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MCDM, operational research and sustainable development in the trans-border Lithuanian–German–Polish co-operation

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A B S T R A C T
The article presents a description of scientific achievements concerning Multiple-Criteria Decision-Making (MCDM) methods attained as part of the cooperation between scientific centres of Lithuania, Germany and Poland with a special emphasis on the input by Professor Edmundas K. Zavadskas and his scientific school. The cooperation, which commenced in 1986, focused on "Colloquia" — the systematic, international scientific seminars. The article aimed to summarise and popularise the achievement of these "Colloquia" in the area of MCDM as well as spotlight the outstanding theoretical and application significance of accomplishments by Prof. Zavadskas. Also, the work presents the most recent MCDM methods developed by Prof. Zavadskas that improve the accuracy of calculations and extend the area of their application.

K E Y W O R D S
Multiple-Criteria Decision-Making (MCDM), trans-border Lithuanian–German–Polish co-operation, operational research

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Introduction

The cooperation between three academic centres — Vilnius Gediminas Technical University (Lithuania), Leipzig University of Applied Sciences (Germany) and the Poznań University of Technology (Poland) — in the area of theory and application of Multiple-Criteria Decision-Making (MCDM), in what is broadly understood as the field of construction, was both inspired and initiated by Dr Edmundas K. Zavadskas from the Vilnius Institute of Construction. It began with the Professor's scientific scholarship for a traineeship at the Leipzig University of Applied Sciences (Technische Hochschule Leipzig) in 1980–1981. The German side of the partnership was represented by Prof. Kurt Fiedler and Dr Friedel Peldschus, and the Polish side — by Prof. Oleg

Kapliński. In 1986, this collaboration took the form of systematic scientific seminars, which were dubbed "Colloquia" by the organisers. Subsequent years saw the involvement of other academics such as, among others, Prof. Reinhard Seeling from Aachen (RWTH) who organised the 7th Colloquium in 1999. The Colloquia occur every two years in Germany, Lithuania and Poland. The 17th Colloquium will be held in May 2019 in Vilnius.

This form of cooperation not only resulted from the need to exchange experience and confront scientific achievement but also allowed access to a wider scope of information, periodicals and books, which the collaborating centres had at their disposal. It also created a possibility to have the results of scientific work published in journals from Germany, Lithuania and Poland. Additionally, it established a platform where doctoral and habilitation dissertations could be offered for consultations and professors from individual centres were and are still invited to review promotional theses. The knowledge accumulated by the cooperating centres, namely, multiple criteria methods (Vilnius), the development and application of gaming theories (Leipzig), and the queueing and reliability theories (Poznań), was combined and created a synergy which gave rise to many original MCDM methods.

The subject matter addressed by subsequent Colloquia kept evolving. First Colloquia were dominated by mathematical methods in the organisation of construction processes, planning instruments and, generally, elements of theory for decision-making. Later, presentations were offered concerning decision support systems, expert systems, controlling, life cycle, cash flow, IT, production economics, new educational methods, e-business, sustainable development in production engineering & management and intelligent green construction. The most recent Colloquia (of 2011 and later) dealt with new multipurpose evaluation methods, application peculiarities related to various methods used for practical problems as well as elements of biometrics and neurosophia. Next, issues connected to neural design are expected to be addressed.

MDCM methods that were developed by the team lead by Prof. Zavadskas evolved the most. New methods consider fuzzy and grey numbers. Verbal decision methods also gained some attention. There was much significance attached to criteria normalisation and the problem of weights. New, hybrid models of MDMC methods were presented.

Fig. 1 shows the Colloquia calendar and addressed topics. It is not only a characteristic and evolutionary way to consider the mentioned methods, research interests and applications but, above all, the transition from micro to macro issues. Initially, research work focused on production and technological (construction) processes, hence dealing only with a building site. Gradually, on account of having to consider economic criteria, the subject matter expanded to real estate, construction projects and companies. This evolution corresponded to needs resulting from political and economic changes as well as new education requirements posed to universities of technology.

1. Development of the trans-border cooperation

On the international scene, regular scientific meetings involving three academic centres from Lithuania, Germany and Poland was a rather unusual phenomenon, but this type of trans-border cooperation earned much praise.

The experience gained through subsequent Colloquia showed the necessity for underlining the significance of shared achievements by popularising them and, most of all, making them more international. Participants of the Colloquia and especially employees of the Vilnius Gediminas Technical University (previously VISI) established several subject-related scientific periodicals. Most of them are already cited by ISI Web of Science of the Thomson Reuters Services.

The output of the Colloquia consists of several dozen monographs and several hundred articles. In 2009, three works were distinguished by Essential Science Indicators [SM] of Thomson Reuters for the greatest percentage increase of citations:

- as New Hot Papers in the field of Engineering, the paper by Zavadskas et al. (2008),
- in the field of Economics & Business, the paper by Ginevicius et al. (2008),
- as Fast Breaking Paper in the field of Economics & Business, the paper prepared by Turskis (2008).

The subject matter addressed during the Colloquia always touched upon new trends, both in theory and practice, and there was always a need to expand the range of research topics. The addressed problems evolved from the modelling of construction (industrial) processes to project management. The combi-

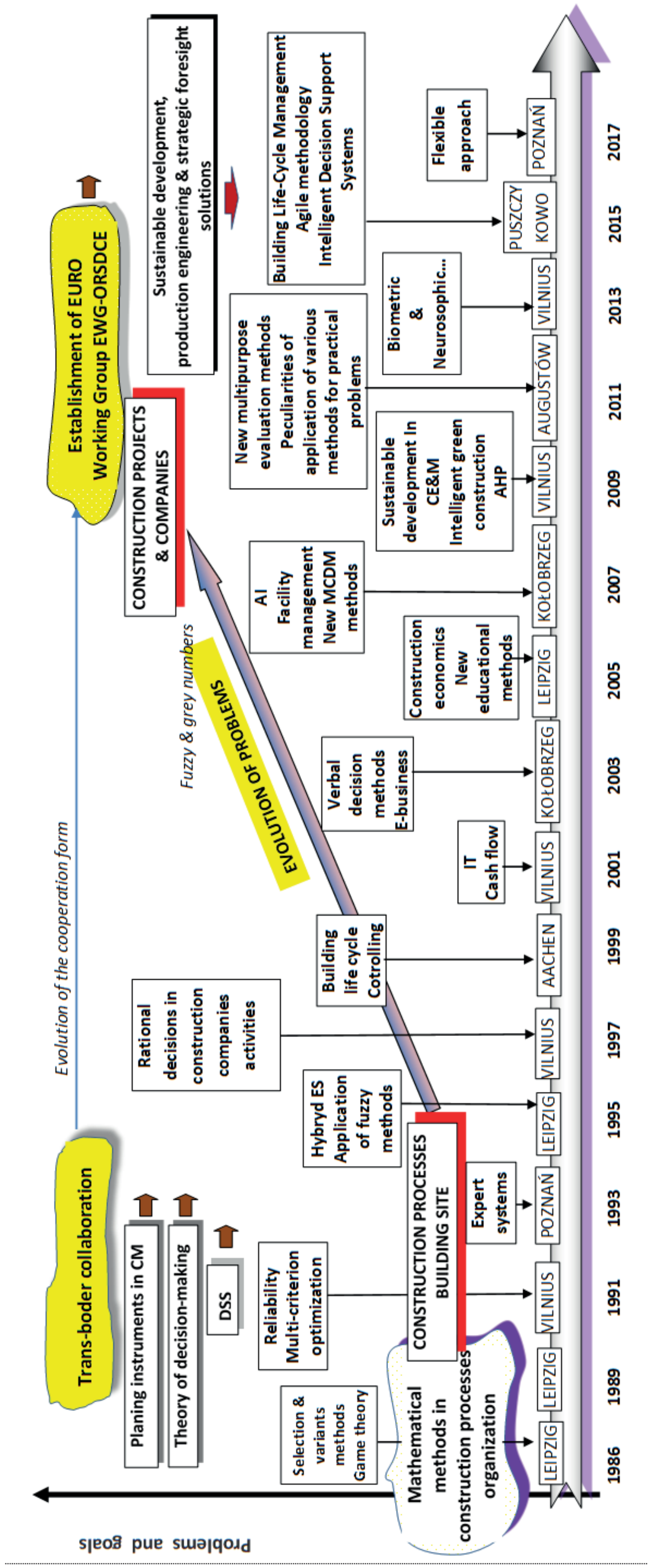

Fig. 1. Colloquia calendar and characteristic topics

Source: author's elaboration on the basis of (Vilutiene, 2019, pp. 87-92).

nation of Operational Research methods and sustainable development gave a stimulus to look for new applications. During the 12th Colloquium (2009), it was decided that the cooperation had to focus mainly on becoming a platform for young research practitioners who could share their experience and ask advice while developing their dissertations. The meetings consulted and initially assessed several research promotion texts. The Colloquia also opened opportunities for participants to extend their research volume, which was a significant factor in the advancement of their academic careers.

The establishment of the Colloquia created a basis for the development (through the initiative of Prof. Zavadskas) of the new EURO Working Group EWG-ORSDCE — "Operational Research in Sustainable Development and Civil Engineering (EWG-ORSDCE)." The Executive Committee of the Association of European Operational Research Societies (EURO) approved this Group during the 23rd annual European Conference on Operational Research "OR Creating Competitive Advantage", which took place in Bonn, Germany, 5–8 July 2009. Currently, the group joins 80 members from 19 countries (Lithuania, Germany, Poland, the United Kingdom, Belgium, Denmark, Netherlands, Portugal, Latvia, Estonia, the Czech Republic, Slovenia, Romania, Peru, Mexico, Russia, Ukraine, Australia and the USA). (Tamosaitiene et al., 2010). More detailed information concerning EWG-ORSDCE, its objectives, members, publications in the field of Operational Research and activities of the EURO Working Group OR in Sustainable Development and Civil Engineering (EWG-ORSDCE) can be found on its official website http://www.orsdce.vgtu.lt.

2. About Professor Edmundas K. Zavadskas

In 1990, Professor Edmundas K. Zavadskas became the first democratically elected rector of the Vilnius Institute of Construction. The transformation of the institute into Vilnius Technical University, to a large extent, was owed to his efforts. Later, the University also added the name of the Grand Duke Gediminas to the title. The University staff elected Prof. Zavadskas to the rector's position twice more, which he held for a total of 12 years, later acting as vice-rector for nine more years. During his terms of office, Professor Zavadskas maintained close cooperation with Polish universities, including the Białystok University of Technology.

His influence on the development of good relations with Poland is attested by the fact that Prof. Zavadskas was one of the founders of the Adam Mickiewicz Foundation — an organisation working towards the improvement of Lithuanian and Polish relations (1998). He was decorated with the medal for "Integral Humanism", awarded by a Polish journal "LITHUANIA" and a Lithuanian journal "KULTUROS BARAI". In 2001, he was univocally elected as a member of the Civil Engineering Committee of the Polish Academy of Sciences. Additionally, for his outstanding achievement in the development of cooperation between Poland and Lithuania, Professor Zavadskas was honoured by the Presidium of the Assembly of Parliamentarians to the Sejm of the Republic of Poland and the Seimas of the Republic of Lithuania with the "Nagroda Obojga Narodów" (Award of Both Nations) (2004), which he received in July 2004, at the Oratorium Marianum assembly hall of the University of Wrocław.

In 2002, the Poznań University of Technology (based on recommendations from supporting senates of the Warsaw University of Technology, Wrocław University of Technology and Gdańsk University of Technology) conferred the title of Doctor honoris causa on Prof. Zavadskas for the "Cooperation of academic communities in the spirit of integral humanism." Prof. Zavadskas is also a laureate of numerous other international awards and distinctions.

For many years, Prof. Zavadskas focused his research efforts on the issue of MCDM, which finds its application in various areas of technical, economic and social sciences. The monograph Multiple Criteria Evaluation of Projects in Construction (Vilnius, Technika 1994) by Zavadskas, Peldschus and Kaklauskas, received a review by professors Erhan Kozan and Martin Skitmore from the Australian Queensland University of Technology, which appeared in 1997 in the journal "Construction Management and Economics" (Taylor & Francis). According to the review, the book initiated a new era of scientific research in construction concerning MCDM methods.

Articles by Prof. Zavadskas were published in 84 journals referenced in the Clarivate Analytics database. Many of them were published in Q1 (High Quality Publications) of the Elsevier publishing company, such as "Applied Soft Computing", "Expert Systems with Application", "European Journal of Operational Research", "Buildings and Environment",

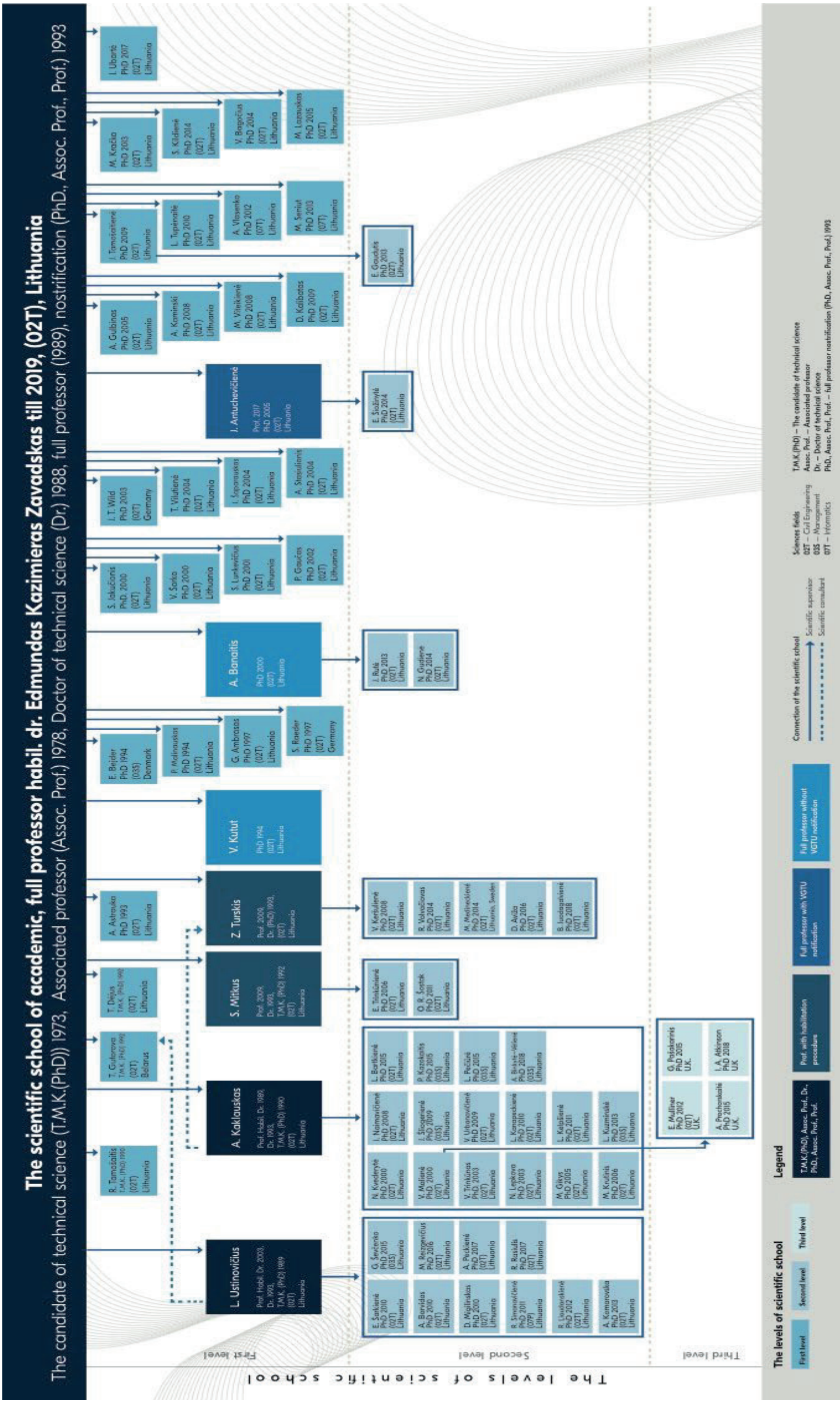

Fig. 2. Scientific school of Prof. Zavadskas

Source: author's elaboration on the basis of (Tamosaitiene, 2019, pp.64-75).

"Energy and Buildings", "Engineering Application of Artificial Intelligence", "Omega. The International Journal of Management Science" and "Land Use Policy". Thomson Routers deemed his 18 articles to be "Hot Papers". For many years, Prof. Zavadskas continued to cooperate internationally. He co-authored many publications together with scientists from 35 different countries (such as Belgium, Denmark, India, Iran, Canada, Germany, Poland, Sweden, the United States or Taiwan).

The Clarivate Analytics database has 462 his publications indexed, cited 10891 times in 4010 articles, with H = 55. In 2018, he was cited 2088 times. 469 articles are referenced in the SCOPUS database and cited 12302 times in 4663 articles, with H = 58. In 2018 alone, Prof. Zavadskas was cited 2286 times (20% self-citation). Google Scholar has 812 publications cited 21242 times, with H = 77. In 2018, the number of citations was 3681.

Prof. Zavadskas established a scientific school, which now includes scientists from three generations: his former doctoral students (35), doctoral students of doctors whose dissertations he promoted (approx. 30), and the third-generation doctoral students (2). About 20 former colleagues of Prof. Zavadskas have become professors themselves. Not only these academics currently work in Lithuania but have also dispersed throughout the entire world, including such countries as Poland, Great Britain, Ireland, Germany, Denmark or Russia. Fig. 2 presents a schematic illustrating the organisational structure of the scientific school of Prof. Zavadskas.

3. Scientific achievements

The authors believe that Edmundas Kazimieras Zavadskas has a personality which leaves an unforgettable impression. The next chapter is dedicated to two of the most outstanding traits of this prominent scientist, namely, creativity and the ability to accept and discuss new ideas. The earlier works by Prof. Zavadskas have been widely described in various papers (Kaplinski et al., 2014a; Kaplinski et al., 2014b; Kaplinski, 2009). This work presents a detailed description of scientific achievements by Professor and academician Zavadskas over the period of the last five years, when he focused on the investigation and solution of various sustainability problems (Fig. 3).

The number of research works in this field has been rapidly growing. It should be mentioned that solutions to sustainability problems are closely associated with MCDM strategies. This solidifies the importance of MCDM methods and their intense development. The increase in the number of papers on MCDM methods is shown in Fig. 4.

First, the new MCDM methods created with the participation of Prof. Zavadskas are described. The presented paper (Keshavarz Ghorabaee et al., 2018) offers a new original MCDM method that allows a simultaneous evaluation of criteria and alternatives (SECA) using a problem of multicriteria non-linear programming. The method aims for a more accurate evaluation of the significance of alternatives by con-

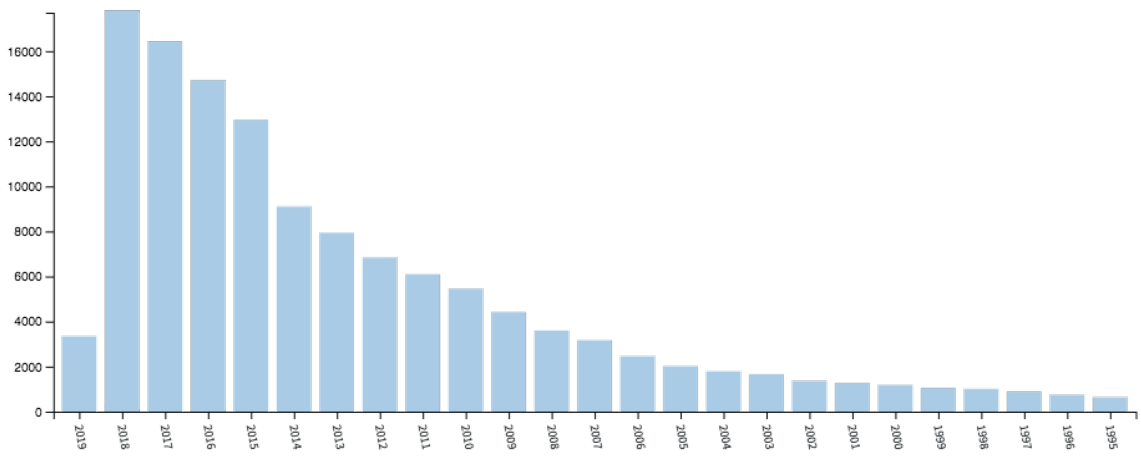

Fig.3. Increase in the number of papers dealing with sustainability problems

Source: author's elaboration on the basis of (Bausys, 2019, pp. 76-86).

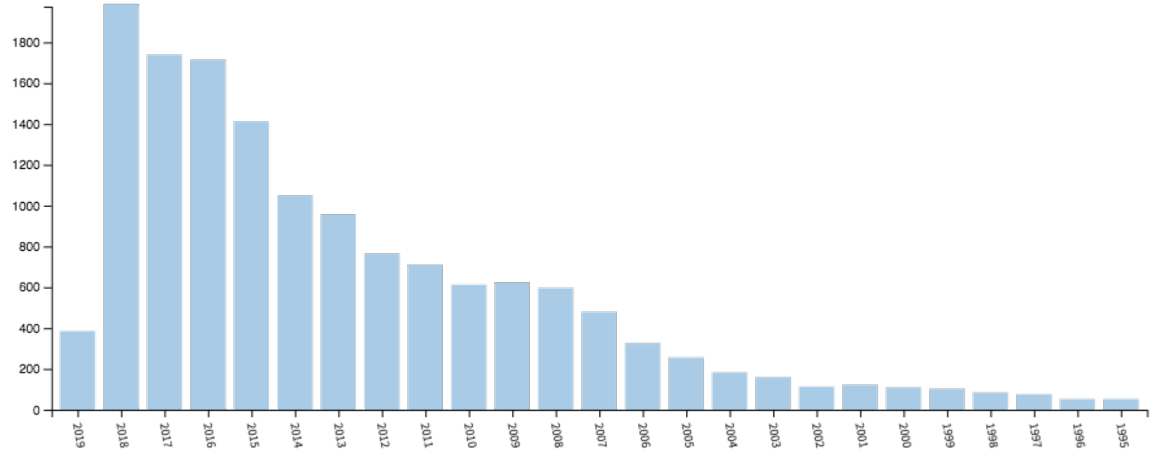

Fig. 4. Increase in the number of papers describing MCDM methods

Source: author's elaboration on the basis of (Bausys, 2019, pp. 76-86).

sidering the variation in solution matrix information, depending on particular criteria. As a result, the estimates of the alternatives and the weights of the criteria are calculated simultaneously.

In recent years, Prof. Zavadskas developed several methods for determining the weights of criteria. The accuracy in determining the criterion weights is very important for final results of MCDM problems. One of these approaches is WEBIRA based on the strategy of the weights balancing (Krylovas et al., 2017). This method is more effective in solving the considered problems described by a large number of criteria. Another method referred to as PIPRECIA (Stanujkic et al., 2017a) can be used for determining the weights of criteria when the consensus among experts cannot be achieved. This method allows determining the expert opinion about the significance of the particular criteria as well as the reliability of the obtained data. The modified KEMIRA method (Krylovas et al., 2016) aims to calculate the weights of criteria in the cases with several groups of criteria. In this case, experts assess the significance of the criteria in each group. Besides, this method requires much smaller amounts of the initial data compared to the original KEMIRA method and, therefore, the smaller amount of calculations. The original KEMIRA method was offered in (Krylovas et al., 2014). Its main idea was the use of the Kemeny's median for considering expert opinions. Three various metrics were used for calculating the median. Then, two other methods of the criterion weight determination were developed by Prof. Zavadskas et al. (Zavadskas & Podvezko, 2016). The first method is CILOS, which is based on the analysis of variation in the criterion significance, considering changes in the significance values of other criteria. Another method, referred to as IDOCRIW, was developed based on using the best characteristics of the entropy method.

