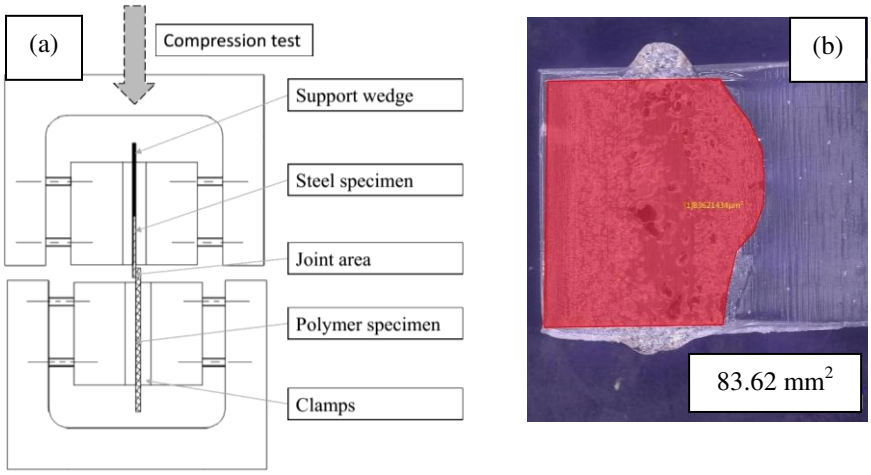


Figure 5
Schematic of the compression test performed on the welded specimens (a), and evaluating the joint surface on the specimen shown in Figure 4 using the Keyence VHX-5000 optical microscope (b)

3 Experimental Design

Based on our preliminary experiments, the mechanical properties of the joints are influenced by the type of polymer, the fiber content, and the laser power in addition to the applied joining method (transmission or direct laser joining). We experimentally determined the technological window and the ideal values (based on subjective examination of the strength and aesthetics of the created joints) for these process control parameters. These values are as follows

- Equipment: Trumpf TruDiode 151 with a maximum power output of 150 W or Trumpf TruDisk 4001 Yb:YAG disc laser with a maximum power output of 4 kW;
- Laser beam power: 30 W – 250 W;
- Laser beam velocity: 1 m/min;
- Type of irradiation: direct (from metal part) and transmission (from polymer part);
- Type of joining: projection joining;
- Number of cycles: 3.

Based on this technological window, three further experiments were designed (Table 1).

1. The purpose of the first experiment (denoted by C1) was to apply as low power as possible to create joints with transmission laser joining to minimize the degradation of the polymer. We created a full-factorial (2^p) design with the following parameters:

- PMMA: Sitramac and Altuglas;
- Reinforcement: 0 wt% and 1 wt% cellulose;
- Laser beam power: 30 W, 40 W and 50 W;
- Equipment: Trumpf TruDiode 151 with a maximum power output of 150 W;
- Laser beam velocity: 1 m/s;
- Type of joining: projection joining;
- Number of cycles: 3.
- Type of irradiation: transmission joining (from polymer part);
- Number of specimens: 10 pcs for each combination of factor settings.

2. The purpose of the second experiment (denoted by C3) was to apply as high power as possible to maximize the strength of the joints with transmission laser joining with acceptable degradation of the polymer. We created another full-factorial (2^p) design with the following parameters:

- PMMA: Sitramac and Altuglas;
- Reinforcement: 0 wt% and 1 wt% cellulose;
- Laser beam power: 110 W, 130 W, and 150 W;
- Equipment: Trumpf TruDiode 151 with a maximum power output of 150 W;
- Laser beam velocity: 1 m/s;
- Type of joining: projection joining;
- Number of cycles: 3.
- Type of irradiation: transmission joining (from polymer part);
- Number of specimens: 10 pcs for each combination of factor settings.

3. The purpose of the last experiment (denoted by C2) was to test whether the polymer part affects the strength of joints when specimens are irradiated by the laser beam from the metal part. We created a third full-factorial (2^p) design with the following parameters:

- PMMA: Sitramac and Altuglas;
- Reinforcement: 0 wt% and 1 wt% cellulose;
- Laser beam power: 210 W, 230 W, and 250 W;
- Equipment: Trumpf TruDisk 4001 Yb:YAG disc laser with a maximum power output of 4 kW;
- Laser beam velocity: 1 m/s;
- Type of joining: projection joining;
- Number of cycles: 3.
- Type of irradiation: direct joining (from metal part);
- Number of specimens: 10 pcs for each combination of factor settings.