In recent years, Prof. Zavadskas focused on the development of new MCDM methods. The first two new methods were based on the properties of T-type fuzzy sets, and EAMRIT-2F was (Keshavarz Ghorabaee et al., 2016a) was the first among the two. It is used when MCDM problems are modelled in terms of the interval T-2 fuzzy sets. The optimality characteristic of this method is based on the area under the lower and upper membership function graphs as well as the probability analysis of the fuzzy sets. AFRAW is another original method (Keshavarz Ghorabaee et al., 2016c), which is also used when MCDM problems are modelled in terms of interval T-2 fuzzy sets. The method firstly calculates the weights of criteria by integrating the subjective data on the criterion weights provided by experts and the objective data on these weights, which are determined by using the deviation method. CODAS is yet another original MCDM method (Keshavarz Ghorabaee et al., 2016b), which helps to find the best alternative by using two metrics (Euclidian and Taxicab) simultaneously. The distances from the smallest (negative) ideal point are measured, which solves the problem of searching for the maximum. EDAS (Keshavarz Ghorabaee et al., 2015) is an MCDM method that allows selecting the best alternative based on the positive and negative deviations from the average solution. WS-PLP is an original decision-making method, based on summing up the weights and a new normalisation procedure, providing a decision-maker with a wider choice of the best and preferred alternatives (Stanujkic & Zavadskas, 2015). The ARCAS method (Stanujkic et al., 2017b) is used for solving problems particular to group decision-making. According to this method, the best alternative is the one which is either awarded first places in the rating of alternatives or was indicated in the expert consensus. One of the most recently developed MCDM methods is the CoCoSo algorithm (Yazdani et al., 2018). This algorithm is based on the use of the combined compromise decision-making strategy, together with some data aggregation approaches.

In recent years, several authors published papers about the application of the methods developed by Prof. Zavadskas for the solution of various problems. The authors analysed the methods and the areas of their application: SWARA and WASPAS (Mardani et al., 2017a), various aspects of using the utility function (Mardani et al., 2018a), COPRAS (Stefano et al., 2015) and MULTIMOORA (Balezentis & Balezentis 2014; Hafezalkotob et al., 2019).

In several papers, Prof. Zavadskas et al. focused on methodological principles of the MCDM method analysis (Zavadskas et al., 2014), the application of fuzzy sets (Mardani et al., 2015a), using the considered methods for solving the problems in various areas, such as determining the quality of services (Mardani et al., 2015c) and choosing suppliers (Keshavarz Ghorabaee et al., 2017a), as well as in power engineering (Mardani et al., 2015b; Mardani et al., 2017b; Siksnelyte et al., 2018), engineering (Zavadskas et al., 2016a), transport (Mardani et al., 2016b), sustainability (Zavadskas et al., 2016b), construction (Zavadskas et al., 2018a), supply chains (Soheilirad et al., 2018), etc. The principles were also used in the VIKOR method (Mardani et al., 2016a), hybrid methods (Zavadskas et al., 2016b; Shen et al., 2018) and fuzzy aggregation operators (Mardani et al., 2018b).

Recently, Prof. Zavadskas offered several different method extensions adapted to deal with various sets e.g., the application of ARAS (Radovic et al., 2018) and SWARA (Zavadskas et al., 2018b) methods to the analysis of rough sets, the use of EDAS to deal with interval T2 fuzzy sets (Keshavarz Ghorabaee et al., 2017b), grey numbers (Stanujkic et al., 2017c), intuitionistic fuzzy sets (Kahraman et al., 2017; Keshavarz Ghorabaee et al., 2016b) and the stochastic problem solution (Keshavarz Ghorabaee et al., 2017c), as well as the use of the entropy method in the KEMIRA method (Krylovas et al., 2017). Now, MCDM problems are solved using new neutrosophic sets. The application can range from the market value determination (Zavadskas et al., 2017c), the use of the extensions of MULTIMOORA (Stanujkic et al., 2017e; Zavadskas et al., 2017b), the WASPAS method (Zavadskas et al., 2015), the application of VIKOR to deal with the interval neutrosophic sets (Bausys & Zavadskas, 2015) and COPRAS with ordinary neutrosophic sets (Bausys et al., 2015). Other notable achievements of Prof. Zavadskas include the extension of the WASPAS method for dealing with fuzzy sets (Keshavarz Ghorabaee et al., 2016a; Turskis et al., 2015), the MULTIMOORA method for interval triangular fuzzy numbers (Stanujkic et al., 2015), the extension of the COPRAS method (Roy et al., 2019), COPRAS-WIRN (Zolfani et al., 2018), the extension of SWARA (Hashemi et al., 2016), the CODAS

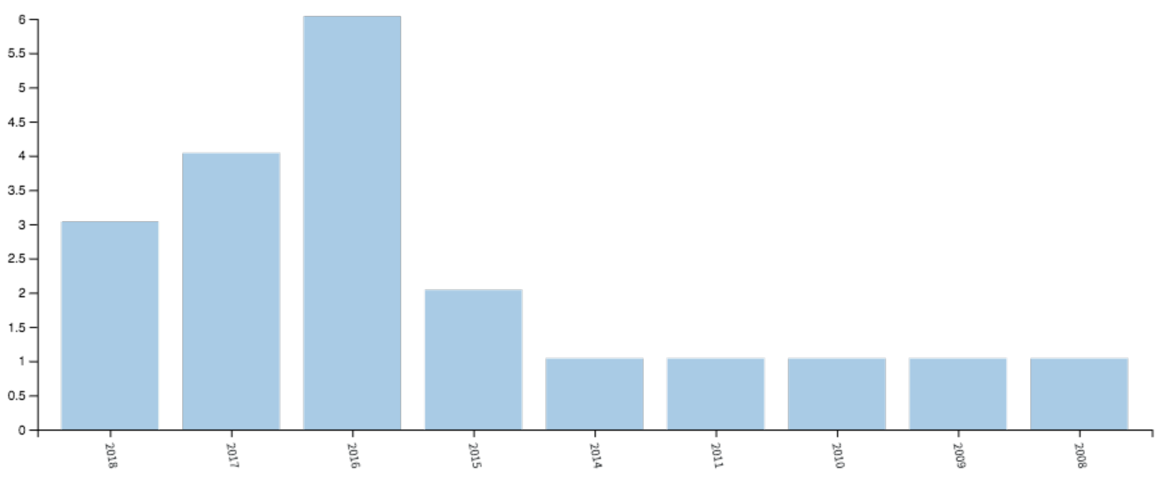

Fig. 5. Annual changes in the number of the most often cited papers by Prof. Zavadskas

Source: author's elaboration on the basis of (Bausys, 2019, pp. 76-86).

method (Seker & Zavadskas, 2017), the extensions of the OCRA method applied to grey numbers (Stanujkic et al., 2017d) and the extensions of the ELECTRE method (Jahan & Zavadskas, 2019; Hashemi et al., 2016).

Recently, the research achievements of Prof. Zavadskas received international recognition. Twenty of his works were included in the list of the most frequently cited papers (Fig. 5), which illustrates an exceptionally high quality of research works produced by Prof. Zavadskas et al.

Conclusions

The trans-border Lithuanian–German–Polish co-operation in the area of MCDM, operational and sustainable development is currently counting its 33rd year. It is a good example of international collaboration, which has resulted in numerous high-quality publications and was recognised by scientific communities. This cooperation created a platform for the exchange of experience and inspired to establish new directions for scientific research. It especially aided in the creation of new instruments for planning and decision-making. Professor Zavadskas is both an originator and a co-creator of this concept; therefore, he is rightfully praised for his numerous documented scientific achievements and the promotion of the scientific development of the Colloquia participants.

Notwithstanding the three-sided cooperation between Lithuania, Germany and Poland, the scientific school of Professor Zavadskas at Vilnius Gediminas Technical University is an exemplary educational facility. Its domain is the promotion of young scientists, i.e. doctoral students. It is already the third generation of the Professor's academic students who have become doctors. The MDCM topic has always stood out in the area of team work, and the achieved results have been applied in various fields of technical, economic and social sciences. The reach of the school is international. Now, scientific works address new research areas dealing with biometrics and neurosophia.

On the occasion of the 75th birthday, we would like to wish Professor Edmundas K. Zavadskas good health, many more personal successes and joy observing the growth achieved by his students, as well as offer him sincere gratitude for many years of laborious yet fruitful efforts.

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Analysis of the opportunities to implement the BIZ-TRIZ mechanism

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ABSTRACT

Aiming to strengthen cooperation between scientific entities and enterprises and to overcome related obstacles, the authors propose to create a mechanism of incentives called BIZ-TRIZ, which is an abbreviation for "TRIZ for Business". This mechanism is used to support cooperation between scientific entities and companies. Close cooperation is achieved by implementing R&D&I services, which is the responsibility of the scientific unit operating for the benefit of the companies involved. Research services are used together with the scientific instrument that reflects achievements in the modern theory of innovative problem solving (TRIZ). The analysis was made using the Maritime University of Szczecin and SME-type companies as an example. This paper describes the basic assumptions concerning the implementation of the BIZ-TRIZ mechanism. Also, it presents the use of SWOT analysis, needs/stakeholder analysis and risk analysis for the implementation of the BIZ-TRIZ mechanism. The paper describes preventative actions for the most important implementation risks and discusses the results of the analyses. Finally, it introduces the main conclusions regarding the purpose of implementing the BIZ-TRIZ mechanism.

KEY WORDS

Theory of Inventive Problem Solving (TRIZ), BIZ-TRIZ mechanism, SME sector, R&D&I services, feasibility analysis

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Introduction

The annual Innovation Union Scoreboard is one of the instruments that enable the determination of the skilful use of knowledge for the economic development of EU member states, including Poland. This measure was introduced by the European Commission to evaluate achievements in the broadly described area of innovation of the EU Member States. Despite a significant financial injection from the EU's structural funds, Poland demonstrates a minimal upward trend in the value of the innovation indicator. Poland is still about 40% below the EU-28 average and ranks 4th from last among EU countries (Chybowska, Chybowski & Souchkov, 2018a; European Commission, 2018). To rely on the knowledge and overcome the average income trap, the Polish economy must possess national knowledge resources (Chybowska, Chybowski & Souchkov, 2018a; Chybowski & Idziaszczyk, 2015c), as well as a developed R&D base and technologies and products capable of entering many markets. This knowledge should be adequately transferred from the scientific sector to the economy (Powell & Snellman, 2004).

The process of commercialisation of research results has been visualised in Fig. 1. The model shown in Fig. 1a is typical for economies with a developed R&D market and should be considered a proper model of the cooperation between an enterprise and a university (business–university). Characteristically, the company and the university work hand in hand to develop the potential technology. For companies, the first phase, which the world of science calls the research phase, is, in fact, a pre-investment phase (Chybowska, Chybowski & Souchkov, 2018b). From the perspective of a university, the second phase involves the preparation of a prototype and the validation of its operation as well as the removal of obstacles which could not be predicted during the research phase. In the case of enterprises, this phase is an investment phase. The culmination of the cooperation between science and business is the exploitation (operational) phase when a technology/device etc. is introduced to the market. As demonstrated, the entire process of converting research results into a product that can be launched onto the market may take more than ten years.

The model in Fig. 1b represents the situation, in which the main players — the scientists and entrepreneurs of the R&D market in Poland — currently operate. Due to the impaired cooperation between the private and scientific sectors, the latter does not verify the usefulness of the achieved results for the benefit of the potential recipient. This means that the recipient would have to repeat the research phase (for pre-investment) before purchasing the research results, thus prolonging the whole process. In other words, the world of science produces a certain technology and then looks for investors to bring it to the market. The investor will not take a financial risk and will not invest in untested technology; so, in the best-case scenario, there will be a regression to the previous step, and in the worst case, there will be zero cooperation. It should be noted that Polish enterprises are mainly focused on the acquisition of already finished foreign technological solutions, primarily using low labour costs as their competitive edge. SMEs constitute 99.8% of companies operating in Poland, employing 2/3 of the workforce, with over 45% of them operating in the service sector and 30% — in the commercial sector (Chybowski & Idziaszczyk, 2015a).

Observations of the relations between science and business show three main barriers to the implementation of shared projects:

- The lack of financial resources on the part of SME-type companies to solve complex internal

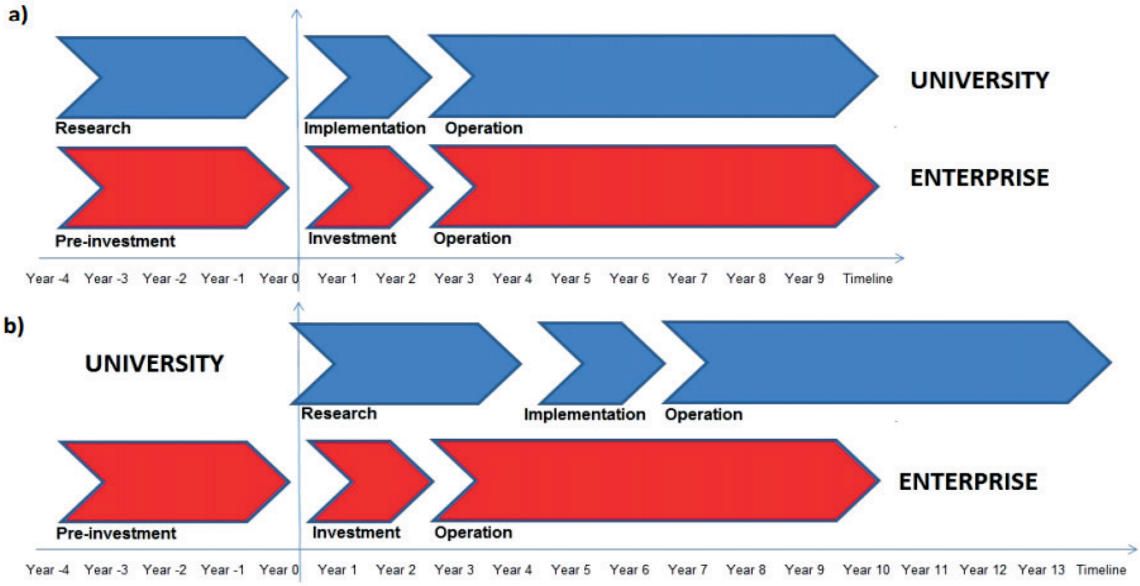

Fig. 1. Commercialisation of research results: a) the correct way, typical for knowledge-based economies, b) shifted in time, currently occurring in Poland

Source: author's elaboration based on (Półkoszek, 2016).

problems, which requires the involvement of many different specialists at the same time and the coordination of such activities:
- The anxiety among scientists arising from the confrontation between their scientific research and the market reality ("research utilitarianism test");
- The inability to innovate in SMEs and the conviction that innovation occurs only in corporations and large companies.

Aiming to strengthen the cooperation between scientific entities and enterprises and to overcome related obstacles, the authors propose to create a mechanism of incentives called BIZ-TRIZ, which is an abbreviation for "TRIZ for Business". The analysis was made using the Maritime University of Szczecin and SME-type companies as an example. This mechanism is based on services provided for these companies by researchers solving, complex internal production/organisational/technical problems, among other things, using the TRIZ methodology (Boratyński, 2013).

The article is structured as follows: the first chapter provides a literature review on the subject and outlines the basic assumptions and objectives for the use of the methods attributed to the Theory of Innovative Problem Solving for closer cooperation between academic entities and enterprises. The following chapter presents a SWOT matrix to elaborate on the results of the analysis into the strengths and weaknesses arising from the application of the BIZ-TRIZ mechanism. The analysis was based on the results of the survey and the literature review. The results of the SWOT analysis showed significant benefits from the application of the BIZ-TRIZ mechanism. This required a needs analysis of the individual stakeholders implementing the BIZ-TRIZ mechanism. The stakeholder analysis is described in the third chapter. Not only did the selected entities have the relevant resources for the implementation of the TRIZ mechanism, but the implementation of the BIZ-TRIZ mechanism was also highly cost-effective in their case. Subsequently, based on the obtained results, the risk associated with the implementation of the BIZ-TRIZ mechanism was analysed. The results of this analysis encompassing 12 primary risks are presented in Chapter 4; the risks are quantified and illustrated using a risk matrix. For particular risks, actions to prevent and minimise them are proposed. Next, the obtained results are discussed as well as their interconnections and the advisability of implementing the BIZ-TRIZ mechanism. Finally, the article is summarised, providing general conclusions.

1. Literature review

TRIZ is the Russian acronym for "теория решения изобретательских задач", which can be translated as the Theory of Inventive Problem Solving (Cempel, 2013; Chybowski & Idziaszczyk, 2015b). It is a methodology that was developed by Russian inventor Genrich Altshuller, who started working on it in 1946. Altshuller continued developing TRIZ until his death in 1998. Further development of TRIZ was carried out by his successors at the TRIZ School of Inventions (Cempel, 2013).

TRIZ is currently one of the most effective methodologies for so-called systematic innovation (Chybowski & Chybowska, 2016a). TRIZ is based on a solid empirical foundation of inventiveness, technical knowledge and the achievements of applied sciences (manufacturing engineering, machine construction and operation, materials engineering, technical physics, etc.). TRIZ relies on the use of tools to create and develop innovative technical and organisational solutions based on "hard" scientific and technical knowledge (Chybowski & Idziaszczyk, 2015b). The tools include functional analysis, trimming of systems, the contradiction matrix, the algorithm of innovative task solving (ARIZ), function-oriented analysis (FOS), transfer of functions, the S curve, "inventive tricks", i.e. removing technical, physical and organisational contradictions, Su-Field analysis (substance-field models), programs and databases for patent information processing and many more (Chybowski & Chybowska, 2016a; Chybowski & Chybowska, 2016b; Chybowski, Gawdzińska & Przetakiewicz, 2017; Chybowski, 2018). From a scientific point of view, TRIZ builds on the achievements of systems theory, invention theory, bionics and psychology, and is constantly being improved.

Owing to the wide application of TRIZ for real problem solving and its local popularity, this methodology has contributed significantly to the economic development of such countries as Japan, South Korea and the USA (Chybowski & Idziaszczyk, 2015c; Yatsunenko & Karendał, 2016). In terms of the number of trained TRIZ specialists, South Korea is the leader, which, in large Korean companies, significantly translates into the number of patents obtained by large South Korean companies and the value of their brands (Fig. 2).

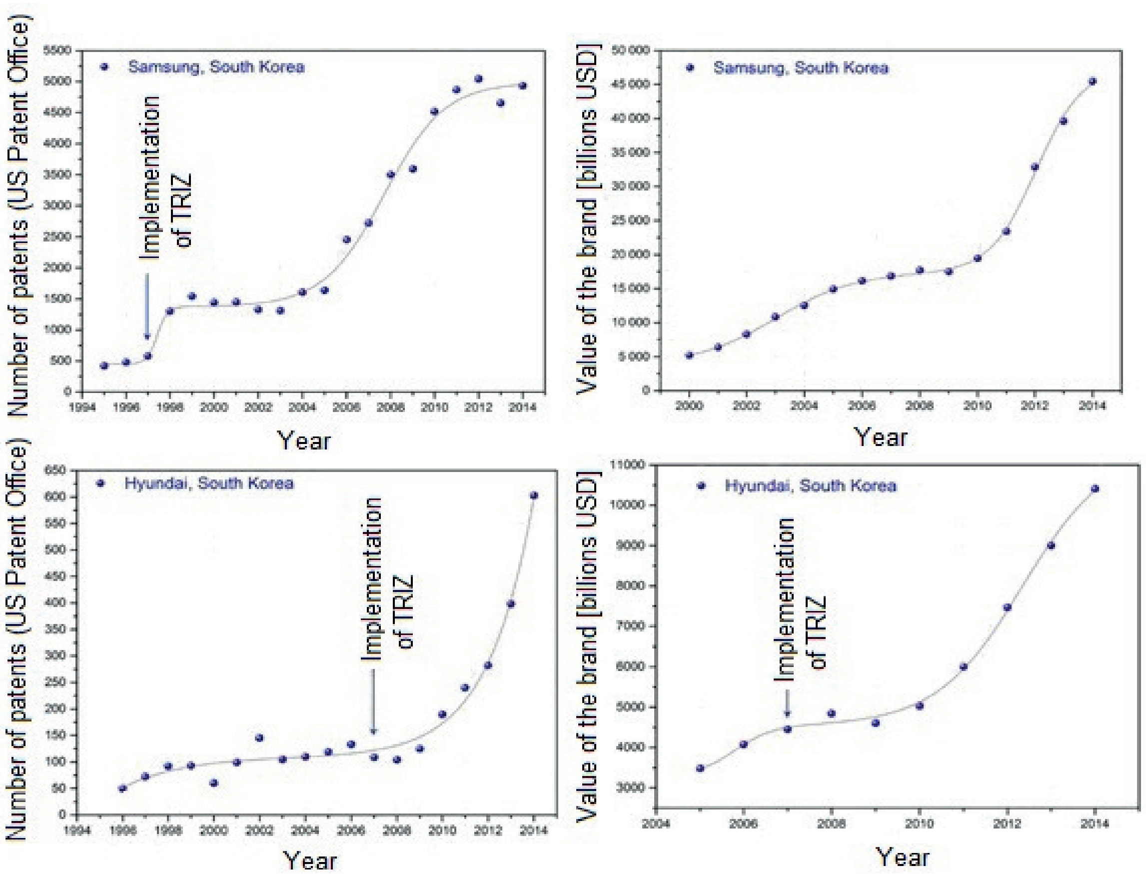

Fig. 2. Increase in the number of companies' patents showing the correlation with the increase in brand value after implementation of TRIZ based on the example of Samsung and Hyundai

Source: (Yatsunenko & Karendał, 2016).

According to the cited statistics, TRIZ can act as a bridge between science and the economic environment, improving the effectiveness of their cooperation. It provides researchers with a solid foundation and tools enabling them to use the existing advanced technical knowledge to create practical solutions for enterprises. The solutions help enterprises gain a competitive advantage in the market by introducing new products or eliminating existing production/organisational/technical problems. The authors believe that the idea of using TRIZ to promote innovation among scientists and entrepreneurs will contribute to the emergence of good practice for cooperation between science and business entities, new technological solutions, as well as creating opportunities for their commercialisation (Souchkov, 2015; Souchkov, 2017; Souchkov & Roxas, 2016). An additional advantage arising from the implementation of the BIZ-TRIZ mechanism is cooperation in the creation of strong links between science (specialist knowledge), innovation (new solutions through TRIZ) and SMEs (recipients and co-participants in the creation of innovations). The BIZ-TRIZ mechanism has the following specific objectives: increasing the competence of university team members working in the field of inventive methods, systematically creating innovations using training, the (optional) process of certification in the field of the Theory of Innovative Task Solving (TRIZ) according to the MATRIZ guidelines, and participating in thematic conferences and/or study visits to TRIZ educational centres and/or companies using TRIZ with the aim of creating innovative technical solutions.

The literature analysis enabled the identification of the possibility of using the TRIZ methodology to bridge the gap that is presented in the introduction, i.e. the lack of proper cooperation between scientific entities and enterprises. According to the results of the literature analysis, the TRIZ methodology effectively contributes to the growth of enterprises and entire economies. The authors decided to adopt this methodology in Poland by applying and adapting it to the local circumstances, which the authors called the BIZ-TRIZ mechanism. The main aims of this mechanism are:

- To develop effective mechanisms of cooperation between the Centre for Technology Transfer (CTT), university research teams and the private sector;
- To establishing multidisciplinary university working groups as well as to create a unique scientific workshop as a result of the research and adaptation of TRIZ tools to the specific fields covered by project team members and the case study;
- To implement research services for SMEs aimed at solving complex production, organisational and technical problems.

2. Strengths, weaknesses, opportunities, and threats of the BIZ-TRIZ implementation

To determine the chances of implementing the BIZ-TRIZ mechanism, the authors analysed the possibilities and obstacles relating to the specifics of the Polish operations of the main players (scientists, SME employees and staff of the Centre for Technology Transfer) and the current market realities (political and economic environments). This analysis is based on the results of the survey and the literature review that were conducted earlier. A summary of the analysis in the form of a SWOT (Strengths, Weaknesses, Opportunities, and Threats) matrix is presented in Tab. 1.

The primary strengths related to the implementation of the BIZ-TRIZ mechanism in the analysed university are the growing prestige, the improving staff competence, the expansion of the research base and the support of the university authorities given to the staff. The weaknesses of the BIZ-TRIZ implementation are still the low popularity of heuristic methods, the lack of sufficient knowledge of TRIZ, and the lack of the habit among scientists to use it. The opportunities include the growing popularity of heuristic methods in recent years, increasing competition between enterprises and emerging, increasingly more complex, technical problems. The main threats are the lack of adequate resources necessary to implement the BIZ-TRIZ mechanism, the lack of awareness of the possibility to improve the situation in the companies as well as communication problems.

3. Needs/stakeholder analysis

The results of the SWOT analysis showed the significant benefits of the application of the BIZ-TRIZ mechanism, which required an analysis of individual stakeholder needs while implementing the BIZ-TRIZ mechanism. The selected entities had the relevant resources for the implementation of the TRIZ mechanism and, at the same time, the implementation of the BIZ-TRIZ mechanism was highly cost-effective in their case. A stakeholder analysis identified their needs in great detail. To assess the impact of BIZ-TRIZ implementation on specific recipients, the main stakeholders, directly related to the BIZ-TRIZ implementation, were identified and summarised in Tab. 2.

Another analysis was made of the impact that the identified stakeholders might have on the implementation of the BIZ-TRIZ mechanism and whether they were interested in the result of the mechanism. Thus, the aim was to determine whether the key stakeholders for the implementation of the BIZ-TRIZ mechanism would be interested in the implementation and whether its results would be a good fit with their needs. The classification of stakeholders based on their potential impact on the implementation of the BIZ-TRIZ mechanism and the direct benefits resulting from the implementation are given in Fig. 3.

The most important aspects for the implementation of the BIZ-TRIZ mechanism are the stakeholders that are located in the upper right quadrant of the matrix. Not only do they have a high potential to make an impact but, at the same time, due to the benefits of implementing BIZ-TRIZ, they also would be seemingly interested in implementing the BIZ-TRIZ mechanism as it is directly related to meeting their needs, which in particular concerns the key stakeholders:

- I7 — scientists from the Maritime University of Szczecin will acquire the competences necessary to create innovations using systematic methods (TRIZ), they will establish cooperation with companies, and will solve real problems the companies have, thus they will have to overcome the fear of conducting research for the recipients of SMEs (research for business);
- I8 — companies from the SME sector will gain an opportunity to solve their own technical and organisational problems, thus increasing the market competitiveness of their products; at the same time, companies will establish cooperation with the scientific sector and increase their own

Tab. 1. SWOT analysis for the implementation of the BIZ-TRIZ mechanism

SWOT	Positive factors for achieving the objectives of the BIZ-TRIZ mechanism implementation	Negative factors for achieving the objectives of the BIZ-TRIZ mechanism implementation
Internal factors (characteristics of the implementation producer)	**(S) Strong points** • The strong reputation of the Maritime University of Szczecin (MUS) in the research areas of transport, mechatronics, machine construction and operation and production engineering; • Experience of the Maritime University of Szczecin in the implementation of activities popularising the science of inventive creation and promoting innovation (including co-organisation of the national Design Thinking Week festivals in 2014, 2015 and 2017, as well as supporting the Students' Research Circle Innovator); • Experience of the Maritime University of Szczecin in the implementation of research and R&D projects; • The competent and committed scientific staff of the Maritime University of Szczecin who have extensive professional knowledge; • The competent and committed staff of the CTT (Centre for Technology Transfer) in the Maritime University of Szczecin with experience in R&D projects, knowledge transfer, commercialisation of research results and protection of intellectual property; • High-class research facilities at the Maritime University of Szczecin (laboratories, workshops, simulators, control and measurement facilities, etc.); • The support of the MUS authorities for the implementation of projects that bring the world of science and business closer together	**(W) Weak points** • Heuristic methods, including TRIZ, are unfamiliar to the employees of the Maritime University of Szczecin; • The slogans "innovation", "innovativity" and "commercialisation" are misunderstood among the employees of the Maritime University of Szczecin (when abused, they can become part of internal jargon); • Researchers are distrustful and have conservative attitudes towards the science of inventive creation/ innovation/heuristics (they often perceive these disciplines as parascientific); • Scientists have problems assimilating new knowledge that breaks their routine approach, habits, stereotypes and comfort zones; • The high cost of acquiring TRIZ competences (costs of study visits, training and optional certification); • Lack of complete comprehension of the principles of cooperation between researchers and external stakeholders and the role of the CTT in this process; • Anxiety amongst scientists about the confrontation with the real problems of recipients (SMEs) and the need to start application-oriented research activities (anxiety among scientists about making a mistake and low utilisability of the research conducted so far)
External factors (characteristics of the environment)	**(O) Opportunities** • Awareness of central authorities (Ministry of Science and Higher Education) concerning the need to improve relations between science and business; • The growing popularity of the use of heuristic and invasive methods in solving complex problems (the *so-called wicked problems*); • Large market of potential buyers (companies from the SME sector); • Growing market competitiveness makes it necessary for SME companies to implement innovative solutions to improve the position of the company; • The technological development of society requires the use of systematic innovation methods (instead of "blind" trial and error methods); • Difficult-to-solve technical problems increasingly require the involvement of a multidisciplinary team of specialists instead of a single expert	**(T) Threats** • Lack of financing for the Maritime University of Szczecin from the Ministry of Science and Higher Education; • Lack of understanding on the part of SMEs and the related anxiety of cooperation between the company and the university and the resulting risk that the Maritime University of Szczecin will not find key partners; • Lack of awareness by SMEs of the need to invest in intellectual services (consulting, expertise, commissioned work etc.); • Distrust and lack of willingness on the part of SMEs to cooperate fully (fear or reluctance to disclose full information about the problem). • Problems in communication between the scientific community and entrepreneurs (lack of knowledge of the rules of cooperation, "a different language" of cooperation); • Surveys carried out on behalf of entrepreneurs will not produce satisfactory results (will not solve the problems or will have low commercial value)

Tab. 2. Main stakeholders in the implementation of the BIZ-TRIZ mechanism

Symbol	Stakeholder
I1	The Ministry of Science and Higher Education — the Government of the Republic of Poland
I2	A recognised TRIZ training and research Centre (e.g. ETRIA Berlin Institute)
I3	A high-class specialist(s) of TRIZ, e.g. the TRIZ MASTER
I4	A supplier of TRIZ training materials
I5	Institutions of the business environment
I6	Employees of the CTT of the Maritime University of Szczecin (the producer of the implementation)
I7	Scientists of the Maritime University of Szczecin (the producer of the implementation)
I8	Companies in the SME sector
I9	Individuals responsible for managing the implementation of the BIZ-TRIZ mechanism at the Maritime University of Szczecin
I10	Technical and administrative staff of the Maritime University of Szczecin (the producer of the implementation)

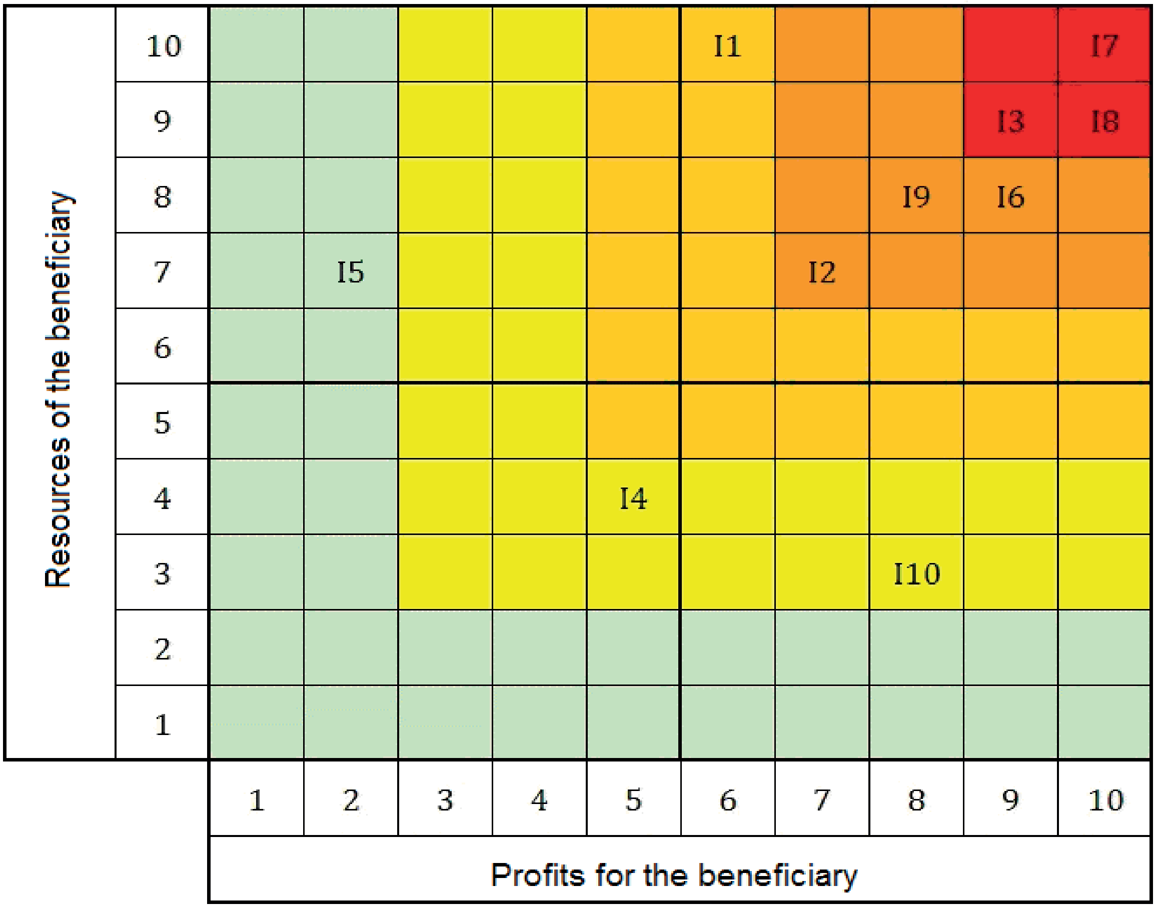

Fig. 3.Stakeholder matrix for the implementation of the BIZ-TRIZ mechanism

awareness of the need to invest in intangible advisory services and the creation of innovations, an awareness that is still undeveloped in Poland;

- I3 — world-class specialists of the 5th degree of the TRIZ MASTER (affiliated MATRIZ, MIT, etc.) and I2 — a recognised training and research centre in the field of TRIZ (e.g. the ETRIA Berlin Institute) will fulfil their "statutory task" to disseminate TRIZ, thus increasing social awareness amongst Poles that the methods of systematic innovation development are worth using and that their use is a powerful stimulator of innovation.

- I6 — employees of the CTT of the Maritime University of Szczecin (the producer of the implementation) will establish fruitful cooperation and develop mechanisms of cooperation between science and business; the CTT will highlight the main objectives for which these units were created in Poland, and the awareness of which is very limited among Polish scientists;
- I9 — individuals responsible for the management of the BIZ-TRIZ implementation at the Maritime University of Szczecin (the producer of the implementation) will gain new experience and competences in the field of innovative project management, at the same time they will establish fruitful international and local cooperation focused on the implementation of further joint ventures with business;
- I1 — institutions co-financing research and the Government of the Republic of Poland will implement planned activities aimed at overcoming obstacles on the path of science and business (which are still very significant), directing scientific research to the needs of the Polish market, stimulating the pro-innovative activity of Polish scientists and intensifying activities aimed at putting Polish society on the track leading to a knowledge-based economy.

4. Risk assessment

Based on the results obtained from the stakeholder analysis, the risk associated with the implementation of the BIZ-TRIZ mechanism was analysed.

Tab. 3. Identification of the risks related to the implementation of the BIZ-TRIZ mechanism

No.	Risk	Source	Effects	The probability of occurrence
1	A lack of external financing	E	C	M
2	Exceeding the budget for the BIZ-TRIZ implementation	I + E	S	VL
3	A lack of entrepreneurs, preventing timely implementation	E	C	M
4	Problems encountered by scientists regarding the acquisition of TRIZ knowledge	I	S	M
5	Mistakes during the preparation of the technical appraisal (research work on behalf of entrepreneurs)	I + E	S	L
6	A lack of data for the drafting of a full technical appraisal for entrepreneurs	E	M	L
7	Problems in cooperation/communication between the scientific community and entrepreneurs (a lack of knowledge of the cooperation rules)	I + E	S	M
8	Low utilisation of the performed research (fear among scientists regarding the fit of the solution to real problems)	I	S	L
9	Surveys made for entrepreneurs will not produce satisfactory results (will not solve problems identified by the entrepreneurs)	I + E	M	L
10	Execution of the contracts for entrepreneurs will be longer than scheduled	I + E	S	M
11	As a result of the implementation, solutions of low commercial value will be created	I + E	N	M
12	The qualifications of the contractors may not be sufficient to solve the problem and it will be necessary to expand the team to include additional people who have not yet been trained in TRIZ	I + E	C	M

Source: internal (I), external (E)
Effects: critical (C), big (B), moderate (M), negligible (N)
Probability of occurrence: very high (VH), high (H), medium (M), low (L), very low (VL)

For particular risks, actions to prevent and minimise them have been proposed. The risk analysis has been developed considering the main objective: which is to strengthen cooperation between universities (Maritime University of Szczecin) and SME-type enterprises by providing services for these enterprises. The following analysis is synthetic in nature and does not include a detailed description of the planned activities within the framework of risk management of the implementation of BIZ-TRIZ.

Tab. 3 presents threats for the achievement of the identified objectives through the implementation of all the tasks provided in the project. For each hazard, the effects were classified as critical (C), significant (S), moderate (M), low (N) and the probability of each hazard occurring was determined using expert knowledge and the available statistics, which were classified as a probability: very high (VH), high (H), medium (M), low (L) and very low (VL).

The executors of the BIZ-TRIZ implementation have several tools that allow for effective management of the identified risks. The vast majority of risks can be eliminated or reduced during the preparation phase of the BIZ-TRIZ implementation. The implementation operator has the greatest impact on the threats of an internal nature, although it may indirectly affect the mitigation of negative external effects. For each of the identified threats, a risk matrix for the implementation has been prepared, which can be seen in Fig. 4.

	VL	L	M	H	VH
C			**1, 3, 12**		
B	**2**	**5, 8**	**4, 7, 10**		
M		**6, 9**			
N			**11**		

Fig. 4. Risk matrix for the implementation of the BIZ-TRIZ mechanism

The risk matrix shows that there is a group of acceptable threats that only require monitoring (the lower left corner of the matrix) and a group of threats that require preventive and compensatory action (the upper right corner of the matrix). According to the adopted classification, the hazards numbered 2, 5, 6, 8, 9 and 11 were classified in this first group. The actions foreseen for the remaining risks are summarised in Tab. 4.

Tab. 4. Risk minimisation and prevention in the implementation of the BIZ-TRIZ mechanism

No.	Risk	Preventive/compensatory action
1	A lack of external financing	• A very well-prepared application form. The fulfilment of competition requirements for external financing
3	A lack of entrepreneurs will prevent timely implementation.	• The CTT promoting engagement (searching for partners during business breakfasts, cooperation exchanges and making direct contacts); • A well-prepared contract with companies; • Good communication between partners (adherence to the agreed rules of cooperation)
4	Problems encountered by scientists regarding the acquisition of TRIZ knowledge	• The implementation of training courses, study visits and case studies under the supervision of recognised TRIZ specialists (mentoring by MATRIZ certified specialists)
7	Problems in cooperation/communication between the scientific community and entrepreneurs (the lack of knowledge of the cooperation rules)	• Promotion by the CTT; • A well-prepared contract with companies; • Good communication between partners (adherence to the agreed rules of cooperation)
10	Execution of contracts for entrepreneurs will be longer than scheduled	• The continuity of the execution of implementation tasks. • Appropriate planning and supervision of the implementation of individual works commissioned for entrepreneurs by the manager; • Possible revision of the implementation schedule
12	The qualifications of the contractors may not be sufficient to solve the problem and it may be necessary to expand the team to include additional people who have not yet been trained in TRIZ	• Training a team member in the scope of competences and authorisations to carry out further training (level 3 MATRIZ); • Expanding the team with additional specialists required for the implementation of a specific research service; • Training of additional team members in-house by a team member who has previously obtained appropriate competences and authorisations to conduct further training (level 3 MATRIZ)

In the close vicinity of the producer of the implementation, a large number of potential customers were found by the CTT, starting in 2014 since it started organising business breakfasts and co-organising cooperative science-business exchanges in the West Pomeranian Voivodeship. These efforts made the risk of failure in achieving the implementation assumptions relatively low. Nonetheless, if such a situation occurs, preventive actions may be taken in the form of the customer searching in more remote areas (e.g. through networks operating for enterprises, e.g. PARP (the Polish Agency for Enterprise Development) and other CTTs, special-purpose companies or the Top 500 Innovators Association).

5. Discussion

The results obtained from the analyses presented in this paper show that the implementation of the BIZ-TRIZ mechanism may contribute to the identified obstacles being overcome in the cooperation between university and business entities using the opportunities and strengths of the universities listed in Tab. 1.

The implemented BIZ-TRIZ mechanism will significantly contribute to the delivery of assumptions required for the knowledge-based economy by showing SMEs the possibility of creating innovations in cooperation with science and thus potentially increase the competitiveness of these enterprises. During implementation, the working groups will conduct scientific research on three levels of activity:

- The development of specific analytical tools based on the knowledge of the disciplines represented by team members (materials engineering, machine construction and operation, electrical engineering, etc.) (Chybowski & Gawdzińska, 2016a; Chybowski & Gawdzińska, 2016b) and general system models provided by TRIZ;
- Sub-studies, research and technical reports and the implementation of stages related to the solution of problems reported by companies from the SME sector (diagnosis of the problem and preparation of proposals for its solution) (Gawdzińska et al., 2017; Wiśnick et al., 2017a; Wiśnicki et al., 2017b);
- The collection of partial data from case studies (orders for SMEs) and the evaluation of the implementation, which will enable the development of new cooperation models for universities and businesses, the evaluation of the usefulness of inventive methods in the realities of the Polish economy and lessons learned that stemmed from the effects of the implementation of BIZ-TRIZ.

The implementation of the mechanism will also demonstrate to entrepreneurs that it is worth investing in research services provided by the scientific sector and that innovations can even be introduced in small companies. In turn, scientists will find that, by working with other professionals and with the SME sector, they will be able to provide solutions that are useful to society.

Potentially, the detailed tangible effects of the implementation of the BIZ-TRIZ mechanism will be:

- Increased awareness by entrepreneurs and scientists of the possibility to effectively cooperate (including after the implementation of the BIZ-TRIZ mechanism);
- A unique workshop for the scientific staff of the producer of the implementation that will allow them to use their profound and extensive scientific knowledge to systematically create innovations (including after the implementation of the BIZ-TRIZ mechanism);
- The formation of multidisciplinary working teams of the producer of the implementation as a result of the implementation of the BIZ-TRIZ mechanism, which will create the potential for similar activities to be carried out after the implementation of the BIZ-TRIZ mechanism;
- The acquisition by scientific employees, of the producer of the implementation, of valuable experience and competences to build their scientific careers and to obtain degrees and titles based on cooperation with the local economy;
- The expansion of the contacts of the producer of the implementation with the business community (SME database);
- The expansion of the portfolio of the producer of the implementation as an entity that can effectively cooperate with business entities (success stories);
- The development of tools for effective technology transfer by the CTT for the producer of the implementation.

Conclusions

Through the practical use of TRIZ and the dissemination of the results, the BIZ-TRIZ mechanism will significantly contribute to the dissemination of the methodology in the Polish economy. The promotion of the systematic creation of innovations (TRIZ) and inventions should be a priority for the authorities that want to improve Poland's position in international innovation rankings.

The results of the BIZ-TRIZ implementation and the applied solutions should be popularised in several following ways: the publishing of books and scientific and popular articles (e.g. in magazines for entrepreneurs), the participation in conferences and thesis defence presentations for the award of scientific degrees to participants of the implementation. Such an approach would make it possible to use the effects of the implementation for other scientific entities and SMEs and would strengthen the position of the producer of the implementation as a pro-innovation university, which can provide tailor-made solutions for entrepreneurs.

The main limitations on the BIZ-TRIZ implementation are financial, because entrepreneurs have to cover the costs of the commissioned R&D works. The analysis presented in the article revealed significant possibilities and potential benefits from the implementation of the BIZ-TRIZ mechanism. The next proposed stage is the preparation of a project that will be financed by external sources, which is intended to implement the mechanism in practice. The university will also provide R&D services to entrepreneurs. A possible approach would be to select entrepreneurs by way of a competition. A favourable implementation of such a project and the dissemination of knowledge about benefits received by participating companies will possibly become the basis for the further development and use of the BIZ-TRIZ mechanism for the commercial resolution of problems encountered by entrepreneurs, so that the university would be able to increase its share in the implementation of research work for local companies.

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Identification of prospective industrial clusters in Slovakia

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A B S T R A C T

Clusters became an integral part of regional policies intended to build and strengthen competitive advantages within specifically identified geographical areas. They are still considered crucial for economic development and employment, although their orientation has slightly changed as the distance and geographical boundaries lost their importance. This article analyses crucial regional data that indicates potentially beneficial economic concentrations as an assumption for the preparation of prospective clusters in Slovakia. Potential clusters were identified based on significant employment concentrations of particular regional industries that appear extraordinary when compared with national employment and the dynamic development within the selected time frame. Prospective clusters were identified, and opportunities of their development were described, including the harmonisation with the current regional and urban strategy. Analysing absolute and relative quantities in employment, sections and divisions of SK NACE were used for the proper identification of industries. The location quotient served as a tool for the spatial concentration of employment in the Banská Bystrica region, the threshold value for the selection of cluster candidates was set to 2. The shift–share analysis was used for the identification of long-term changes in employment, and 10% of the most dynamic industries were presented at the level of divisions once and then, at the level of sections of SK NACE. Forestry and logging, the manufacture of wood products and the manufacture of basic metals were confirmed by both methods as significant concentrations. The result partially corresponded with the previously active and currently inactive cluster in Banská Bystrica, which was focused on mechanical engineering, still significant when considering numbers of companies and employees as well as sales. Forestry was the most concentrated industry, while the wholesale and retail trades were the most dynamic. Forestry, logging and manufacture of wood products might be strongly interlinked with the current entrepreneurial and social strategy of self-governing regions that is still at the stage of potential cluster identification and fitting to its priorities. The article assumed basic quantitative methods utilised for the identification of prospective clusters. It confirmed the practicality of their application, the gravity of data processing and also certain possible limitations due to the extraordinary focus on the employment concentration. According to the analysis and gained results, the former cluster in the Banská Bystrica region was confirmed as the potentially significant actor in the regional policy (although, currently, having no industrial or public interest) and the new cluster candidates were identified. Outcomes indicated the need to continue the research with a more detailed examination of qualitative aspects that could complete the effort by focusing on clusters not only having higher employment statistics but also the support from regional institutions, also reflecting the preferences of businesses.