Table 1

Experiment designs for optimizations of laser beam joining parameters for different purposes

2^p Experiments	C1	C3	C2
Purpose	To apply as low power as possible to create joints with transmission laser joining to minimize the degradation of the polymer.	To apply as high power as possible to maximize the strength of the joints with transmission laser joining with acceptable degradation of the polymer.	To test whether the polymer part affects the strength of joints when specimens are irradiated by the laser beam from the metal part.

PMMA	Sitramac and Altuglas		
Reinforcement	0 wt% and 1 wt% cellulose		
Laser beam power	30 W, 40 W and 50 W	110 W, 130 W and 150 W	210 W, 230 W, and 250 W
Equipment	Trumpf TruDiode 151 with a maximum power output of 150 W		Trumpf TruDisk 4001 Yb:YAG disc laser with a maximum power output of 4 kW
Velocity	1 m/min		
Type of joining	projection joining		
No. of cycles	3		
Type of irradiation	Transmission joining (from polymer part)		Direct joining (from metal part)
No. of specimens	10 pcs for each combination of factor settings		

4 Experimental Results

The degradation of the polymer was qualified by the flame intensity in C2. The strength of joining was tested by compression shear tests in a Zwick Z005 universal testing machine. The effective joining area was measured and calculated for each tested specimen on a Keyence VHX-5000 optical microscope. The levels of significance of factors' effects were analysed by Minitab and MS Excel.

The shear strength of the joints was calculated by dividing the maximum force and the area of joining (1).

$$\tau = \frac{F_{max}}{A} \, [MPa] \, (1)$$

It was proven on 95% confidence level that the power of the laser beam had a significant effect on the strength of joints, but only in experiments C2 and C3. In experiment C2 the matrix material also had a significant effect on the strength of joints as well (Table 2). The intensity of flame (i.e. the degradation of polymer) was affected significantly only by the power of laser beam. The amount of fiber and combinations of factors have no significant effect on any of the dependent variables.

Table 2
Significant factors for the strength of joining

Factors	Experiment C1	Experiment C2	Experiment C3
Laser Beam Power	No	Yes	Yes
Matrix Polymer	Yes (?)	Yes	Yes (?)
Fiber Amount	No	No	No

The values of average compression strength of joints are demonstrated in Figs. 6-8. In Experiment C1 (Figure 6) shear strength could be calculated only in the case of Sitramac PMMA. The reason for this is that in the case of the Altuglas PMMA, the adhesion between metal and polymer was not strong enough to create measurable joints. Results suggest that the difference between matrix materials determines shear strength, but this theory could not be proven statistically due to the missing shear force values. It seems that the optimum value of laser beam power is 40 W (τ = 5.81 MPa), and cellulose fibers weaken the connection in the case of 30 W and 40 W, but strengthen it in the case of 50 W power. Since the effects of these factors are not significant, the logical connections between the difference in shear strength, laser beam power, and amount of reinforcement are not proven.

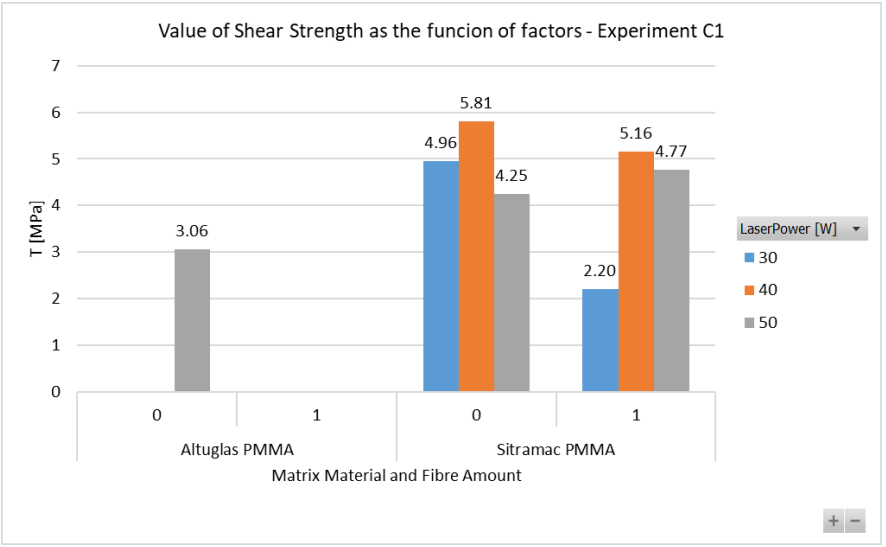


Figure 6
Average values of Shear Strength for different factor combinations – Experiment C1