K E Y   W O R D S
cluster, region, location quotient, shift-share analysis

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Introduction

The concept of cluster development is considered an important element in the national economic structure of the European Union (EU) Member States. The main task of a cluster is to obtain a local, regional and global synergistic effect of a group of interrelated institutions. Clustering should help to increase the operational effectiveness of entities that are members of a cluster as well as increase their competitiveness, innovation, development, production and dissemination of knowledge and experience, and to contribute to the overall economic growth of the region. In developed EU countries, current trends in the planning of regional development policy are based on supporting the creation and cluster building. Trends represent a significant shift from the traditional approach, such as the creation of regional development programmes aimed at promoting the development of individual enterprises, to regional policies based on cluster support. A cluster-based policy understands businesses and the industry as a system. It focuses on developing strategies designed to promote an efficient allocation of scarce resources for the economic development of regions and provide tools to strengthen the industry in the region.

The history of clusters in Slovakia is relatively short. The first cluster was introduced in 2004, the next industrial clusters emerged in 2008 and were followed by others. After the period of intensive state support of cluster establishment in 2008–2012, the frequency of cluster establishment declined in Slovak regions. The difference in the structure of the industry in Slovak regions and their unequal development played a part in the diverse intensity of clusters creation. Since 2004, only one industrial cluster was established in the Banská Bystrica region, which only operated for several years. Due to the expiration of support from the EU Structural Funds, regional and municipal support stopped, and the cluster has been only hibernating. After the years of factual non-existence of industrial clusters in the Banská Bystrica region, with the introduction of RIS 3 strategy and other initiatives, the need and effort arose to identify and establish new industrial clusters.

The paper aims to analyse the historical aspects of cluster establishment in the Banská Bystrica region, to identify the prospective clusters based on the shift-share analysis and the location quotient and compare the results with the current regional and urban strategy. The research results present the scientific approach to the identification of prospective (potential) industrial clusters as the basis for managing regional strategies.

The methodology for the identification of potential clusters in the region is diverse and continues to change with new emerging approaches. The paper used the location quotient and the shift–share analysis. Even though they are relatively simple, the methods are proved and can be applied to a region with a limited scope of quantitative characteristics of the industry.

1. Theoretical background for clustering

Already in the early 20th century, the great British economist Alfred Marshall addressed the issue of corporate grouping in certain sectors in specific geographical areas (districts). This was due to localisation economies which manifested as an attraction (benefit) for companies supplying inputs and specialised services for the industry, allowing the creation of a specialised workforce with the necessary knowledge and skills in the sector, but also an effective transfer of knowledge between companies.

Clusters represent a complex form of a (mostly) industrial organisation, in which social ties (the community), productive networks of local enterprises, and the web of local institutions and collective agents form a co-operative and competitive density. Porter (1998) defined a cluster as a geographically close group of interconnected businesses, specialised suppliers, service providers and associated institutions in a particular sector and businesses in related industries that are competing, collaborating and sharing common features. The OECD (2001) defined a cluster as a network of interdependent companies and institutions producing knowledge or geographically concentrated similar or related companies active in business transactions, communication and dialogue, sharing specialised infrastructure, labour markets and services, and having common opportunities and threats. The European Commission (2007) defined a cluster as a group of cooperating and competing independent companies and associated institutions locally concentrated in one or several regions; however, clusters may also be of global scope, specialised in specific industrial sectors linked by common technologies and knowledge, and be either knowledge or industrial.

Initial definitions of clusters included two important criteria by which a cluster was defined. Firstly, businesses could be cooperating within a region (spatial area) or across borders, and secondly, the cooperation was between enterprises of the same industry. This concept was outgrown long ago, as both geographical and industrial restrictions were a limitation of further growth and common cooperation.

Enterprises do not cooperate only with each other but also with research institutes, universities and local governments (Ferencz, Dugas & Turisová, 2013; Sölvell, Lindqvist & Ketels, 2006). Authors John and Pouder (2006) specified the form of such a collaborative network as an industrial cluster, although stakeholders may also cooperate in different modes and forms (Šebestová et al., 2017). Local actors, in addition to suppliers, competitors and customers, may include complementary institutions, such as banks, research institutions and vocational training organisations (Amin & Thrift, 1994, cited in Andersen & Bøllingtoft, 2011). Localised advantages and global competitive advantage are often combined. Clusters facilitate knowledge spillovers as they are mediated by the proximity and multiplex relationships between enterprises and other institutions (Andersen & Bøllingtoft, 2011). The mixture of potential stakeholders offers plenty of opportunities for ways how a cluster may be organised and on which activities to be focused. Thus, nowadays, strictly technological clusters engage with non-manufacturing actors, forming various knowledge, financial, culture or creative types of clusters. A typical manufacturing cluster lost its popularity in the period of the knowledge economy and following the industry 4.0 to meet new trends leading towards the mass customisation and servitisation (Park, 2018).

Growth or decline in any of the sectors where a cluster may be established certainly have a significant impact. In the case of positive development, new clusters may arise due to technological innovations, capital and labour productivity, location benefits, changes in product demand, and shifts in input costs which directly or indirectly affect the overall growth of the economy (Bartik, 2004). Thus, such potential heterogeneity of influences requires clusters to be dynamic, with some necessarily condemned to finish their life-cycle and others newly emerging, setting them apart depending on technological progress or changes in the lifestyle of society.

The core of all successful clusters consists of many common elements and bonds, of which the most significant is the understanding that clusters should be led by business and public leaders and the understanding of the importance of cooperation and competition between cluster members as well as knowing that the cluster approach is a system where all participants play an equally important role.

Several authors agree that companies tend to concentrate near similar businesses (including direct competitors) and institutions and build mutually beneficial relationships. This is a fundamental difference between a concentration and a sectoral cluster. The main feature of a cluster is that it is based on a systematic relationship between businesses as opposed to a simple concentration. These relationships are built on similar or complementary products, production processes, technologies and demand for natural resources, specific qualifications or distribution channels. A geographical concentration of economic actors allows personal contacts but also cheaper and more flexible deliveries (SIEA, 2009). It is indubitable that a purely quantity-oriented approach is incorrect as it could lead to forcibly created artificial clusters; on the other hand, the literature emphasises a more in-depth understanding of industry linkages (Munnich & Iacono, 2016) or a mix of quantitative and qualitative factors (Täucher & Laudien, 2018). In this article, the concentration of businesses is considered the basis for the identification of potential clusters, supplemented with a proper linkage to current strategic perspectives and priorities of regional self-governance institutions.

Geographically clustered enterprises must cooperate while they compete (Mesquita, 2007, cited in Felzensztein et al., 2012). Institutional aspects, formal organisations such as trade associations and the presence or absence of social capital, may play a critical role in creating the right environment and then influencing the climate for cooperation in regional clusters (Bergman & Feser, 1999). Entrepreneurship in cluster formation is important with respect to new products and approaches to new markets. It is well known that entrepreneurs with business experience are more likely to build a sustainable business in a cluster (Lesáková, 2014). The public policy support of this entrepreneurial behaviour in clusters is also a very important element for successful clusters (Stam, 2009, cited in Felzensztein et al., 2012).

It has been argued by various authors that clustering confers many advantages to participating enterprises (Jacobs, 1969; Moretti, 2011). It is well known that co-location results in lower transportation and transaction costs as travel, time and increased trust should produce lower costs. Clusters can also attract the required skilled labour, the mobility of which can enhance the exchange of ideas and knowledge throughout the cluster. There is also a possibility of un-traded benefits, such as cooperation, learning and resource sharing. They are sometimes referred to as either embedded benefits or "un-traded interdependencies." The literature on clusters also emphasises numerous benefits for small businesses. This is especially the case given their resource constraints, the absence of internal specialisation and relatively weak supplier and market power (Blackburn & Conway, 2008, cited in Felzensztein et al., 2012). Many recent studies focused on different aspects of cluster influence on enterprises (enterprises inside and outside the cluster). Most of them consider the innovation intensity and productivity (Hervas-Oliver et al., 2018; Knoben et al., 2016; Rigby & Brown, 2015) or employment, including labour mobility and wages (Power & Lundmark, 2014).

On the other hand, potential clusters should also consider threats or disadvantages. Lee (2009) found that being in a cluster has a negative effect on the intensity of a company's research and development (R&D) or some enterprises in clusters may face difficulties accessing resources at reasonable terms (Arthur, 1990). The same was stated by Žižka and Rydvalová (2014) mentioning that there were more variables supporting the intensity of innovations than just a cluster membership, and there were no significant changes in the growth of implemented innovations. It must be aded that for various reasons, wages were usually higher in clusters when compared with those of employees working for more isolated enterprises (Freedman, 2008). Moreover, a relatively high probability of conflict was determined, which was mainly due to the coexistence and interaction of streams of cooperation and competition in the relationship between concentrated parties (Cygler & Sroka, 2016), even more so in the case of direct competitors.

Some of the above-stated relations, pros and cons of cluster activities were difficult to examine under Slovak conditions due to the lack of data. The low number of active clusters, their higher/lower importance within the regional economics, a low number of clustered companies and short cluster history resulted in insufficient data for certain generalisation (Lesáková et al., 2017). Consequently, in the case of prospective clusters, it is even more important to consider all aspects of cluster establishment (advantages and disadvantages) to avoid the potential wasting of time and capital, expecting unfeasible results.

2. Methods for identification of prospective clusters

The methodology for the identification of prospective clusters is rather varied, considering either quantitative or qualitative approaches, both having certain limitations and disadvantages. New methods or indices are constantly created, based on different statistical processing or different entry data. Most of the methods identify cluster opportunities only based on the geographical concentration of industrial activities while ignoring the relations between companies, on which clusters are conceptually based (Malmberg & Maskell, 1997). The international scientific literature on cluster identification (Lindqvist et al., 2008; Sölvell et al., 2009) offers the methodology based on the territorial concentration of such economic indicators as the number of enterprises, availability of labour force, the total employment or the concentration of added value, summarised depending on a regional area, namely, a region, state, district or land (Maggioni & Riggi, 2008). Other authors also explain the unequal distribution of specific economic activity in space (Bottazzi et al., 2007; Bottazzi & Gragnolati, 2015), although different definitions of space/spatial issues, economic activity, threshold values and common relations between stakeholders make it impossible to identify a generally acceptable approach.

The Gini coefficient (Krugman, 1991) is considered one of the simplest methods for the identification of geographical concentration. The Ellison-Glaeser index is more sophisticated as it also involves the size of enterprises and measures the overall manufacturing clustering and industrial concentration, whose values are comparable across industries and levels of the geographic aggregation (Ellison & Glaeser, 1997). Duranton and Overman (2005) focused on distance-based measurement, developing an index using the bilateral distance density. They measured the distribution of geographical distances between pairs of enterprises in industry and compared these distributions with a hypothetical random distribution.

The location quotient is also one of the simpler methods as it quantifies the regional specialisation and the strength of a cluster while being applied on national or regional levels (Brenner 2006; Crawley et al., 2013). Stronger localisation of the certain industry makes good assumptions for the prospective cluster establishment (such approaches for the identification of clusters are used also by the US Cluster Mapping and the European Cluster Observatory). A similar spatial orientation is examined within the G Statistics or the shift-share analysis.

The G Statistics quantifies whether a region and the surrounding regions show high or low values of activity. It considers activities in the surrounding regions for estimating the cluster strength in a region (Getis & Ord, 1992). The shift-share method, which analyses regional growth, was offered by Creamer in the 1940s and summarised by Dunn in 1960s (Shi & Yang, 2008). It does not only consider employment but also analyses its dynamics in time.

On the other hand, methods are available that identify the linkages between industries and the intensity of supply chain relations (the input–output analysis). But all methods are considerably dependable on available data, as the extent and details of a dataset influence the punctuality of the research. NUTS or other similar classifications are more detailed, offering more data yet requiring more effort for more complex processing. However, even the region's specialisation is more accurately explained.

Other authors (Täuscher & Laudien, 2018; Munnich & Iacono, 2016; McRae, 2004) stressed the necessity to identify clusters according to the combination of quantitative and qualitative characteristics, which means that in the case of qualitative research, expert methods must be used to process the data that is impossible to be measured directly in a numerical way. As the following analysis did not focus on primary questioning and other qualitative approaches, therefore, these methods were not described in detail; however, the authors were aware that the preparation and establishment of a cluster could not be subjected to a pure spatially intensive business activity but should also consider other factors (non-numeric). Nevertheless, the use of various methods to ask local actors about what they see as dominant or vital to the economy can reinforce or alter the results of the quantitative analyses (Britton, 2003). Thus, in the end, the outcomes from the analysis were confronted with the strategic priorities of the self-governing Banská Bystrica region.

3. Research methodology

The method of documentary analysis was used to study the literature related to clusters and relevant methods for prospective cluster identification. The industry's homogeneity (sections and divisions of SK NACE), the geographical area (the Banská Bystrica region) and the quantity (absolute and relative quantities of employment) were used as criteria for potential clusters. From the methodological perspective, the location quotient was used based on the total employment and the shift–share analysis (certain simplification in their application was considered and the results were presented individually and compared at the end).

The location quotient represented the local extent, to which the region was specialised in the appropriate industry. It expressed the uniqueness of such industry in comparison to its position in the national economy or the national average employment. In most cases, it was expressed as the relative importance of employment in the region in comparison to its national importance.

The location quotient of 1.0 meant that the region was not specialised in such industry and its employment was comparable with its development on the national level (the standard distribution close to the normal distribution of employment in regions). The index bigger than 1.0 represented the higher importance of the industry's employment and identified a potential cluster of similar companies on the regional level. It was assumed then that the regional cluster cumulated the economic activity of the same type. For the identification of potential clusters, authors like Bergman and Feser (1999) recommended the location quotient of 1.25 and Isaksen (1996) suggested more than 3.0. The following analysis relied on the recommendation of the European Cluster Observatory, according to which the location quotient should exceed the value of 2.0. Such a statement was confirmed even by Sölvell (2008). Thus, the potential clusters in the Banská Bystrica region were be identified based on the number of employees in each sector (divisions and sections of SK NACE).

The shift–share analysis revealed that part of employment in the industry or cluster (based on the number of employees), which resulted from national, regional or sectoral trends (or competitive advantages). It helped to consider the overall regional performance in comparison to other regions and identify cross-regional problems that could be considered by all policymakers on regional or national levels (Potomová & Letková, 2011). The shift–share analysis quantified the total change in employment and split it into national, industrial and regional effect (Karlsson, 1999; Matáková & Stejskal, 2012).

The limited validity in time is the main disadvantage of such a method (Yasin et al., 2004), as well as its predictability, which is close to none. It may only have some theoretical contribution when applied without considering the regional situation. The identified effects stem from the following relations:

$$NS_{ir}^{t} = E_{ir}^{t-1} x \left(\frac{E_{SK}^{t}}{E_{SK}^{t-1}} - 1 \right) \quad (1)$$

$$IM_{ir}^{t} = E_{ir}^{t-1} \; x \left[\left(\frac{E_{iSK}^{t}}{E_{iSK}^{t-1}} \right) - \left(\frac{E_{SK}^{t}}{E_{SK}^{t-1}} \right) \right] \quad (2)$$

$$RS_{ir}^{t} = E_{ir}^{t-1} \; x \left[\left(\frac{E_{ir}^{t}}{E_{ir}^{t-1}} \right) - \left(\frac{E_{iSK}^{t}}{E_{iSK}^{t-1}} \right) \right] \quad (3)$$

where:
NS = national share,
IM = industrial share,
RS = regional share,
t = time period
i = industry
r = region
ESK = total employment in Slovakia
EiSK = total employment in industry
Eir = total employment in the region

Although some authors prefer the dynamic shift-share analysis as a more appropriate research method splitting longer period into shorter seasons (Barff & Knight, 1988), this article used its static form.

4. Research results and discussion

4.1. History and the current state of clusters in the Banská Bystrica region

The first cluster initiatives in Slovakia started after 2004, with most clusters created in 2008, 2009 and 2012. These years correspond to the periods when support schemes for the emergence and functioning of clusters were announced, allocating financial resources mainly from the EU funds. Since 2004, the government issued several documents to support the emergence and functioning of clusters: the Innovation Strategy of the Slovak Republic for 2007–2013 (consisting of two consecutive innovation policies) and the Research and Innovation Strategy for Smart Specialization of the Slovak Republic (RIS 3). RIS 3 is the framework strategy document for the promotion of research and innovation in the programming period 2014–2020 and serves as the basis for the development of operational programmes. The issue of cluster development in Slovakia is a part of RIS 3, while the growth of existing and creation of new cluster initiatives is included under the measure 1.1. The development of innovative capacities through cooperation between companies and research institutions is under measure 3.2. Supporting research and innovation in environmental matters, including adaptation to climate change.

Since the year 2004, only one cluster was officially established in the Banská Bystrica region, namely, the First Slovak Engineering Cluster. It was created in 2008 as an initiative of the local authority of the region. The memorandum was signed by the local authority of the Banská Bystrica region, ten engineering companies, one research and development organisation, one consultancy company, eight secondary schools focused on engineering and the Technical University of Zvolen. In the beginning, the cluster had 22 members. Unfortunately, the cluster operated only for several years, and after the decrease in the financial support provided by the local authority of the region, the cluster stopped all the activities.

The Banská Bystrica region also had another cluster initiative centred around the aluminium processing of (not yet a formalised cluster organisation). The cluster formed around the aluminium producer ZSNP in Žiar nad Hronom. This innovative cluster motivated the establishment of the scientific competence and innovation centre INOVAL by the Slovak Academy of Science (Institute of Materials and Machine Mechanics) in 2011 to cooperate with the companies in the area of scientific research and innovation projects as well as the commercialisation of innovative solutions.

Despite evident effects of cluster operations, they have insufficient support in Slovakia as well as no systemic approach to this issue. Although many official documents declare the importance of clusters for the economic growth and competitiveness as well as the need to support them, the real implementation of incentives aimed at the creation and development of clusters in practice inexistent (Klement et al., 2016). Therefore, clusters in the Slovak Republic primarily result from natural needs, especially sectoral collaboration, rather than targeted state support of cluster initiatives.

4.2. Identification of prospective clusters in the Banská Bystrica region according to the employment concentration

The analysis was based on the data gained from the Statistical Office of the Slovak Republic. The data

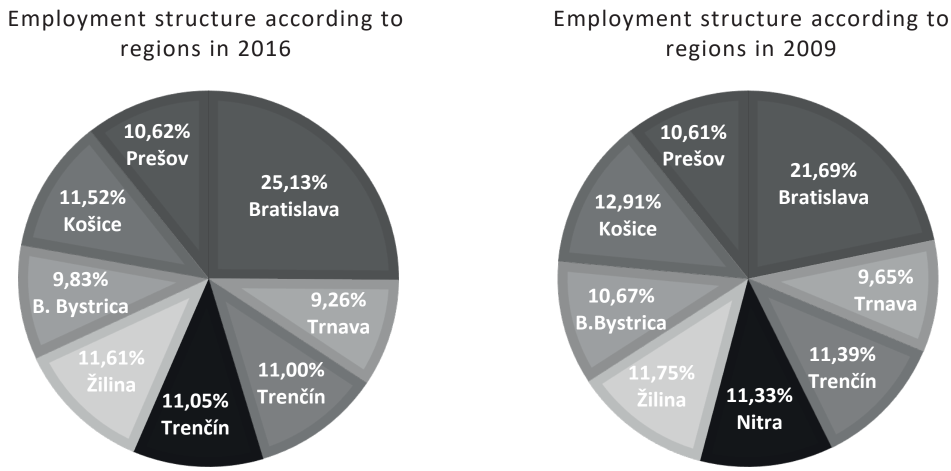

Fig. 1. Structure of employment according to regions in 2016 and 2009
Source: elaborated by the authors based on data of the Statistical Office of the Slovak Republic.

covered the development of employment in the Banská Bystrica region during 2012–2016, so the analysis also focused on changes in time. Employment data covered all types of companies and other organisations regardless of the company size and according to their prevailing activity. Data did not cover employees of self-employed business owners.

The total employment in Slovakia went up by 0.32% in 2016 compared to 2015. In comparison to 2009, the shift was even higher and reached + 15%. In both years, the Bratislava region had the biggest share on the total employment (25.13% in 2016, 24.24% in 2015, 21.69% in 2009), the smallest share in the total employment belonged to the Trnava region (9.26% in 2016, 9.67% in 2015, 9.65% in 2009).

During last two years, an increase in employment was noticed in all regions except for Trnava and Košice, while the Bratislava region had the biggest increase (+6.9%) and the Trenčín region had significant growth as well (+5.5%). In Trnava and Košice regions, the employment was in decline (-1.2% and -1.24%, resp.).

Employment in the Banská Bystrica region indicated the same trend as in most other regions, namely, a gradual, although a slight increase in employment. The industrial production had the biggest share of the total employment (30%). The shares of particular industries in the total industrial production were rather low, which indicated a lower regional industrial specialisation and rather general distribution of employment within the region. The manufacture of basic metals had the biggest share (4.11%) of employment, while the total industrial production had 30%. Wholesale and retail trade (according to the SK NACE division) was the second biggest employer in the region with 13.88%, and the public administration had 12.17%, which ranked it third.

In comparison with 2015, the significant decrease in employment was quantified in financial and insurance activities (-29%), real estate activities (-17%), transportation (-9.85%) and agriculture (-7%). Industrial production/manufacturing grew by 8.5%, water supply by 69%, administrative and support activities by 32% and construction by 14%, although some minor sectors had lower initial employment, thus the increase may have seemed significant.

As already mentioned, firstly, the location quotient was used to identify prospective clusters. According to processed data, there were four potential clusters in 2016, 2015, 2013 and three in 2014, 2012, although the industries changed a bit. Other industries with lower quotients are not presented in the chart, as the analysis focused only on potential clusters and the gap in quotients was too big in the case of remaining industries.

In 2016, the importance of forestry and logging grew, but the manufacture of wood significantly declined, which indicated the growth in timber harvesting or "raw wood" production and limited processing ability of the region as the manufacture of wood products declined. On the other hand, the manufacture of furniture is not presented in the chart, as it was under the level of the desired quotient, but its value increased since 2015 by 0.62 and reached 1.86. Therefore, the above-mentioned statement should be amended and interpreted also in the frame of this even more sophisticated production.

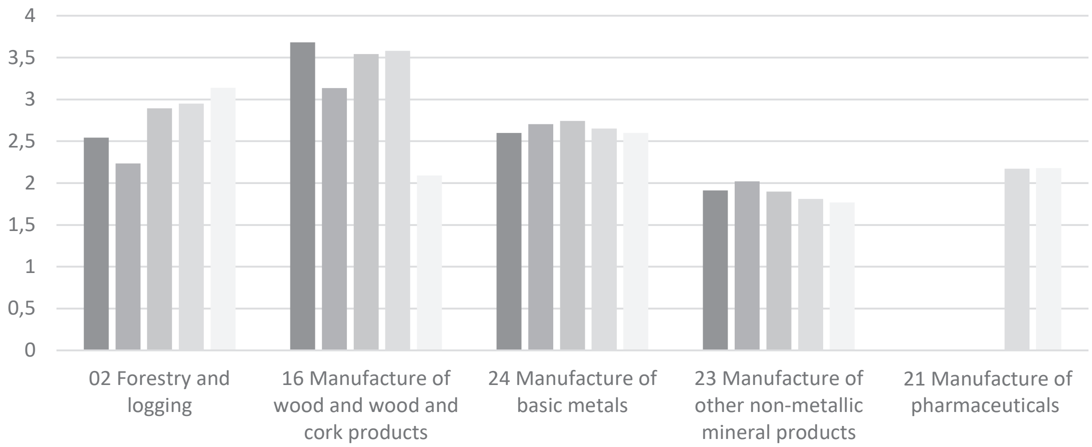

Fig. 2. The highest location quotients in Banská Bystrica region
Source: elaborated by the authors based on data of the Statistical Office of the Slovak Republic.

It should be mentioned that the Statistical Office of the Slovak Republic did not publish forestry data of one region; thus, the employment of the previous year was used instead. As employment in the Banská Bystrica region continually grew while it declined in the missing region, it is probable that the calculated quotient was underestimated. The manufacture of basic metals was rather stable in time, while the manufacture of other non-metallic mineral products was not considered a cluster candidate in recent years. On the other hand, in 2015 and 2016, the manufacture of pharmaceuticals emerged among potential clusters. According to Fig. 2, this industry was not presented in previous years because similarly to the case with the forestry, the related employment data in the Banská Bystrica region was not published by the Statistical Office of the Slovak Republic due to some confidentiality reasons. Values from the past were not used as the trend (increase or decrease) was not obvious.

According to Fig. 2, wood processing activities recorded the biggest downfall in the quotient's value (not the total employment, but the regional importance of employment after it was compared with the national employment). It went down by 1.6. The opposite trend was noticed in forestry and logging (+0.6). On the other hand, the manufacture of basic metals slightly fell (-0.003), and the quotient for the manufacture of non-metallic mineral products indicated a non-prospective cluster candidate (-0.14).

4.3. Identification of prospective clusters in the Banská Bystrica region according to the shift–share analysis

While the previous chapter identified potential clusters according to the development of employment (although including some dramatic changes during the long-term period, but still fixed individually in each year), the shift-share analysis considered even a longer period, and its outcomes were influenced preferably by the dynamics in the regional employment between 2009 and 2016.

This method was (similarly to the location quotient) based on the employment data as according to Isaksen (1998), clusters are more probably to be found in the case of extraordinary employment or more concentrated production, which enables the regional specialisation and establishment of local production networks. On the other hand, this analysis was not limited only to industrial sections (even though their dominance was confirmed in the previous chapter), as they can also be effectively supplemented by various commercial or public services.

The wholesale and retail trade section was the most dynamically developed activity in the Banská Bystrica region during 2009–2016, with a regional contribution of +2295 working places (the total employment grew by 8326 employees). Except for the sale of household goods, these activities cover the maintenance of motor vehicles and supplementary trade activities (deliveries assembling, packaging or holding in storage).

Tab. 1. Prospective clusters in the Banská Bystrica region

SECTION/DIVISION	NATIONAL EFFECT	SECTORAL EFFECT	REGIONAL EFFECT	TOTAL
A - Agriculture, forestry and fishing	873	-1858	490	-496
E - Water supply, sewerage, waste management	435	-28	1892	2299
G - Wholesale and retail trade	1867	4163	2295	8326
O - Public administration and defence	2661	-2924	850	587
C24 - Manufacture of basic metals	237	105	1752	2094
C31 - Manufacture of furniture	222	-261	780	741
E38 - Waste collection	162	133	2074	2369
F41 - Construction of buildings	102	-19	2150	2233
G47 - Retail trade	1101	2120	1345	4566

Source: elaborated by the authors based on data of the Statistical Office of the Slovak Republic.

Water supply, sewerage and waste management was the second most important section with a regional contribution of +1892 jobs (although, the total effect on employment was +2299 jobs). In Slovakia as a whole, the wholesale and retail trade utilised the positive growth of the sector (+4163) while the water supply, sewerage and waste management section lost some jobs (-28).

The public administration was the third most dynamic section according to the long-term changes in employment, and thanks to regional shifts, it gained 850 working places. Its employment from the point of view of a sector underwent an annual decline, and this trend pulled the regional employment down (-2924). Thus, the total employment did not increase as intensively (+587) as it was in the case of trade activities (+8326). More results of the analysis are presented in Tab. 1.

The industrial production (C) was not a dynamically developed section but had two dynamic divisions — manufacture of basic metals and manufacture of furniture (confirming the interpretation from the location quotient about the increase of its importance). Also, water supply, sewerage and waste management and the wholesale and retail trade activities had one representative within the group of dynamically developed divisions.

Surprisingly, the second highest regional contribution and regional effect in employment were found in the construction of buildings with the total increase of 2150 workplaces and the total effect of 2233 jobs (although, the sector generally decreased in Slovakia). Waste collection regionally reached +2074 new jobs (confirming that this activity alone helped the development of the whole section E) and the manufacture of basic metals had +1752 jobs. Although the region did not help the development of employment in the retail trade as intensively ("just" +1345 jobs), the division took advantage of the positive national development (+ 1001) and the development of the sector (+2120), thus reaching the total employment increase of 4566 jobs between 2009 and 2016.

Consequently, it can be assumed that quantitative methods can be used to reveal trends and identify extraordinary business concentrations. However, if companies are unable to follow the same path, join forces or have the same vision, no clusters would probably occur despite the potentially favourable environment and intensive employment. Even a somewhat stable industry with a huge regional share of employment (or a dynamic industry with a lower share of employment) can be a good cluster candidate when enough stakeholders are engaged.

As already stated in the literature review, quantitative methods were considered a single part of cluster identification. The forcible support of huge concentrations just because "there are so many businesses" could be misleading. The confrontation with current strategies implemented by national, municipal and regional institutions may significantly change the possibilities to create new clusters. While the national strategy for SMART specialisation (RIS 3) is rather general (focused on manufacturing, key enabling technologies, ICT, services, sustainable innovations) and similar to other European countries, it opens more possibilities for towns and regions to specialise and create their own competitive advantages. Banská Bystrica, as the centre of the region has no specific industrial strategy. Its primary industrial park is open for every investor and currently hosts companies primarily from the pharmaceutical, mechanical engineering and construction industry. Although it fully confirms the results of the analysis and demonstrates the fact that significant employment rates observed in the past are still increasing through the integration of foreign investors, it is rather a coincidence and a result of generic development. Although the forestry or furniture manufacturing is not as intense in Banská Bystrica, it may have more benefits and faster development in smaller settlements (forestry, logging) in eastern districts and the second biggest town of Zvolen and its surroundings.

Conclusions

Despite the clear effects achieved by operating clusters, their support in Slovakia is insufficient, having no systematic approach. Although many official documents declare the importance of clusters in the economic growth and competitiveness as well as the need to support it, the real implementation of incentives aimed at the creation and development of clusters is lagging. Clusters in the Slovak Republic primarily arose as a result of natural needs, especially the sectoral collaboration, rather than a result of targeted state support of cluster initiatives.

The history of clusters in Slovakia is somewhat short: the first cluster was established only in 2004. In 2008, the First Slovak Engineering Cluster in the Banská Bystrica region was established, which only operated for several years. Although there were some other cluster initiatives, up to now, no clusters were officially created in this region. Using the selected methods of prospective cluster identification, the changing potential of industry sectors was analysed, identifying those that promised the highest potential for the cluster establishment in the Banská Bystrica region.

The location quotient and the shift–share analysis are simple instruments used for the identification of prospective clusters within strictly specified geographical areas and selected periods. The undertaken one-time analysis focused on the data of 2012–2016 (with a partial comparison from the point of view of the development in time) was completed with an analysis of dynamics in long-term development. In some sections and divisions, similar results were revealed, while other results significantly varied.

The manufacture of basic metals was a significant industry in terms of regional employment (in all years), and its importance also increased since 2009. Other industries (forestry and logging, manufacture of wood products, manufacture of non-metallic products) were either large employers (in the case of location quotient analysis) or changed dynamically during the time (wholesale and retail, construction, waste collection in the case of the shift–share analysis results). From the point of view of the regional strategy, the forestry and logging and the manufacture of wood products seemed to have received more support, which may boost underdeveloped regions and help with the effort to support the social economy as well as employ people partially excluded from the labour market.

Results of the analysis are strongly influenced by the extent of business activity, total employment, foreign investor contributions, education structures and other factors. In the case of developed regions, the number of potential clusters is much bigger than in the case of underdeveloped regions. The regional effect is three or four times bigger in the case of Bratislava than in the Banská Bystrica region. The shift–share analysis covered the period from 2009 to 2016, so the results were partially influenced by post-crisis development and the performance of some industries may be over-estimated. As the location quotient was calculated for more years, the analysis was able to exclude one-time effects to employment (post-crisis revitalisation, a sudden change of small initial employment, etc.).

As already mentioned, the continuity in the supply chain was not examined and the relations between supplying companies were not revealed. In some industries, the "flow of values" between companies was rather obvious (such as the integration of production and services, or further processing of basic raw materials), but sometimes, the interaction between companies was not known to a neutral analyst. Therefore, expert methods are necessary (panel discussions, case studies, etc.) for a more detailed analysis while the input-output analysis is efficient for the examination of cross-sectional relations, and in the case of geographical proximity, the Ripley's K method could bring interesting results as it considers distances and ignores regional borders.

Cross-sectional industries are frequently ignored by the location quotient and the shift–share analysis as they are not concentrated within the region but spread in more regions (so their employment results are also spread in those regions). This can also be a good opportunity for future research, as then, another type of a cluster may be identified and supported. On the other hand, it gives more possibilities to combined industries compared to a single industry-oriented cluster (INNO, 2010). It is clear that such relations are possible even in the case of the Banská Bystrica region (metals and machines more intensively in the past or wood processing nowadays).

As only the most attractive candidates (in terms of the regional effect) were summarised, some others are considered as not so dynamically developing within the scope of used methods. Regardless, integration of other players into the analysis and full supply chain coverage would characterise the cluster potential from other perspectives. Another possibility might also be given by the evaluation of inter-regional cooperation when the distances between companies are preferred, and administrative regional borders are ignored.

Slovakia is a small country with significant regional disparities. Political decisions made in the past created artificial regions with administrative borders. Thus, many methods bring strictly geographically defined results as the Statistical Office keeps records according to such borders between regions. In the case of areas with huge industrial activity (mostly abroad), it is a common practice to apply such methods within suburban areas or cities. The identified cluster members are clearly heavy concentrated as the area of a city and the area of a region are mostly incomparable (except for large metropolitan areas). On the other hand, the current trend of virtual or knowledge clusters may overcome whatever distance-related effects encountered by companies.

The presented data about the concentration of employment in analysed industries is only one out of many crucial factors, which are necessary for a factual creation and development of an industrial cluster. It is the willingness of member enterprises to cooperate or the level of mutual trust between potential competitors, which could be even more important for the establishment of clusters than the presented results based on the employment concentration.

Research outcomes bring a more scientific approach to the effort to equally develop the whole Banská Bystrica region and support even those parts that are considered underdeveloped. Results reflect the employment concentration and its dynamic development over the period of eight years and are indirectly linked to the current strategy of the Banská Bystrica self-governing region, as they are helping to develop its priorities.

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Gerontechnology — the assessment of one selected technology improving the quality of life of older adults

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ABSTRACT

Older adults experience difficulties in their daily lives as their health deteriorates. Gerontechnology (the compilation of terms “gerontology” and “technology”) helps in the resolution of problems faced by older adults by improving their quality of life and, above all, developing tools to facilitate the access of older adults to all goods, services and infrastructure, which is also the understanding of the term used in this paper. The article mainly aimed to assess the selected gerontechnology that improved the quality of life of older adults in terms of different criteria, namely, innovation, demand, socio-ethics, usability, and functionality. It also analysed whether the respondent's age and gender had any influence on the assessment. Care robots were chosen from among the variety of gerontechnologies. The survey was conducted in the first quarter of 2018 and involved 643 people from different voivodships of Poland. Two types of questionnaires were designed. The electronic form of the survey was distributed using social media and snowball techniques, and the paper form was sent by traditional post to all nursing homes in Poland.

KEY WORDS
technology assessment, gerontechnology, humanoid robots, older adults

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Introduction

At the turn of the 19th and 20th centuries, the average life expectancy barely exceeded 40 years. The percentage of older adults in the total population was minor and equalled 4–6% of people over 60 years of age (Antoszkiewicz, 2014). For several years now, Poland has been faced with the problem of an ageing society. In Poland, the total population is declining, and the percentage of older adults is growing. According to the Central Statistical Office of Poland (GUS), in 2017, Poland had 6 520 247 people over 65 years of age. It is forecasted that in 2050, this number will almost double and reach 11 097 488. The analysis of the Polish demographic structure in terms of age demonstrates that in 2017, older adults constituted 17% of the total population. The Central Statistical

Office of Poland reports that this percentage will be 32.7% in 2050 (United Nations, 2017), which means that one in three Poles will have reached the retirement age. In the current policy, the Polish government gives a serious priority to many initiatives supporting older adults. One of them was responsible for the founding of the Department of Senior Policy at the Ministry of Labour and Social Policy in 2012. The Department focuses on the needs of the older population while creating and developing guidelines, creating conditions for improving the system of support, executing tasks in the area of active ageing and other forms of cooperation as well as monitoring the implemented solutions (website of the Department of Senior Policy). Moreover, in 2014, the government published the document entitled Long-term Senior Policy in Poland for 2014–2020, which included a number of measures aimed at improving the situation of older adults to ensure dignified ageing in good health. Recognising the issue of the ageing society, the government also published the Government Programme for Social Participation of Senior Citizens for 2014–2020. The document lists support areas and directions that foster the achievement of the major objective, namely, improving the quality and level of life of older adults in terms of dignified ageing by means of social activity.

It should be remembered that the increase in the number of older adults is also associated with the need to provide them with institutional support in the form of care, especially in the case of a low level of independence (Polak-Sopinska, 2015). The increasing life expectancy and ageing will also stimulate changes in a family model. A significant part of older people will live separately, often away from their family, and depend on themselves. Lonely people will need full geriatric care offered at home and nursing homes (Ejdys, 2016). It is important, however, to improve the well-being of the society as well as meet the needs of older adults and use their potential. Several researchers focused on exploring new methods to improve the quality of life of older adults and meet their needs by allowing them to remain independent and healthy to the maximum possible extent.

1. Literature review

One of the fields aiming to find answers to the challenges of the population ageing is gerontechnology — an interdisciplinary field of scientific research that uses technology for the aspirations and opportunities of older adults. Gerontechnology is the answer to the needs of older adults concerning their personal development, self-esteem, belonging (which is the main problem due to a drastically reduced number of contacts that causes loneliness), realisation of life plans, adaptation to changing environmental conditions, social expectations, as well as personal capabilities. Gerontechnology is the science of technology and ageing aimed at the improvement of the daily lives of older adults (Graafmans, Taipale & Charness, 1998). In the narrow sense, gerontechnology means technologies that facilitate the access of older adults to all goods, services and infrastructure (Bronswijk et al., 2009). This paper uses a definition of gerontechnology understood as technologies improving the quality of life of older adults and facilitating access to all goods, services and infrastructure for older adults (Bronswijk et al., 2009; Burdick, 2007). Among other things, gerontechnology should enable older adults:

- to prevent problems,
- to increase self-reliance without changing skills and environment,
- to compensate for the loss of options if the facilities are unable to provide them,
- to provide the service only if needed,
- to streamline the existing projects.

In the global literature, research on gerontology focuses on the following issues: (i) analyses of application areas of different gerontological technologies such as health and self-esteem, housing and daily life, mobility and transport, communication and management, work and leisure; the International Society for Gerontechnology); (ii) studies of the attitudes and experiences of older people towards the use of gerontological technologies and the identification of causes that may form the basis for their use or rejection (Chen & Chan, 2013): (iii) technology analysis for four categories of older people's needs: social, medical, activeness and safety (Fozard et al., 2000); (iv) the impact of gerontology on the physical, mental health and social functions of its users (Fozard, 2000; Khosravi et al., 2016; Prada et al., 2018; Fraile et al., 2014; Frisardi & Imbimbo, 2011; Usman et al., 2013; Koops et al., 2013; Piezzo & Suzuki, 2017).

In the Polish literature, gerontology research is causal and most often reproducible based on foreign research results. Wieczorek (2016), for example, reviewed two types of robots used in the care for older adults: assistive robots that were not social robots (e.g. intelligent wheelchairs) and social robots communicating with the user, pointing to examples of their use. Boruta (2017) indicated gerontechnologies as one of the tools for satisfying the housing needs of older people, pointing to the possibility of housing improvements based on the example of model housing for older adults in Warsaw's Bielany (Boruta, 2017). At the same time, the author concluded that the large diversity of needs and expectations of older adults creates the possibility to generate various technological solutions that adequately satisfy these needs. Similarly, Rzeczyński analysed gerontechnologies from an urban perspective (Rzeczyński, 2009). Comparable issues were addressed by Giezek and Iwański, who presented a concept of organising protected and assisted housing for older people requiring support and assistance in everyday life (Giezek & Iwański, 2017).

In order for such technologies to be marketed and used, it is necessary to identify the priority attributes required from technologies that facilitate ageing. These technologies must be assessed in the light of criteria such as their functionality, competitiveness, innovation and socio-ethical aspects. To date, no studies have been carried out in Poland to assess technologies that improve the quality of life of older adults, considering various criteria. No studies have been carried out to check whether age and gender have an impact on the assessment of gerontechnology. The main areas of gerontechnology were, among others, as follow (Obia, Ishmatovab & Iwasakic 2013):

- technologies supporting the functioning of older adults,
- technologies accompanying older adults,
- emotions/mastery over them/recognition and mood regulation,
- personalised adaptation of the environment,
- social/caring cognitive robots and agents,
- technologies guaranteeing entertainment for older adults,
- smart telehealth, telemedicine and communication services,
- social networks for older adults.

This paper presents the results of the assessment, depending on the age and gender of the respondent, of one gerontechnology, namely, social/supporting humanoid robots used in the care for older people.

Robots can be used by older adults to capture, transmit, recall information related to the use of medication, recognise and assess health, monitor and motivate walking, and meet social needs through interaction (Broadbent et al., 2009; Broekens et al., 2009; Ejdys & Gdvilaite, 2017; Flandorfer, 2012; Grant et al., 2004; Piezzo & Suzuki, 2017). Given the technological potential of robots and the rate of the ageing of the population in the near future, robots may start being used for helping people to care for older adults and offer some company for this group of the population (Ejdys & Halicka, 2018; Choi et al., 2014; Klamer & Allouch, 2010; Martinez-Martin & del Pobil, 2018; Pollack et al., 2002; Usman & Tomimoto, 2013). The literature studies and exploratory research conducted so far allow the following research questions to be formulated:

- How the technology has been assessed against different criteria?
- Does age influence the assessment of humanoid robot technologies used in the care for older adults?
- Does gender influence the assessment of humanoid robot technologies used in the care for older adults?

2. Research methods

Based on the literature review, five groups of technology assessment criteria were selected: innovation, demand, socio-ethics, usability, and functionality (Ejdys, 2015; Nazarko et al., 2015; Radziszewski et al., 2016). The criteria were formulated in the form of statements. The authors prepared the catalogue of criteria consisting of 27 statements, which included seven concerned marketing aspects (D1—I D7) and five of each of the following: technology innovation (I1—I5), socio-ethical aspects (S1—S5), usability (U1—U5) and technology functionality (F1—F5). To assess the technology, questionnaire surveys were used. The research was conducted on a sample of 643 Poles between March and April 2018. The respondents represented all the voivodships of Poland. The respondents evaluated the assessment of the analysed technology using the 7-point Likert scale, where 1 meant "it definitely means I do not agree with the given statement" and 7 — "I definitely agree." Considering the fact that not all respondents were familiar with the concept of a humanoid robot, it was replaced with the term "robot" in the questionnaire. In the sample structure, 32.7% (210) of people were aged 18–25, 24.9% (160) were 26–40, 25.8% (166) were 41–60 and 16.4% (107) were over 60. All in all, 42% (270) respondents were men, and 58% (373) were women.

Initially, the respondents assessed the technology in terms of such criteria as innovation, demand, socio-ethics, usability, and functionality (step I).

It was further examined whether the age and gender of respondents influenced the assessment of the humanoid robots used for the care of the older adults in terms of demand and the socio-ethical aspect (step II). The level of demand for this technology was verified using seven statements (Halicka, 2017; Nazarko, 2017): D1: On the part of older adults, there is a need for care robots supporting the older adults; D2: On the part of family members, there is a need for care robots supporting the older adults; D3: On the part of institutions responsible for the care of the older adults (e.g. nursing homes), there is a need for care robots supporting the older adults; D4: The use of robots for the care of the older adults will be a source of additional benefits for their users (24-hour attendance, 24-hour care, a sense of security), which are unavailable through other solutions; D5: The global demand for care robots supporting the older adults is associated with temporary fashion; D6: Using a robot to care for an older adult will not require new, specialist knowledge; D7: The robot's appearance will have a significant impact on the scale of its use in everyday life. In turn, in socio-ethical terms, this technology was evaluated using the following five statements: S1: The widespread use of robots in the care of the older adults will bring measurable social benefits; S2: The widespread use of robots in the care of the older adults will create new jobs; S3: The widespread use of robots in the care of the older adults will bring measurable benefits to human health and the quality of human life; S4: The widespread use of robots in the care of the older adults can be a source of social problems; S5: The widespread use of robots in the care of the older adults can be the cause of moral dilemmas and doubts as to whether robots can be entrusted with the care for the older adults.

3. Research results

Firstly, the respondents rated the technology in terms of its innovativeness. Then, the respondents assessed the technology in terms of demand. The respondents also made a technology assessment in terms of socio-ethical aspects and usability. Then, average scores of technologies of personal care robots for older adults in terms of the innovation criterion, demand, socio-ethical aspects, usability and functionality were calculated based on individual data (Fig. 1).

According to Fig. 1, the technology was ranked the best in terms of its functionality. The average assessment of respondent compliance with claims regarding the functionality of the technology was 5.82 (on a scale from 1 to 7). On the other hand, the average assessment of respondent compliance with statements regarding innovation amounted to 4.87. Respondents also highly rated the technology of personal care robots for older adults in terms of demand. The average of respondent compliance assessments with this regarding the above-mentioned criteria was 4.57. In turn, the lowest score was given to the technology in terms of socio-ethical aspects. The average assessment of respondent compliance with statements regarding socio-ethical aspects was 3.69.

Next, it was checked whether the age and gender of respondents influenced the technology assessment.

A critical significance level was assumed at $p = 0.1$. The non-parametric Mann-Whitney U test (Wilcoxon, 1945; Mann & Whitney, 1947) was used to study the effect of gender on the technology assessment. In turn, the ANOVA Kruskal-Wallis test was used to examine the influence of age on technology assessment. The Statistica 13 software was used in the research.