The same logical connection can be seen in Experiment C3 (Figure 7): the higher the laser beam power is, the stronger the adhesion is. In the case of Sitramac PMMA, shear strength seems to be greater than that of Altuglas PMMA, but it is not proven by ANOVA. The amount of reinforcing fibers used does not influence

adhesion significantly. So, the optimal choice is 150 W and Sitramac PMMA matrix, resulting in $\tau = 2.34$ MPa.

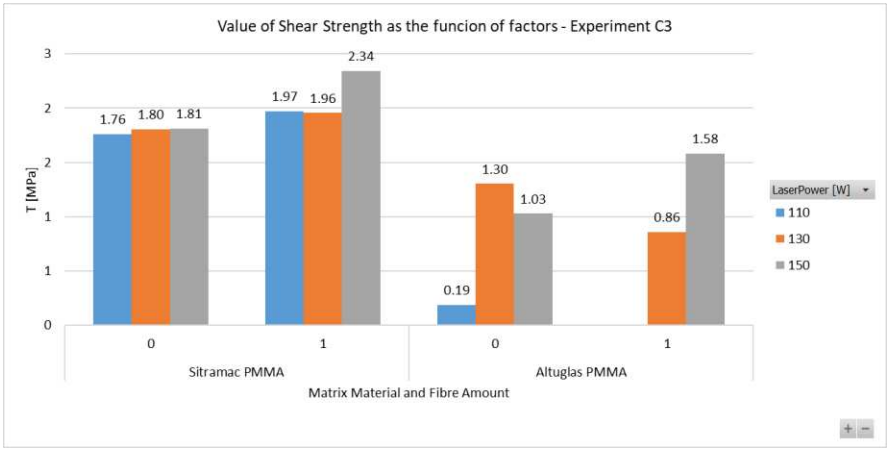


Figure 7

Average values of Shear Strength for different factor combinations – Experiment C3

In Experiment C2 (Figure 8) the statistically proven optimal choice is 250 W and Sitramac PMMA ($\tau = 5.61$ MPa). Results suggest that fibers weaken adhesion in the case of 230 W and 250 W, but strengthen in case of 210 W.

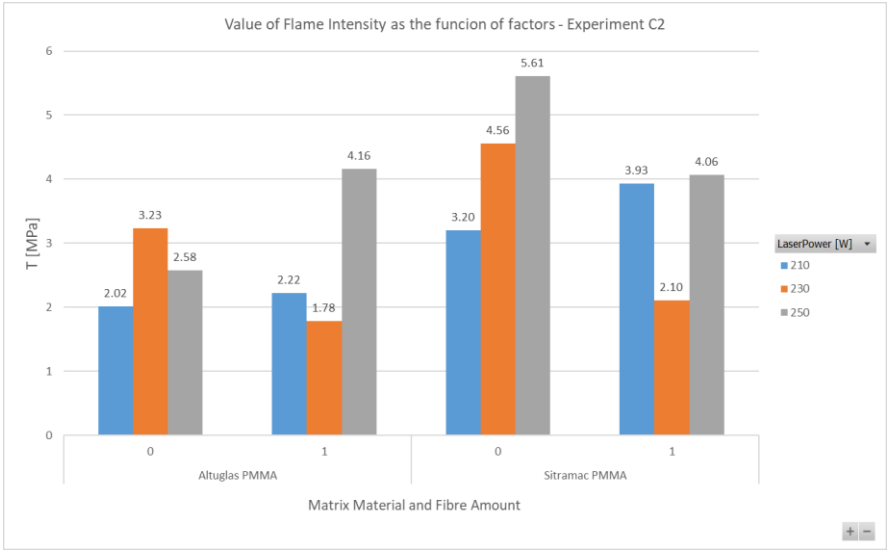


Figure 8

Average values of Shear Strength for different factor combinations – Experiment C2

Conclusions

It is proven that PMMA – steel joints can be created by NIR laser beam both with direct and transmission irradiation methods. Maximum values of shear strength of joining are 5.61 MPa (250 W, Sitramac PMMA) and 5.81 MPa (40 W, Sitramac PMMA). Adding 1 wt% of reinforcing fiber to the polymer does not influence the adhesion significantly. Due to relatively small strength, these kinds of PMMA – steel hybrid joints can be used primarily as non-load-bearing structures and as an additional joining method to traditional and stronger joining techniques.