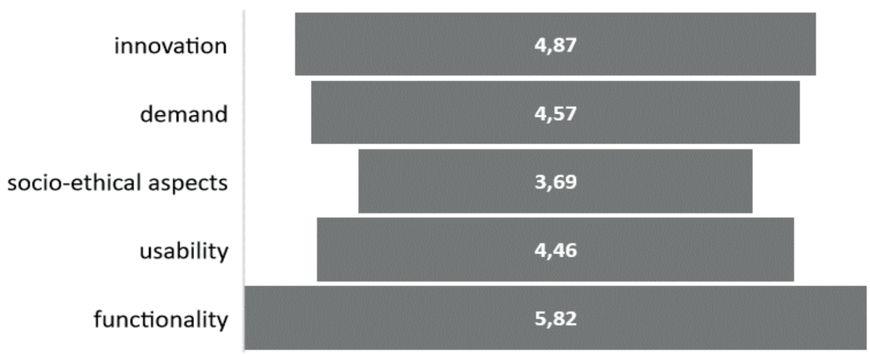

Fig. 1. Collective assessment of the technology of personal care robots for older adults in terms of the innovation criterion, demand, socio-ethical aspects, usability and functionality

Tab. 1. Values of statistics for technology assessment of personal care robots for older adults in terms of demand

Acronym	Statistics of the Mann–Whitney U test		Statistics of the ANOVA Kruskal–Wallis test	
	U	p	T	p
D1	47108.00	0.162578633	11.18819	0.0108
D2	48041.00	0.319672595	12.73677	0.0052
D3	49822.50	0.818997074	4.385920	0.2227
D4	49117.50	0.594667432	3.812452	0.2824
D5	49203.50	0.620534872	7.994963	0.0461
D6	44379.50	0.0101674892	3.775917	0.2867
D7	44966.00	0.0204598559	19.69931	0.0002

Tab. 2. Values of statistics for the technology assessment of personal care robots for older adults in terms of socio-ethical aspects

Acronym	Statistics of the Mann–Whitney U test		Statistics of the ANOVA Kruskal–Wallis test	
	U	p	T	p
S1	47890.5	0.289205106	7.925149	0.0476
S2	45829.5	0.051608717	9.091852	0.0281
S3	45462.00	0.035338459	11.10373	0.0112
S4	48663.5	0.467000255	2.767013	0.4290
S5	50338.5	0.994508795	2.094907	0.5529

Initially, the respondents assessed the demand for technologies. The values of statistics for technology assessment in terms of demand are presented in Tab. 1.

Analysing Tab. 1, it can be noticed that the significant gender differences in the assessment of the level of demand for personal care robots for older adults ($p < 0.1$) only occur in the case of statements D6 and D7. According to Tab. 1, statistically significant differences depending on the age occur in the case of acceptance of drivers D1, D2, D5 and D7 ($p < 0.1$). In the case of other statements, no significant differences were observed between the assessment of these statements and age.

The respondents also assessed the technology in terms of socio-ethical aspects (Tab. 2).

Analysing Tab. 2, statistically significant differences in relation to gender in the assessment of this technology in terms of social-ethical aspects occur in the case of assessing statements S2 and S3 ($p < 0.1$). However, statistically significant differences depending on age occur in the case of acceptance of statements S1, S2 and S3 ($p < 0.1$). In the case of other statements, no significant differences were observed between the assessment of these statements and age.

4. Discussion of the results

Detailed analysis of the responses in the context of the demand for technology revealed that men found the appearance of a robot more important than women (D7). The average value of answers for men was 5.3 while it amounted to 4.9 for women (Fig. 2). There were also different opinions — depending on the sex — in the assessment of the statement D6: Using a robot to care for an older adult. The average value of answers was 3.8 for men and 3.3 for women.

Fig. 3 graphically illustrates the values of the acceptance response of selected statements (statistically significant) regarding the technology assessment of personal care robots for older adults in terms of demand in four age groups.

The analysis of Fig. 3 revealed the smallest acceptance of the D1 statement occurring among respondents aged 41‑60 (the average score of 3.3), and the largest among the participants aged 26‑40 (the average assessment of the D1 statement amounting to 4.1). On the other hand, the D2 statement had the lowest acceptance among people over 60 (the average grade of 4.3), and the largest among the youngest participants of the study (the average grade of 5.3). In the case of people aged 18‑25 and 41‑60, the accep-

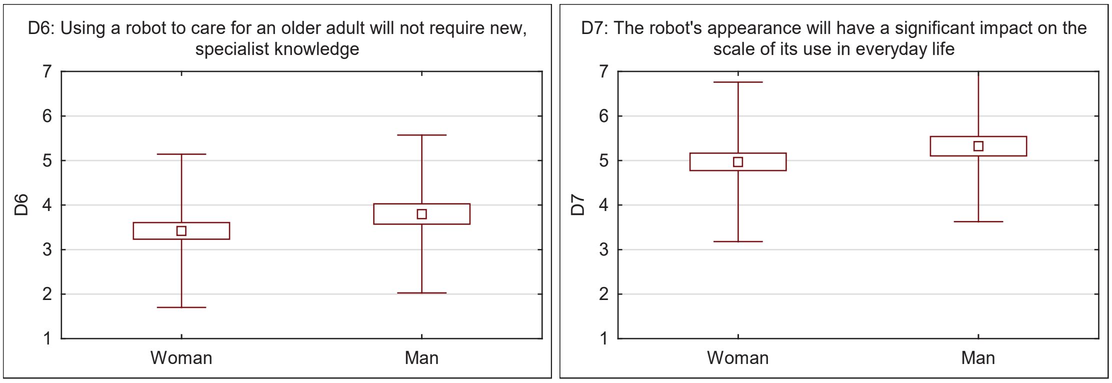

Fig. 2. Technology assessment of personal care robots for older adults in terms of demand in gender groups — selected answers

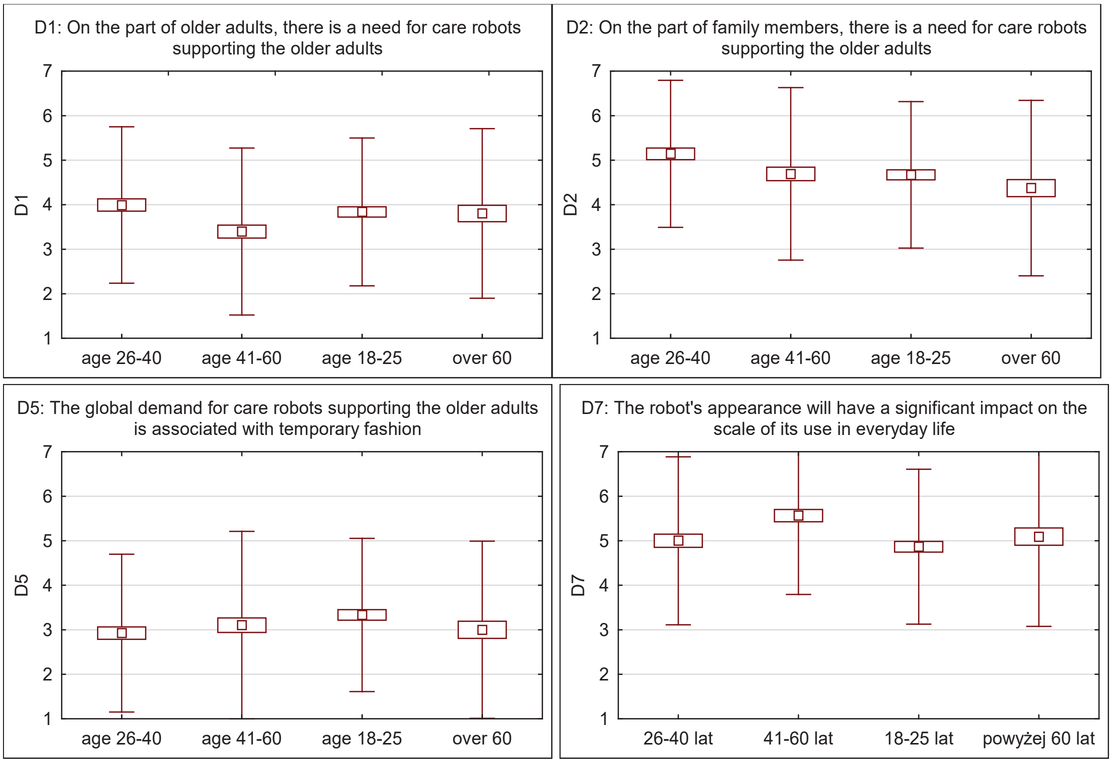

Fig. 3. Technology assessment of personal care robots for older adults in terms of demand in four age groups — selected answers

tance of this statement was similar (the average grade of 4.7). The D5 statement enjoyed the highest acceptance among people aged 18–25 (the average grade of 3.4). The lowest assessment was given by respondents of 26–40 (the average grade of 2.8). In turn, the D7 statement was rated the lowest by the youngest respondents (the average grade of 4.8), and the highest by respondents aged 41–60 (the average grade of 5.6).

On the other hand, analysing the responses regarding the assessment of technology in terms of social-ethical aspects, it was noticed that the acceptance of S2 was greater among men than women: the widespread use of robots in the care of the older adults would contribute to the creation of new jobs (the average assessment for S2 was 3.4 for men and 3.1 for women). The average score for the S3 statement (The widespread use of robots in the care of the older adults will bring measurable benefits to human health and the quality of human life) was also statistically significant and amounted to 4.7 for men and 4.2 for women (Fig. 4).

Fig. 5 graphically illustrates the response values for the socio-ethical aspects in four age groups. The analysis of Fig. 5 showed that the smallest acceptance of S1 was found among respondents aged 18–25 (the

Fig. 4. Technology assessment of personal care robots for older adults in terms of socio-ethical aspects in gender groups — selected answers

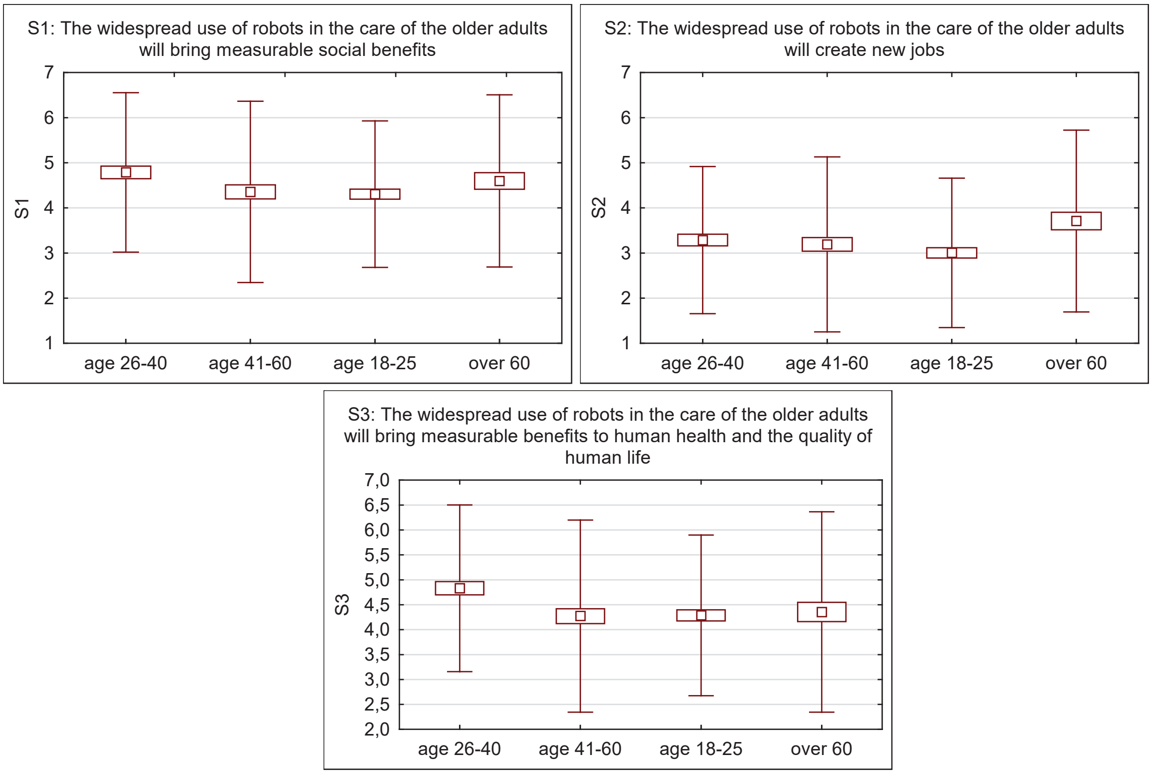

Fig. 5. Technology assessment of personal care robots for older adults in terms of socio-ethical aspects in four age groups — selected answers

average grade of 4.3) and 41–60 (the average grade of 4.3), while it was the largest among participants aged 26–40 (the average grade of the S1 statement amounting to 4.9). On the other hand, the S2 statement enjoyed the highest acceptance among people over 60 (the average grade of 3.8), even though it was the lowest among the youngest participants of the study (the average grade of 3.0). Statement S3 had the highest acceptance among people aged 26–40 (the average grade of 4.9). It received the lowest assessment from respondents aged 41–60 (the average grade of 2.9) and 18–25.

Conclusions

This article assesses technologies of personal care robots for older adults in different terms. The main premise of the research was searching for answers to the following questions: (1) How the technology has been assessed against different criteria? (2) Does age influence the assessment of humanoid robotic technologies used in the care for older adults? (3) Does gender influence the assessment of humanoid robotic technologies used in the care for older adults?

Based on the conducted research, it can be concluded that the technology of personal care robots for older adults has been rated the highest in terms of functionality. This technology was also highly rated in terms of innovativeness and demand. The lowest score was given for this technology in terms of socio-ethical aspects. Considering the average values of the survey results, it should be stated that the assessment of this technology in terms of demand as well as socio-ethical aspects is influenced by the age and gender of respondents. A conclusion can be made with a probability of 90% that the gender of a respondent influences the assessment of technology in terms of technology demand and socio-ethical aspects. The results of the research also allow making an observation with the same probability of 90% that the age of a respondent influences the assessment of technology in terms of socio-ethical aspects.

The results of the research tasks described in this article can be used as a knowledge base for the development of technology cards of humanoids used in the care for the older adults. In the cards, it is possible to collect and organise the most important information regarding the analysed technology, improving the quality of life of older adults.

Further scientific activities will include research efforts into the preparation of technology development paths that improve the quality of life of older adults. Various aspects will be considered, including usability, functionality and trust. In addition, other gerontechnologies will be identified and assessed in further research. A ranking of the best gerontechnologies will then be developed using-multi attribute decision-making methods.

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Fourth industrial revolution: a way forward to attain better performance in the textile industry

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ABSTRACT

The textile industry is one of the fastest growing industries which expressively contributes to the economic growth of Malaysia. However, in recent years, the situation has changed and demonstrates a downward trend. The imports are growing faster compared to the exports, consequently resulting in a low contribution to the gross domestic product (GDP). To address the issue, this study aims to investigate the role of Industry 4.0 on the performance of firms engaged in the production and services of the Malaysian textile industry. To achieve the objective, this study adopted a cross-sectional research design. A survey was carried out to collect data from employees of textile firms. Results of the study found that Industry 4.0 positively contributed to the effectiveness of the production and services of the textile industry. Production and services have a positive role in the performance of textile firms. The current study provides an interesting insight into the future direction of research for studies on organisational performance, which can be extended to different manufacturing-based industries. In addition, it provides the rationale for the adoption and implementation of smart technologies in these industries. It has been found that cyber-physical systems (CPS), interoperability, a smart city and a smart product have a positive effect on production and services. Additionally, it is not possible without the effective implementation of technology. Thus, the current study provides valuable insights into the improvement of the textile industry's performance.

KEY WORDS

Industry 4.0, firm performance, cyber-physical systems, interoperability, smart product; smart city

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Introduction

The fourth industrial revolution is most significant in having the latest technology, which leads to improved performance. This industrial revolution has a key role in the attainment of higher performance (Lalic et al., 2017; Nagy et al., 2018; Sandengen et al., 2016; Tonelli et al., 2016) by promoting production and services in an organisation. Industry 4.0 provides the latest technology for the manufacturing process, which promotes organisational performance. It can also deliver improved services through the latest and unique technology. Therefore, the fourth industrial revolution is key to the promotion of organisational performance.

Industry 4.0 has important elements, such as big data, cyber-physical systems (CPS), the interoperability, the Internet of Things (IoT) and a smart city. The industrial revolution is mostly based on these five factors. However, the current study examined the effect of three major factors, namely, CPS, the interoperability and a smart city (a smart factory, a smart product) on the production and services of textile companies in Malaysia. These three elements of Industry 4.0 (CPS, the interoperability and a smart city) have a significant role in production and services. It should be mentioned that Industry 4.0 has a major role in boosting the manufacturing process of various industries (Gentner, 2016; Theorin et al., 2017; Zheng et al., 2018; Alaeddin et al., 2018; Ślusarczyk, 2018; Muzekenyi et al., 2019).

This study considered the textile industry of Malaysia. The textile industry is one of the fastest growing industries which expressively contribute to the economic development of many countries, including Malaysia (Pang & Abdullah, 2013; Meyer & Meyer, 2016), where this industry makes a significant contribution to the GDP. In Malaysia, the contribution of the textile and apparel industry to the GDP amounts to approx. 1.2% (Ali & Haseeb, 2019). Therefore, this industry is significantly important for the economy.

However, in recent years, the situation has been changing, and performance has been decreasing. In Malaysia, this industry has been demonstrating the greater growth of imports compared to the exports, which resulted in the decrease of the contribution to GDP between 2015 and 2016 (Ali & Haseeb, 2019). The performance of the Malaysian textile industry from 2006 to 2016 is presented in Tab. 1. This shows the decreasing trend in exports and the increasing trend in imports. The increase in imports and the decrease in exports have a negative effect on the overall performance. Aiming to improve perfor-

Tab. 1. Malaysian textiles and apparels trading (2006–2016)

Year	Import	Export	Balance
2006	6	10.9	4.9
2007	5.6	10.3	4.7
2008	5.4	10.5	5.1
2009	4.4	8.93	4.53
2010	5.65	9.33	3.68
2011	8.17	10.81	2.64
2012	8.91	9.46	0.55
2013	8.78	10.25	1.47
2014	9.1	11.03	1.92
2015	14.93	11.9	***-3.03***
2016	16.4	12.06	***-4.34***

Source: elaborated by the authors based on (Ali & Haseeb, 2019).

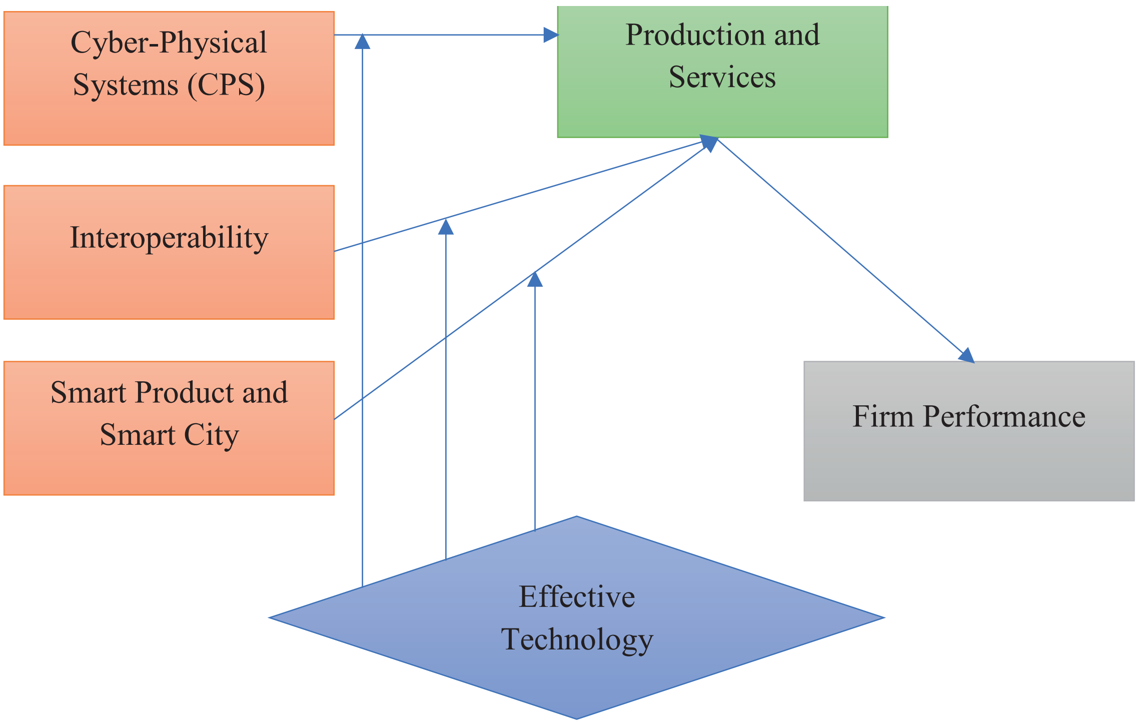

Fig. 1. Theoretical framework of the study showing the relationship between Industry 4.0, production, services, technology implementation and firm performance

mance, a balance should be ensured between exports and imports. In this case, Industry 4.0 has the features to control the decreasing performance of the Malaysian textile industry performance as the features of Industry 4.0, such as CPS, the interoperability and a smart city (a smart factory, a smart product), have a positive effect on the production and services of textile companies.

Many researchers investigate the manufacturing of the textile industry (Bryson & Ronayne, 2014; Cancer, 1990; Dabas et al., 2019; Magnani et al., 1993; Rai et al., 2005); however, studies rarely document the role of Industry 4.0 in the production and services sector of the textile industry. Therefore, a gap exists in the body of literature. Hence, this study investigated the effect that Industry 4.0 has on the performance firms acting in the Malaysian textile industry.

The theoretical framework of the current study is presented in Fig. 1. It shows the relationship between Industry 4.0 (CPS, the interoperability, a smart city, a smart product), production, services, technology implementation and firm performance. The objective of this study is to investigate the role of Industry 4.0 on the performance of firms based on the production and services of the Malaysian textile industry. The selection of the textile industry is further motivated by the literature, which maintains that the adoption of Industry 4.0 solutions tends to give rise to barriers, such as uncertainties, to the potential financial benefit as well as the lack of specialist knowledge (Küsters, Praß & Gloy, 2017). Additionally, this study has two sub-objectives: 1) to examine the mediating role of production and services, and 2) to examine the moderating role of effective technology implementation.

The rest of the paper is organised in the following manner: Section 1 reviews the relevant literature to develop the hypotheses; Section 2 describes the methodology used in the study; Section 3 presents the results of the analysis; and Section 4 provides the implications of the results, which are discussed. The final section concludes the study and discusses its main contributions.

1. Literature review

As an evolving piece of technology, Cyber-Physical Systems (CPS) are likely to provide capable solutions to the conversion of processes in a company as well as play a role in numerous current industrial arrangements (Bondar et al., 2017; Gürdür, El-Khoury et al., 2016; Mao et al., 2016; Yan et al., 2015; Zhai et al., 2016). The present research study has evaluated thirteen articles shown in Tab. 2, which researched CPS — systems related to the industry automation that combine different innovative functions with the support of networking to allow linking of the operations with better computing as well as communication substructures (Bagheri et al., 2015; Branger & Pang, 2015; Jazdi, 2014; Shafiq et al., 2015).

Shafiq et al. (2015) described CPS as "the convergence of the physical and digital worlds by establishing global networks for a business that incorporate their machinery, warehousing systems and production facilities" (p. 1149). Monostori et al. (2016), on the other hand, noted that "CPS are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet" (p. 621). CPS are comprised of micro-controllers that handle the devices as well as actuators. Data and knowledge are replaced among various embedded terminals of computers, with various applications of wireless, houses, or clouds. The multifaceted, dynamic as well as combined CPS will cooperate to produce an analysis related to planning, various designs of modelling, implementation and preservation in the manufacturing procedure. All these procedures show a positive effect on manufacturing performance. It also positively affects the service performance of a company.