Acknowledgment

This work was supported by the Grant No. EFOP-3.6.1-16-2016-00009, "Basic research project in the field of laser beam technologies and energetics".

References

[1] I. T. Abdullah, S. K. Hussein: Shear strength and temperature distribution model of friction spot lap joint of high density polyethylene with aluminum alloy 7075. International Journal of Structural Integrity, 10(4), pp. 469-483, 2019

[2] A. Albert, W. Zorn, M. Layer, W.-G. Drossel, D. Landgrebe, L. Kroll, W. Nendel: Smart process combination for aluminum/plastic hybrid components. Technologies for Lightweight Structures, 1(2), pp. 44-53, 2017

[3] A. Al-Obaidi, C. Majewski: Ultrasonic welding of polymer-metal hybrid structures. In: *Transactions on Intelligent Welding Manufacturing* (Eds.: S. Chen, et al.). https://doi.org/10.1007/978-981-13-3651-5_2

[4] S. T. Amancio-Filho, C. Bueno, J. F. dos Santos, N. Huber, E. Hage Jr.: On the feasibility of friction spot joining in magnesium/fiber reinforced polymer composite hybrid structures. Materials Science and Engineering A, 528, pp. 3841-3848, 2011

[5] S. T. Amancio-Filho, L. Blaga: Joining of polymer-metal hybrid structures - principles and applications. John Wiley & Sons, Inc., Hoboken, NJ, 2018

[6] S. Arai, Y. Kawahito, S. Katayama: Effect of surface modification on laser direct joining of cyclic olefin polymer and stainless steel. Materials and Design, 59, pp. 448-453, 2014

[7] A. Bauernhuber, T. Markovits: Laser assisted joining of metal pins and thin plastic sheets. Physics Procedia, 39, pp. 108-116, 2012

[8] A. Bauernhuber, T. Markovits: Investigating thermal interactions in the case of laser assisted joining of PMMA plastic and steel. Physics Procedia, 56, pp. 811-817, 2014

[9] A. Bauernhuber, T. Markovits, J. Takács: Investigating the pulse mode laser joining of overlapped plastic and metal sheets. Physics Procedia, 83, pp. 1094-1101, 2016

[10] R. Borrisutthekul, A. Saengsai, P. Mitsomwang: Dissimilar materials laser welding between stainless steel 304 and thermoplastics. Key Engineering Materials, 719, pp. 142-148, 2016

[11] J. Cheon, S. J. Na: Relation of joint strength and polymer molecular structure in laser assisted metal and polymer joining. Science and Technology of Welding and Joining, 19(8), pp. 631-637, 2014

[12] H. A. Derazkola, R. K. Fard, F. Khodabakhshi: Effects of processing parameters on the characteristics of dissimilar friction-stir-welded joints between AA5058 aluminum alloy and PMMA polymer. Welding in the World, 62, pp. 117-130, 2018

[13] Y. Farazila, Y. Miyashita, W. Hua, Y. Mutoh, Y. Otsuka: Yag laser spot welding of pet and metallic materials. Journal of Laser Micro/Nanoengineering, 6, pp. 69-74, 2011

[14] Y. Farazila, M. Fadzil, M. Hamdi: A brief review: laser joining of polymer-metal structures. ASEAN Engineering Journal, 2(2), pp. 5-12, 2012

[15] A. Fortunato, G. Cuccolini, A. Ascari, L. Orazi, G. Campana, G. Tani: Hybrid metal-plastic joining by means of laser. International Journal of Material Forming, 3, pp. 1131-1134, 2010

[16] J. Hirsch: Recent development in aluminium for automotive applications. Transactions of Nonferrous Metals Society of China, 24, pp. 1995-2002, 2014

[17] Y. Huang, X. Gao, Y. Song, N. Zhang, N. Ma: Visual inspection of pulsed Nd:YAG laser welding of PMMA and stainless steel 304. Conference paper submitted to the 2017 IEEE International Conference on Imaging Systems and Techniques (IST) https://doi.org/10.1109/ist.2017.8261528

[18] F. I. Hussein, E. Akman, B. Genc Oztoprak, M. Gunes, O. Gundogdu, E. Kacar, K. I. Hajim, A. Demir: Evaluation of PMMA joining to stainless steel 304 using pulsed Nd:YAG laser. Optics & Laser Technology, 49, pp. 143-152, 2013