Based on combined information regarding CPS, decentralisation and independence play vital roles in increasing the complete industrial performance (Iva-

Tab. 2. Studies on a smart factory and manufacturing

Research Category	Publication
CPS of Industry 4.0	Bagheri et al. (2015)
	Brettel, Friederichsen, Keller & Rosenberg (2014)
	Harrison, Vera & Ahmad (2016)
	Ivanov, Dolgui, Sokolov, Werner & Ivanova (2016)
	Ivanov, Sokolov & Ivanova (2016)
	Jazdi (2014)
	Kobara (2016)
	Lee, Bagheri & Kao (2015)
	Georgakopoulos, Jayaraman, Fazia, Villari & Ranjan (2016)
	Pérez, Irisarri, Orive, Marcos & Estevez (2015)
	Schuster et al. (2015)
	Shafiq, Sanin, Szczerbicki & Toro (2016)

nov et al., 2016). The systems of CPS are skilled in enhancing output, increasing development, adapting the performance of company workforce, and constructing high-quality goods with minor costs by gathering and examining information (Rüßmann et al., 2015), which positively affects the performance of companies. Jazdi (2014) showed the CPS application by demonstrating its features, work procedures, and various advanced methods. Ivanov, Dolgui et al. (2016) claimed that various frameworks were required in CPS to manage actions in different manufacturing measures and to maximise production. According to the latest grounded features, CPS can improve the management of production and services.

According to Shafiq et al. (2015), the joint structure of Virtual Engineering Objects (VEO), Virtual Engineering Factory (VEF) and Virtual Engineering Process (VEP) is a particular method of CPS. VEO is a process of information conversion and data retrieval, in which one could reuse the experience of engineering objects as well as further advance the process of making key decisions in the industrial design and manufacturing (Schuster et al., 2015; Shafiq et al., 2015). VEO participates in IT classifications at diverse classified levels through a production procedure. Additionally, it can contribute to CPS by providing it with more flexibility as well as readjust the product-making procedure. It is an important arrangement that makes steps towards active knowledge management and plays a significant role in factory management (Posada et al., 2015). VEP is an effective representation of knowledge of a manufacturing procedure with all required operational information, while VEF is a representation of the experience-based information of an engineering factory. According to Shafiq et al. (2015), the three important elements must be combined to build Industry 4.0 as well as to attain an advanced level of smart machines with progressive analytics.

In the future, critical tests should be offered to experts to device CPS and to advance them more consistently. As mentioned in the literature regarding the development of wireless communication and different sensor network know-hows, CPS will develop an immense influence on new and latest ICT. Jazdi (2014) described that further improvement of CPS requires to focus on distributed remote application implemented by software agents. According to Monostori et al. (2016), CPS and the cyber-physical production systems (CPPS) of Industry 4.0 will be initiated and implemented by the development of computational entities. They additionally explained that in production organisations, physical manufacturing would be controlled by integrated CPS as the latest series of industry. CPPS includes humans, different types of machinery and various products, networking with physical procedures used in manufacturing to make the production more cost and time effective with extremely capable services and products (Albers et al., 2016). Therefore, CPS is one of the important systems which can control manufacturing. It is capable enough to handle the production process in organisations and to have a positive effect on performance. Pérez et al. (2015) suggested an agenda for CPPS for health care.

Currently, a forward perspective is focused on the creation of a network of VEO, which has extensive applicability of an engineering artefact integrating dual computerised and real-world representation, including complex multitasking machines (Brettel et al., 2014; Posada et al., 2015). Independent information exchange is activated by real and computer-generated production. A VEO can add, supply, advance, and provide knowledge using an effective manufacturing arrangement (Shafiq et al., 2015).

Cyber-Physical Systems (CPS) play a significant role in an organisation through various facilities, such as production and services (Jiang et al., 2016; Lee et al., 2015; Zhang et al., 2017; Zühlke & Ollinger, 2011). They also have a positive role in the improvement of performance (Mo & Sinopoli, 2016). Therefore, CPS are the most important element of Industry 4.0, which positively affects production and services.

H1. CPS has a relationship with production and services

Industry 4.0 has major elements, including integration and interoperability (Chen, Doumeingts & Vernadat, 2008; Romero & Vernadat, 2016). Combined with various software arrangements, Industry 4.0 will attain unified operations across company limitations and will understand interacted organisations (Smirnov et al., 2013). Interoperability is the main benefit of Industry 4.0. Chen et al. (2008) described that interoperability is "the ability of two classifications to understand each other and to use the functionality of one another". It signifies the competence of two systems to replace data and distribute knowledge. The interoperability related to Industry 4.0 will manufacture software elements, solutions of various types of application, business procedures, and the business framework through the expanded, heterogeneous, as well as autonomous process (Berre et al., 2007).

The construction of the interoperability comprises four different levels: operational, systematic, technical, and semantic interoperability (Gorkhali & Xu, 2016; Sowell, 2006). Precisely, the operational interoperability demonstrates overall structures of ideas, values, languages, as well as associations within CPS and fourth revolution. The systematic interoperability classifies the procedures of different methodologies and various domains. The technical interoperability articulates various tools providing the opportunity for technical development, IT systems and effective communication for support. The semantic interoperability confirms knowledge transfer among different groups of people, applications, and numerous levels of institutions. These different stages of operation make the fourth revolution and CPS more industrious and cost-effective. The interoperability framework of Industry 4.0 is presented in Fig. 2.

Previous studies have shown that Industry 4.0 is based on three major frameworks, namely, "Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR); Interoperable Delivery of European eGovernment Services to public Administrations, Business and Citizens (IDABC); and Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Applications (ATHENA)" (Sowell, 2006). Various previous studies on interoperability are provided in Tab. 3.

C4ISR Architecture Framework was established by the Department of Defence of the United States in 1996 to assimilate the associations, principles, and various strategies of the US military. It is one of the operational, systematic, as well as technical views on the latest technology. The operational assessment designates the nature of the required information and knowledge transfer in detail for the objective of defining the required degree of information-exchange interoperability (Sowell, 2006). The methodical view first classifies the essential supports for the system, then interprets the essential degree of interoperability in various system competences, and lastly associates executions with the required capabilities (Sowell, 2006). The technical view details the criteria required to administrate the compliant implementation of each essential system capability (Sowell, 2006). The purpose of C4ISR is to guarantee the integration and interoperability of different levels. Eventually, the interoperability could achieve views that are integratable and comparable across international organisational boundaries.

Another part of the interoperability is IDABC. European Interoperability Framework (EIF) Version 1.0 delivers a reference on interoperability for the IDABC program and offers various e-government

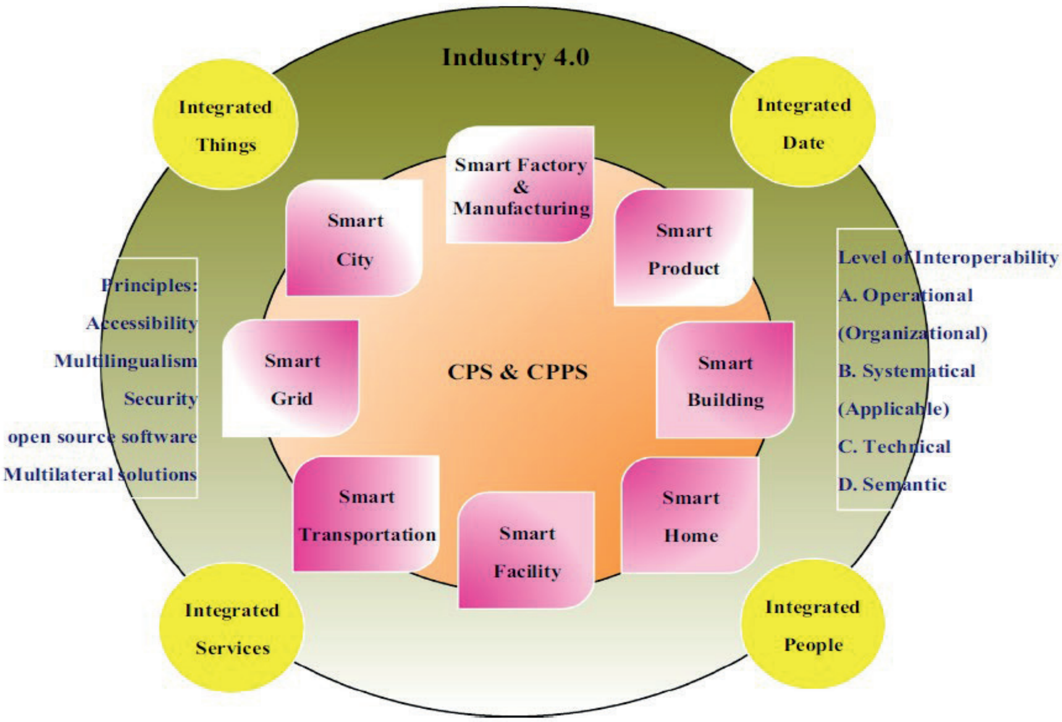

Fig. 2. Framework of interoperability of Industry 4.0
Source: adapted from (Lu, 2017).

Tab. 3. Studies on interoperability

Research Category	Publication
Interoperability of Industry 4.0	Berre et al. (2007) D. Chen et al. (2008) Gorkhali & Xu (2016) Geraci et al. (1991) Lu (2017) Romero & Vernadat (2016) Smirnov et al. (2013) Sowell (2006)

services to peoples as well as enterprises. The EIF framework achieves interoperability with the help of various technical and semantic elements. Organisational interoperability identifies the performers as well as organisational procedures; technical interoperability describes various benchmarks with protocols for the incorporation of technology systems; and semantic interoperability ensures the knowledge transfer among involved people, applications and institutions (Bornman & Puth, 2017). Interoperability has an important role in an organisation through smart products (Schmidt et al., 2015; Thoben et al., 2014; Zug et al., 2015).

These technologies have a positive effect on manufacturing as the latest technology always does (Colombo, Loncan & Caldeira, 2018; Ghani et al., 2003; Hettiarachchi et al., 2007; Hounshell, 1985; Tracey, Vonderembse & Lim, 1999). Consequently, the interoperability of Industry 4.0 also has a positive effect on manufacturing. A positive effect on manufacturing automatically increases organisational performance. Interoperability is based on the latest IT capability and technologies which, in their turn, positively affect the performance. The literature states that the IT capability of the latest technology has a positive effect on organisational performance (Adner & Kapoor, 2010; Aral & Weill, 2007; Benitez-Amado & Walczuch, 2012; Rivard, Raymond & Verreault, 2006; Stoel & Muhanna, 2009).

H2. Interoperability has a relationship with production and services.

A smart city is "a city that comprises six factors in its development policy: smart economy, smart mobility, smart environment, smart people, smart living, and smart governance". Joining the internet, a communications network and the Internet of Things (IoT) will expedite the growth of the latest technology (Roblek, Meško & Krapež, 2016; Tang, 2015). According to Lom, Pribyl and Svitek (2016), a smart city includes a technical discipline and different economic as well as humanitarian aspects. Within a smart city, people change from operators to important stakeholders. In this process, effective technology works like a dynamic enabler and businesses become as partners. The process of production is founded on demand orientation strategies, and transport is one of the smart services with progressive development, effectiveness, and success. The aim of a smart city is to guarantee the sustainability of different cities, to advance the quality of life as well as security and to deliver energy efficiency. Still, the transformation of a traditional city into a smart city takes much time. Additionally, Branger (2015); Branger and Pang (2015) offered a good communication structure for assimilating services in automatic homes. Studies on the smart city are presented in Tab. 4.

Various studies address a smart product — a product related to a smart factory and supported by different sensors and microchips, i.e., various products which make Industry 4.0 smarter (Cao et al., 2015). Industry 4.0 comprises information and communication technology, IoT, CPS, data combination, uniform control and permits humans to interconnect with different products (Schlechtendahl et al., 2015; Schmidt et al., 2015; Thoben et al., 2014). The current manufacturing arrangements require to be combined with Industry 4.0 features. According to Schuh et al. (2015), integrated working and knowledge acquisition is an actual way to improve the performance of Industry 4.0.

Tab. 4. Studies on Smart City

Research Category	Publication
Smart City of Industry 4.0	Lasi, Fettke, Kemper, Feld & Hoffmann (2014) Lom et al. (2016) Tang (2015) Roblek et al. (2016)

Industry 4.0 delivers new technologies in manufacturing (Bagheri et al., 2015; Berre et al., 2007; Schuh et al., 2015). It includes progressive automatic, information and knowledge and real-time accepted production measures (Biao et al., 2016). Therefore, smart products must be shaped based on the latest electronic (digital) technologies and physical procedures (Schmidt et al., 2015). Various features, such as big data, cloud computing, IoT, and improvement in the time of production are offered to control the growth of the fourth revolution (Schmidt et al., 2015). The application in the textile industry has seen the development of clothing capable of measuring various health parameters such as burnt calories, heart

rate, movement etc. (Pang et al., 2015; Roblek et al., 2016).

According to Schlechtendahl et al. (2015), the growth of Industry 4.0 is a procedure that combines the smart production system. As further explained by Gorecky et al. (2014), a cyber-physical construction and user-focused support arrangements offer boundaries to an intelligent user. Additionally, a strategic production preparation procedure is suggested grounded on the central values of integrated design to bring together diverse design, as well as procurement for long-term preparation investment. Another study by Monostori et al. (2016) offered a method grounded on knowledge exchange for evolving production schemes for Industry 4.0.

Therefore, both a smart city and a smart product has a significant role in production and services. A smart factory and a smart product are parts of a smart city. And a smart factory has a significant role in the manufacturing process of a company (Chu et al., 2016; Davis et al., 2012; Kokuryo et al., 2016; Longo, Nicoletti & Padovano, 2017). Previous studies on a smart factory are shown in Tab. 5. Therefore, smart city and smart product have an important role in production and services.

Tab. 5. Studies on a smart factory and manufacturing

Research Category	Publication
Smart Factory and Manufacturing	Chen & Xing (2015) Kolberg & Zühlke (2015) Oses, Legarretaetxebarria, Quartulli, García & Serrano (2016) Paelke (2014) Pisching, Junqueira, Santos Filho & Miyagi (2015) Rüßmann et al. (2015) Wang, Wan, Zhang, Li & Zhang (2016) Sanders, Elangeswaran & Wulfsberg (2016) Scheuermann, Verclas & Bruegge (2015) Thames & Schaefer (2016)

H3. A smart city and a smart product have a relationship with production and services.

The discussion provided above highlighted that Industry 4.0 (the interoperability, Cyber-Physical Systems, a smart city, a smart factory) has a significant relationship with the production and services of a company. A better implementation of Industry 4.0 has a major role in increasing the quality and efficiency of production and services. An increase in the production and services of a company has a direct effect on their performance (Haseebet al., 2019).

Better production and services lead to higher performance. As revealed by previous studies, production and services have a positive relationship with organisational performance (Gray & Hooley, 2002; Hong, Kim & Cin, 2015; Kastalli & van Looy, 2013). Therefore, companies must develop a good production system. Good production also leads to customer satisfaction, and an increase in customer satisfaction improves organisational performance (Saeidi et al., 2015; Sun & Kim, 2013; Zhao, Dröge & Stank, 2001). Thus, as revealed by previous studies, production and services have a major role in organisational performance. In the context of this study, Industry 4.0 factors, such as the interoperability, Cyber-Physical Systems, a smart city and a smart product, have a positive effect on production and services. Besides, production and services improve organisational performance. The implementation of these has also been found to improve energy efficiency in the textile industry, leading to improved organisational performance (Park et al., 2019).

H4. Production and services have a relationship with organisational performance.

H5. Production and services mediate the relationship between CPS and organisational performance.

H6. Production and services mediate the relationship between interoperability and organisational performance.

H7. Production and services mediate the relationship between a smart city, a smart product and organisational performance.

No doubt, Industry 4.0 has the latest technology. However, companies cannot benefit from the latest technology until they implement it properly. Companies must ensure proper implementation of Industry 4.0 to maximise its benefits. According to different studies, the implementation of technology is crucial (Müller, Kiel & Voigt, 2018; Oesterreich & Teuteberg, 2016; Tortorella & Fettermann, 2018; Zawra et al., 2017).

Many companies faced problems related to technology implementation. A successful technology implementation unit offers consistency to the IT unit and makes the complementary view of technology to ensure the best management (Hu & Huang, 2005; Nii, Earl & Ross, 1996; Reich & Benbasat, 2000). Similarly, it fundamentally adds to the influence of business directors in the positioning of the process (Teo & Ang, 1999). For the preparation of business designs, two success features are vital, which are the validation of best management in the IT division, and reliable administrations (Luftman, Lewis & Oldach, 1993). Teo and Ang (1999) theorised that the confirmation of the best management in technology ensures the strategic use of technology, making it bound to distribute assets required for the arrangement as well as the development of IT applications. Furthermore, organisational performance in the textile industry can potentially benefit from technology implementation due to the accelerated design process as well as potential costs savings associated with packaging and transportation (Dilberoglu, Gharehpapagh, Yaman & Dolen, 2017).

H8. Effective technology implementation has a relationship with organisational performance.

H9. Effective technology implementation moderates the relationship between CPS and organisational performance.

H10. Effective technology implementation moderates the relationship between interoperability and organisational performance.

H11. Effective technology implementation moderates the relationship between a smart city, a smart product and organisational performance.

2. Research methods

Research designs are included plans as well as the procedures for research that span the decision from broad assumptions to detailed methods of data collection as well as data analysis techniques. In the area of social science studies, there are three main research approaches in the educational sector, which are 1) quantitative, 2) qualitative, and 3) mixed methods (Creswell, 2009). The current study adopted the quantitative approach. It is one of the most suitable approaches in the case of hypothesis-testing based on primary data. Additionally, this study used a cross-sectional research design.

For this purpose, a survey was carried out to collect the data. Textile companies of Malaysia were used as the population of this study. Data were collected from employees of the textile companies. Only those employees were selected who had direct involvement in new technology adoption events. Aiming to ensure accurate results, employees with no link to the latest technology were not selected as respondents of this study. The latest technology means that technology belongs to the fourth industrial revolution. Therefore, those employees who were involved in Industry 4.0 practices were selected as the respondents. Employees having no experience with Industry 4.0 may not have the required knowledge about this technology and could respond incorrectly.

Different studies provide different methods ensuring the appropriate sample size. This study followed the instructions by Comrey and Lee (1992). According to Comrey and Lee (1992), a "sample having less than 50 participants will observed to be a weaker sample; sample of 100 size will be weak; 200 will be adequate; sample of 300 will be considered as good; 500 very good whereas 1000 will be excellent." Therefore, this study used the 500 sample size to get data from employees of the textile industry. A simple random sampling technique was used in the study to collect the data.

In this study, the survey questionnaires were based on various sections. The first section of the survey questionnaires measured the demographics of the respondents. The second section measured organisational performance. The third section measured CPS, the interoperability, a smart city and a smart product. The fourth section measured the mediating variable, namely, production and services. Finally, the fifth section measured the moderating variable, namely, effective technology implementation.

3. Research results

Results of the study were based on the data collected from Malaysian textile companies. It was expected to have missing values and outliers in the data. Therefore, the analysis was performed to check the missing value issues and outliers. The analysis for missing values and outliers is presented in Tab. 6. It is found that data is free from any case of outliers, missing values and is, therefore, accurate to proceed with further analysis. Skewness and kurtosis can be used as an indicator to check the deviation. Data were said to be normally distributed if the range of skewness and kurtosis lied within + 1.0 and + 3.00, respectively. All the values were under the acceptable range. Maximum and minimum values showed that the data had no outlier.

After the missing value and data outlier analysis, the analysis was made using partial least square (PLS)-structural equation modelling (SEM) techniques. Structural equation modelling (SEM) is a procedure of causal modelling that comprises a varied set of mathematical models, computer algo-

Tab. 6. Missing values and data outlier

	No.	Missing	Mean	Median	Min	Max	SD	Kurtosis	Skewness
CPS1	1	0	3.527	3	1	7	1.852	-0.652	0.371
CPS2	2	0	3.591	3	1	7	1.783	-0.465	0.385
CPS3	3	0	3.555	3	1	7	1.859	-0.725	0.287
CPS4	4	0	3.436	3	1	7	1.758	-0.396	0.432
CPS5	5	0	3.532	4	1	7	1.847	-0.795	0.206
CPS6	6	0	3.455	3	1	7	1.759	-0.507	0.321
INT1	7	0	3.6	4	1	7	1.725	-0.562	0.207
INT2	8	0	2.959	3	1	7	1.399	0.021	0.575
INT3	9	0	3.091	3	1	7	1.339	0.756	0.875
INT4	10	0	3.132	3	1	7	1.295	1.269	0.927
INT5	11	0	3.055	3	1	7	1.4	0.719	0.762
SPSC1	12	0	3.05	3	1	7	1.325	0.985	0.721
SPSC2	13	0	3.1	3	1	7	1.461	0.597	0.732
SPSC3	14	0	3.073	3	1	7	1.409	1.009	0.891
SPSC4	15	0	2.936	3	1	7	1.39	-0.08	0.442
SPSC5	16	0	3.123	3	1	7	1.334	0.773	0.721
SPSC6	17	0	3.027	3	1	7	1.401	0.48	0.68
PS1	18	0	3.005	3	1	7	1.425	0.588	0.75
PS2	19	0	3.136	3	1	7	1.391	0.073	0.549
PS3	20	0	3.041	3	1	7	1.322	0.515	0.578
PS4	21	0	2.95	3	1	7	1.312	0.024	0.543
PS5	22	0	3.068	3	1	7	1.265	0.652	0.617
PS6	23	0	3.032	3	1	7	1.376	0.258	0.722
ETI1	24	0	3.064	3	1	7	1.364	0.419	0.675
ETI2	25	0	3.091	3	1	7	1.262	0.465	0.58
ETI3	26	0	3.209	3	1	7	1.602	-0.488	0.276
ETI4	27	0	3.223	3	1	7	1.735	-0.563	0.405
ETI5	28	0	3.232	3	1	7	1.882	-0.741	0.46
ETI6	29	0	3.25	3	1	7	1.992	-0.988	0.463
FP1	30	0	3.132	3	1	7	2.066	-0.894	0.582
FP2	31	0	3.159	3	1	7	1.935	-0.792	0.535
FP3	32	0	3.268	3	1	7	1.675	-0.429	0.458
FP4	33	0	3.2	3	1	7	1.904	-0.779	0.467
FP5	34	0	3.273	3	1	7	1.873	-0.758	0.502
FP6	35	0	3.241	3	1	7	1.89	-0.739	0.462
FP7	36	0	3.255	3	1	7	2.022	-0.965	0.485

rithms, and statistical procedures that fit networks of constructs to data. Structural equation models are often utilised to measure unobservable "latent" constructs. It is prominent techniques to text the hypotheses in primary data. The procedure is recommended by different prominent authors (F. Hair Jr et al., 2014; J. F. Hair et al., 2006). In this technique, factor loading, composite reliability (CR) and average variance extracted (AVE) must not be less than 0.5, 0.7 and 0.5, respectively (J. Hair et al., 2017; J. F. Hair et al., 2010). These values are shown in Tab. 7 and Tab. 8. Factor loadings in Tab. 7 show the internal consistency

Tab. 7. Factor loadings

	Cyber-Physical Systems	Effective Technology Implementation	Firm Performance	Interoperability	Production and Services	Smart City and Smart Product
CPS1	0.9					
CPS2	0.872					
CPS3	0.906					
CPS4	0.904					
CPS5	0.893					
CPS6	0.874					
ETI1		0.768				
ETI2		0.773				
ETI3		0.849				
ETI4		0.897				
ETI5		0.905				
ETI6		0.863				
FP1			0.932			
FP2			0.921			
FP3			0.872			
FP4			0.922			
FP5			0.916			
FP6			0.907			
FP7			0.901			
INT1				0.66		
INT2				0.863		
INT3				0.893		
INT4				0.888		
INT5				0.893		
PS1					0.844	
PS2					0.9	
PS3					0.854	
PS4					0.885	
PS5					0.894	
PS6					0.909	
SPSC1						0.902
SPSC2						0.914
SPSC3						0.908
SPSC4						0.853
SPSC5						0.869
SPSC6						0.84