[19] F. I. Hussein, K. N. Salloomi, E. Akman, K. I. Hajim, A. Demir: Finite element thermal analysis for PMMA/st.st.304 laser direct joining. Optics & Laser Technology, 87, pp. 64-71, 2017

[20] K.-W. Jung, Y. Kawahito, M. Takahashi, S. Katayama: Laser direct joining of carbon fiber reinforced plastic to zinc-coated steel. Materials & Design, 47, pp. 179-188, 2013

[21] K.-W. Jung, Y. Kawahito, M. Takahashi, S. Katayama: Laser direct joining of carbon fiber reinforced plastic to aluminum alloy. Journal of Laser Applications, 25, 032003, 2013

[22] P. Kah, R. Suoranta, J. Martikainen, C. Magnus: Techniques for joining dissimilar materials: metals and polymers. Reviews on Advanced Materials Science, 36, pp. 152-164, 2014

[23] D. Lehmhus, A. von Hehl, J. Hausmann, K. Kayvantash, R. Alderliesten, J. Hohe: New materials and processes for transport applications: going hybrid and beyond. Advanced Engineering Materials, 1900056, pp. 1-7, 2019

[24] F. C. Liu, P. Dong: Promising high-speed welding techniques for joining polymers and metals and underlying joining mechanisms. In: *Friction stir welding and Processing X, The Minerals, Metals & Materials Series* (Eds.: Y. Hovanski, et al.) https://doi.org/10.1007/978-3-030-05752-7_2

[25] T. Markovits, M. Berczeli: Examination of metal side heating of LAMP joint by CO2 laser beam. Materials Engineering – Materiálové inžinierstvo, 24, pp. 82-87, 2017

[26] PMJoin: Development of a direct laser joining of hybrid plastic-metal components for industrial applications, 2016

[27] J. Rauschenberger, A. Cenigaonaindia, J. Keseberg, D. Vogler, U. Gubler, F. Liébana: Laser hybrid joining of plastic and metal components for lightweight components. From Conference Volume 9356 High-Power Laser Materials Processing: Lasers, Beam Delivery, Diagnostics, and Applications IV Friedhelm Dorsch. San Francisco, California, United States, February 07, 2015, https://doi.org/10.1117/12.2080226

[28] E. Rodríguez-Vidal, C. Sanz, J. Lambarri, J. Renard, V. Gantchenko: Laser joining of different polymer-metal configurations: Analysis of mechanical performance and failure mechanisms. Physics Procedia, 83, pp. 1110-1117, 2016

[29] Vinny R. Sastri: Plastics in Medical Devices: Properties, Requirements and Applications. William Andrew Inc., Waltham, MA, 2014

[30] K. F. Tamrin, Y. Nukman, S. S. Zakariyah: Laser lap joining of dissimilar materials: a review of factors affecting joint strength. Materials and Manufacturing Processes, 28(8), pp. 857-871, 2013

[31] X. Tan, J. Zhang, J. Shan, S. Yang, J. Ren: Characteristics and formation mechanism of porosities in cfrp during laser joining of cfrp and steel. Composites Part B: Engineering, 70, pp. 35-43, 2015

[32] A. Taub, E. De Moor, A. Luo, D. K. Matlock, J. G. Speer, U. Vaidya: Materials for automotive lightweighting. Annual Review of Materials Research, 49, pp. 327-359, 2019

[33] T. Temesi, Z. Kiss, T. Csiszér: Korszerű technológiák fém és polimer anyagok közötti kötések kialakítására. Acta Periodica, 15. kötet; Felkészülés az új évtizedre: a technológia és a gazdaság új kihívásai, pp. 115-125, 2018

[34] T. Temesi, L. Molnár, T. Csiszér: Az acél-polimer kötés az alagút végén eredmények a fém-polimer hibrid szerkezetek lézersugaras kötéstechnológiájának kutatásában. The steel-polymer joint at the end of the tunnel – results of research in the joining of metal-polymer hybrid structures with a laser beam. Acta Periodica, XIX. kötet: Tudomány és modern világ és fundamentumok, pp. 86-98, 2020

[35] J. Zhou, X. Wan, Y. Li: Advanced aluminium products and manufacturing technologies applied on vehicles presented at the eurocarbody conference. Materials Today: Proceedings, 2, pp. 5015-5022, 2015