Tab. 8. CR and convergent validity

	Clpha	rho_A	CR	AVE
Cyber-Physical Systems	0.948	0.95	0.959	0.795
Effective Technology Implementation	0.919	0.929	0.937	0.713
Firm Performance	0.965	0.966	0.971	0.829
Interoperability	0.897	0.914	0.925	0.713
Production and Services	0.942	0.942	0.954	0.776
Smart City and Smart Product	0.942	0.943	0.954	0.777

Tab. 9. Discriminant validity

	CPS	ETI	FP	INT	PS	SPSC
Cyber-Physical Systems	0.892					
Effective Technology Implementation	0.621	***0.844***				
Firm Performance	0.604	0.731	***0.91***			
Interoperability	0.66	0.795	0.681	***0.844***		
Production and Services	0.577	0.799	0.671	0.724	***0.881***	
Smart City and Smart Product	0.601	0.821	0.708	0.72	0.722	***0.781***

Tab. 10. Direct effect results

	(O)	(M)	SD	T Statistics	P Values
Cyber-Physical Systems -> Production and Services	0.053	0.05	0.02	2.647	0.004
Effective Technology Implementation -> Firm Performance	0.093	0.092	0.0026	35.794	0
Interoperability -> Production and Services	0.532	0.531	0.061	8.721	0
Production and Services -> Firm Performance	0.203	0.201	0.037	5.544	0
Smart City and Smart Product -> Production and Services	0.464	0.462	0.058	8.064	0

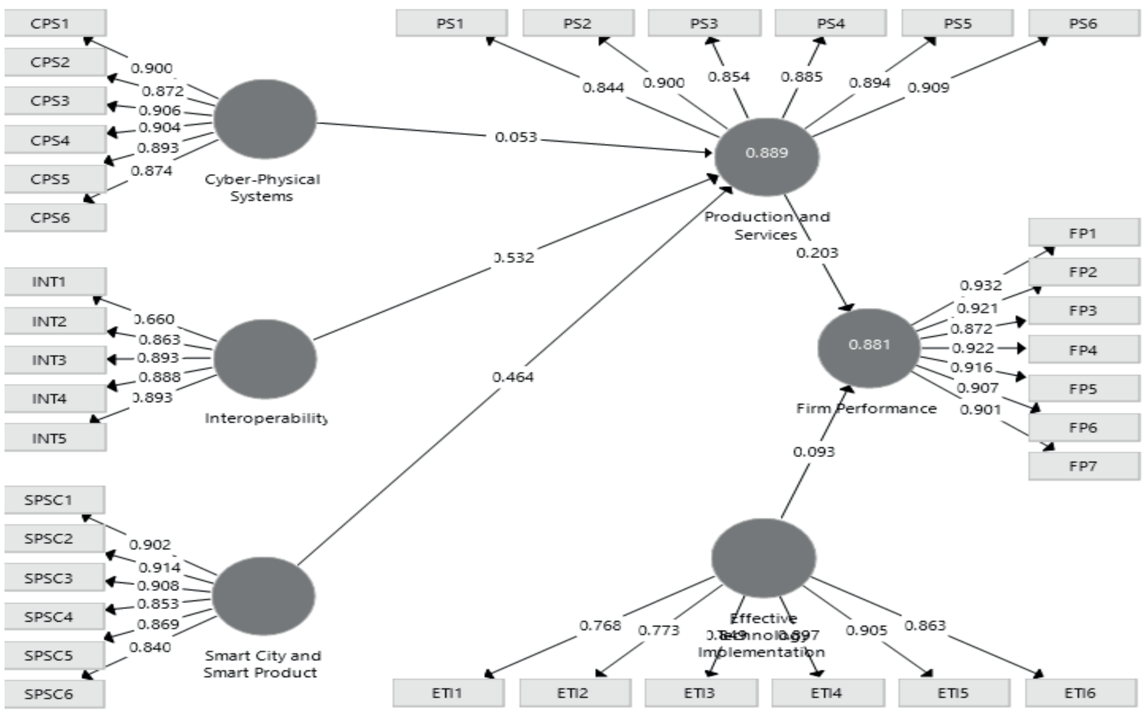

Fig. 3. Measurement model

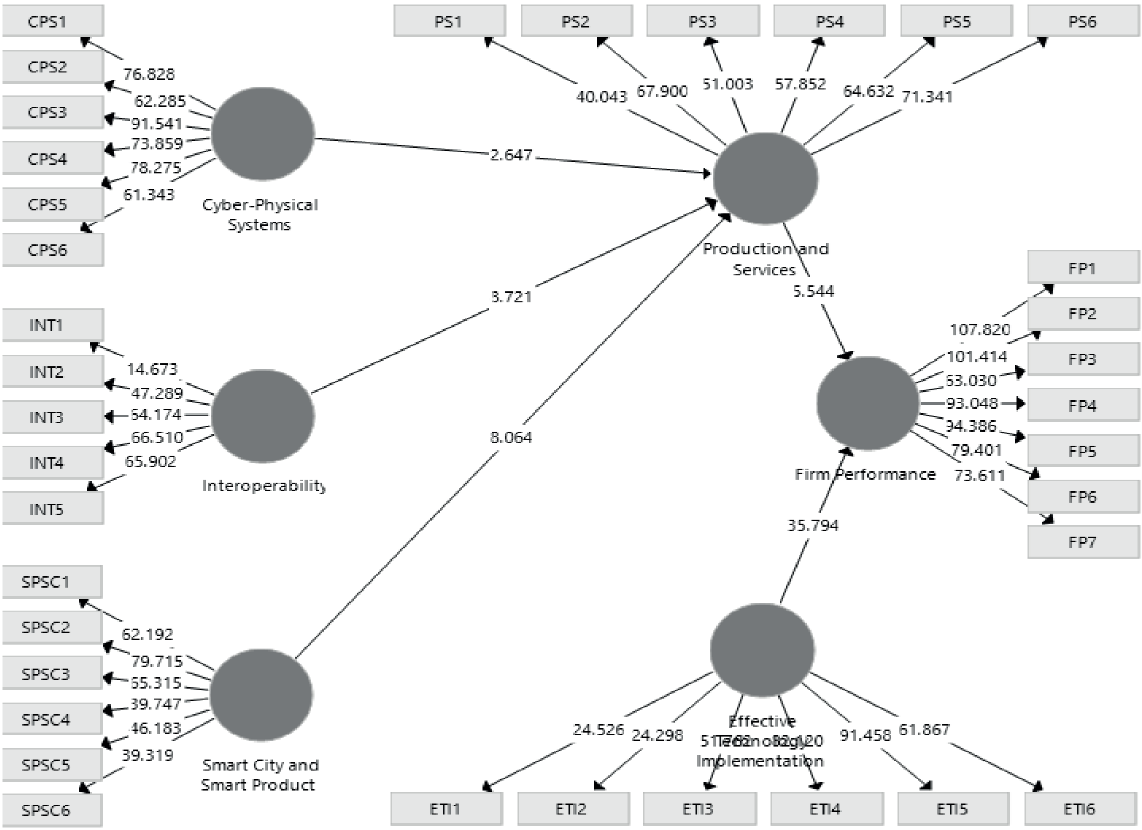

Fig. 4. Structural model

between items. AVE in Tab. 8 shows the external consistency.

All the values of CR, AVE and factor loading is above the minimum threshold level. Additionally, this study examined the discriminant validity by using the criteria of Fornell and Larcker (1981). According to these criteria, the square root of AVE was used to test the discriminant validity. It is given in Tab. 9.

Bootstrapping is one of the good techniques to test the hypotheses. This study also used PLS bootstrapping to test the hypotheses (Fig. 4). A direct effect results are given in Tab. 10. T-value 1.96 was considered for testing the hypotheses. It was found that all the direct effect hypotheses were supported (H1, H2, H3, H4, H8), as the t-value was above 1.96. In Tab. 10, the original sample (O) is given, which shows the beta value (β). The beta value highlighted the direction of the relationship of whether the relationship is positive or negative. SD shows the standard deviation. T-value and p-value show the significance of the relationship.

After a direct effect, an indirect effect was examined by considering the production and services as a mediating variable. The same criteria were followed as the direct effect was examined, and t-value was considered for testing the mediation hypotheses. It was found that the production and services were the mediating variable between interoperability and organisational performance. It was also found that the production and services were a mediating variable between a smart city, and a smart product and organisational performance. However, the mediation effect was insignificant between Cyber-Physical Systems and organisational performance. Therefore, H6 and H7 were supported, and H5 was not.

Additionally, the moderation effect of effective technology implementation was also examined. T-value was considered to check the significance level of the moderation effect. In this study, three moderating effects were examined. Results of the moderation effect of effective technology implementation are shown in Tab. 12. Results of the moderation effect show that effective technology implementation moderates the relationship between interoperability and production and services. The moderation effect is also significant between a smart product, and a smart city and production and services. Thus, H10 and H11 are supported.

Tab. 11. Indirect effect

	(O)	(M)	SD	T Statistics	P Values
Cyber-Physical Systems -> Production and Services -> Firm Performance	0.011	0.01	0.007	1.636	0.103
Interoperability -> Production and Services -> Firm Performance	0.108	0.107	0.024	4.464	0
Smart City and Smart Product -> Production and Services -> Firm Performance	0.094	0.093	0.02	4.819	0

Tab. 12. Moderation Effect

	(O)	(M)	SD	T Statistics	P Values
Moderating Effect 1 -> Production and Services	0.004	0.004	0.037	0.103	0.918
Moderating Effect 2 -> Production and Services	0.059	0.059	0.03	1.961	0.05
Moderating Effect 3 -> Production and Services	0.037	0.033	0.01	3.7	0

4. Discussion of the results

This study focused on Malaysian textile companies. In recent years, the performance of this industry has been decreasing. Aiming to address this issue, this study investigated the role Industry 4.0 has on organisational performance through production and services in the Malaysian textile industry. The current study focused on three key factors of Industry 4.0. It examined the effect of CPS, the interoperability and a smart city (a smart factory, a smart product) on the production and services of textile companies in Malaysia.

The results of the study found that Industry 4.0 makes a major contribution to the production and services of the textile industry as Industry 4.0 has a major role in the manufacturing (Almada-Lobo, 2016; Brettel et al., 2014; Rüßmann et al., 2015; Schumacher, Erol & Sihn, 2016; Durana et al., 2019). Better technologies lead to better manufacturing results. It was found that CPS has a significant positive effect on the production and services with t-value 2.647 and β-0.053. Therefore, an increase in CPS technologies increases the results of the production and services of textile companies operating in Malaysia.

It was found that interoperability has a significant positive effect on the production and services with t-value 8.21 and β-0.532. Consistently with these results, a smart product and a smart factory also had a positive effect on the production and services with t-value 8.064 and β-0.464. Therefore, it was provided that interoperability, a smart product and a smart city have a major role in boosting production and services. Consequently, companies must work to introduce the latest technology related to interoperability, a smart product and a smart factory.

Furthermore, it was found that production and services lead to improved organisational performance. Results of the study demonstrated that production and services had a positive effect on the organisational performance with t-value 5.544 and β-0.203. As it was revealed by the previous studies, production and services have a positive relationship with organisational performance (Gray & Hooley, 2002; Hong et al., 2015; Kastalli & van Looy, 2013; Witkowski et al., 2017).

Therefore, Industry 4.0 leads towards better production and services, improving organisational performance. Additionally, production and services have a positive role in reflecting the effect of Industry 4.0 on organisational performance. However, it is not possible without effective technology implementation. Effective technology implementation strengthens the positive relationship between interoperability and production and services. It also strengthens the positive relationship of smart product and smart city and production and services.

Conclusions

The fourth industrial revolution has the most significant contribution to organisational performance. Major elements of Industry 4.0, such as CPS, interoperability and a smart city (a smart factory, a smart product), have a positive effect on the production and services of textile companies in Malaysia. It is evident that the latest technology is a key contributor to improved performance. Latest techniques in production and services increase efficiency and effectiveness, which shows a significant effect on organisational performance. Additionally, a textile firm cannot benefit from Industry 4.0 unless it implements the technology effectively. Effective technology implementation is a major task for many companies. Introduction of the latest technology is possible; however, the implementation is a tough job. Therefore, proper technology implementation is crucial.

Theoretically, this study has important insights for scholars. The study started a new debate by providing the role of Industry 4.0 in the textile sector using a survey method. This study enhanced the existing literature with a theoretical portion by providing the effect of Industry 4.0 on manufacturing and services. Practically, this study provided valuable insights for practitioners to increase their organisational performance. This study provided valuable insights for the promotion of production and services and reasons why textile companies should introduce Industry 4.0 technologies and ensure effective implementation.

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Smart city concept in the light of the literature review

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ABSTRACT
Nowadays, the transformations of metropolises into smart cities is a crucial factor in improving the living conditions of the inhabitants. The goal of the smart city concept is modern urban management using technical tools that offer state-of-the-art technologies, considering the applicable ecological standards while saving resources and achieving the expected results. The purpose of this article is to identify the areas of research analysed in the international literature in the field of smart cities. The bibliometric analysis was carried out to achieve the purpose. The analysis covered publications on smart cities published in Scopus and Web of Science databases from January 2009 to May 2019. Based on the bibliometric analysis, a bibliometric map was developed using the mapping technique VOS — the visualisation of similarities. Original clusters were created using the VOSviewer software. The bibliometric map visualises the results of the analysis that targeted the word coexistence.

KEY WORDS
smart city, smart city subareas, bibliometric map

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Introduction

A city appears to be an obvious concept only when it is a secondary subject of research and is used as a relatively obvious context. As soon as it becomes the centre of interests, the focus should be not so much on precise and unambiguous definitions but functional conceptualisations (Matyja, 2017). A contemporary city is perceived as a socio-economic system. It is characterised by the complexity of many elements and their interrelations that integrate the city's components so that it can function and develop (Stawasz & Sikora-Fernandez, 2015). Urban development is determined by the constantly increasing migration of people from rural areas to urbanised areas. In 2018, 55% of the global population lived in urban areas. According to forecasts developed by the

Population Division of the United Nations Department of Economic and Social Affairs (UN DESA), in 2050, this share will increase to 68%. The global urban population in 2018 was 4.2 billion. Increasing urbanisation and gradual migration of people from rural to urban areas, combined with the general increase in the global population, means that by 2050, urban areas will accommodate another 2.5 billion people (nearly 90% of this increase will take place in Asia and Africa) (United Nations, 2018). Based on the forecasts, the next few decades should see cities undergoing constant changes, including in their structures. With the expected increase in the number of urban residents around the world, the need is growing for new and innovative ways to manage the complexity of urban life.

Considering the growing importance of cities in the development of many regions and countries, supported each year by the increasing number of smart city initiatives, the authors conducted a bibliographic analysis of the existing publications in this area, collected in Scopus and Web of Science databases. The article aims to identify the areas of research analysed in the literature concerning a smart city. This measure represents the first stage of the research process, aiming to identify the research problems in the field and a solution, which would constitute a theoretical and practical contribution to the development of smart city management.

All the considerations and research in the field of discussed issues are included in four chapters. The first chapter presents a general approach to the conditions of contemporary cities and presents smart city concepts. Next, the methodology used for bibliometric analysis is described. The third chapter is devoted to the results of the conducted bibliometric analysis. The last part of the work analyses the obtained results and presents the conclusions.

1. Literature review

Intensive development, which is undoubtedly a challenge for modern cities, can give rise to positive outcomes for urban communities as well as negatively affect the smooth functioning of the city. The challenges of modern cities are centred around:

- uncontrolled urban sprawl (Kovács et al., 2019; Halmy, 2019; Yu et al., 2019; Mahmoud & Divigalpitiya, 2019);
- environmental pollution (Caparros-Midwood et al., 2019; Alam et al., 2019; Munoz-Pandiella et al., 2018; Kosheleva et al., 2018);
- urban logistics (Nataraj et al., 2019; Firdausiyah et al., 2019; Bjørgen et al., 2019; Cleophas et al., 2019; Faramehr et al., 2019; Mesjasz-Lech, 2014; Tomaszewska & Florea, 2018);
- technical infrastructure (Petrova & Prodromidou, 2019; Faramehr et al., 2019; Pham & Phan, 2018; Juget & Ryckewaert, 2018);
- waste management (Bugge et al., 2019; Amritha & Kumar, 2019; Dlamini et al., 2019; Scorţar et al., 2010);
- aging population (Jayantha et al., 2018; Fang & Lai, 2018; Onoda, 2018; Greenfield, 2018; Jarocka & Wang, 2018);
- stratification of wealth levels, areas of poverty (Muktiali, 2018; Lanjouw & Marra, 2018; Ma et al., 2018; Aguilar & López, 2016);
- low level of citizen participation in the management of public affairs (Mavrodieva et al., 2019; Sou, 2019; van Holm, 2019; de Castro Pena et al., 2017).

Knowing the identified challenges and the expected increase in the number of urban residents around the world, there is an increasing need for new and innovative ways to manage the complexity of urban life. In the last decade, the smart city concept has gained considerable popularity, ultimately enabling residents to better meet their housing, transport, energy and other infrastructure needs, but also as a key strategy to combat poverty and inequality, unemployment and energy management. The smart city concept assumes that a city should be a creative, sustainable area that improves the quality of life, creates a friendlier environment and the prospects of economic development are stronger (Lee et al., 2014). Intelligence as a distinguishing feature of this type of a city, should not be treated in the literal sense of the word but perceived as the sum of various improvements in urban infrastructure, resources and public services (Allwinkle & Cruickshank, 2011). Although there is no formal and widely accepted definition of a "smart city", the ultimate goal is a better use of public resources, the improvement of the quality of services offered to citizens, while reducing operational costs of public administration (Zanella et al., 2014). It is understood that cities can be defined as smart if they have the following elements (Fig. 1).

The smart economy is measured by entrepreneurship and a city's productivity, adaptation to changes, the flexibility of the labour market and

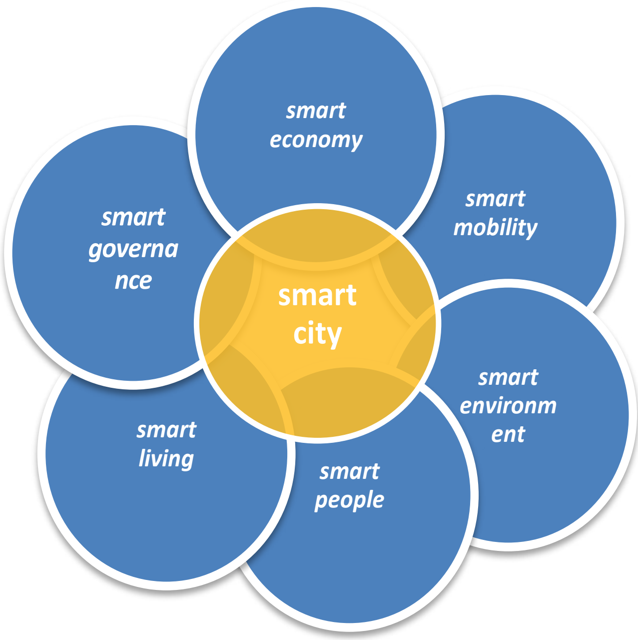

Fig. 1. Smart city elements

Source: elaborated by the authors based on (Stawasz & Sikora-Fernandez, 2016; Zanella et al., 2014; Caragliu et al., 2011).

international cooperation. Smart mobility is perceived by the accessibility of information and communication infrastructure, through the development of sustainable, innovative and safe transport. The smart environment is measured by the attractiveness of the natural environment, pollution levels, environmental protection activities and resource management methods.

Smart people are characterised by the level of qualifications, lifelong learning, social and ethnic diversity, creativity, openness and participation in public life. Smart living is measured by existing cultural facilities, living conditions (health, safety, housing), educational facilities, tourist attractiveness and social cohesion. Smart governance is expressed by the transparency of city management, social participation, the level of public services and the implementation of development strategies (Stawasz & Sikora-Fernandez, 2016; Zanella et al., 2014; Caragliu et al., 2011).

Many authors have attempted to formulate the definition of a "smart city" by binding it with different terms, which is indicative of the lack of a uniform or widely accepted definition (Schaffers et al., 2012; Zhuhadat et al., 2017; Chong et al., 2018). In publications dealing with the subject of a "smart city", there are many alternative terms for this concept, such as: "digital city" (Tan, 1999), "wired city" (Targowski, 1990), "information city" (Fietkiewicz et al., 2017; Sproull & Patterson, 2004; Stolfi & Sussman, 2001), "ubiquitous city" (Shin, 2009), "sensing city" (Mone, 2015). When reviewing the literature, it was noticed that in the vast majority of publications, authors attempting to define the concept of a "smart city" focused on the technological aspect. For example, Peng, Nunes and Zheng (2017) defined a "smart city" as a city using a set of advanced technologies, such as wireless sensors, smart meters, intelligent vehicles, smartphones, mobile networks or data storage technologies. In turn, Guo et al. (2017) claimed that a "smart city" is urban development based on the integration of many information and communication technology (ICT) solutions to manage the city's resources. These definitions of a "smart city" emphasise the role of technology. However, a city can hardly become smart because of technology alone (Nam & Pardo, 2014). Ortiz-Fournier et al. (2010) included citizens of smart cities in the definition of a "smart city". The authors described a "smart city" in the context of its intelligent inhabitants, the quality of social interactions, and integration with public life. In the current perception of the "smart city" concept, there is a return to the needs and preferences of the inhabitants, which are the focus. Thus, technical solutions should serve their interests. Residents, their specific features and abilities are the basis of a modern city (Mizielińska-Chmielewska, 2018). As rightly noted by Noworól (2011), the local government should base their activities on the value system and focus on creating a vision of the future of the city. Szołtysek and Otręba (2015) added that the efficient preparation and implementation of activities were closely related to the need to recognise the feelings and emotions of all groups of residents, which should serve as a basis for efficient city management programmes. Huang, Zhang and Wang (2017) also emphasised aspects of city management. They defined a city as smart if it was managed in intelligently, efficiently and sustainably. According to the assumptions of Manville et al. (2014), a "smart city" is a city where public issues are solved using ICT, with the involvement of various types of stakeholders working in partnership with the city authorities.

As noted by Molpeceres Arnáiz (2017), according to some business and political discourses, a smart city seems to be the city of the future. However, despite the numerous potential amenities of a "smart city" that cities could draw from, there are some barriers that make the implementation of this concept difficult (Dohler et al., 2011). Among the difficulties that arise when implementing the "smart city" concept, several stand out (Ravetz, 2017; Naphade et al., 2011; Krukowska, 2018; Proseedmag, 2017; What ..., 2018; Sikora-Fernandez, 2017; Bashynska & Dyskina, 2018):

- excessive concentration on investing in advanced technologies without the real perception of conflicts and problems in cities;
- the deployment of smart technologies in cities with complex social problems can exacerbate social inequalities through technical improvements;
- the lack of implemented solutions to use the local community to co-manage the city;
- the lack of a comprehensive view of cities considering the needs in all areas of their functioning;
- changes related to the introduction of the "smart city" concept, mainly including the technological aspect, may negatively affect the loss of the existing character and unique charm of some agglomerations, especially those valued due to their traditional character;
- the majority of investments in the development of the "smart city" concept focuses on creating new facilities instead of modernising the old ones;
- the development of smart city infrastructure requires huge investments, which are indirectly made by citizens, e.g. in the form of a higher tax rate;
- managing cities is a huge challenge and requires, above all, intelligence, responsibility, and reasonableness, which cannot be replaced by modern technologies and especially building cities from scratch. City innovation is not glass skyscrapers and cosmic architecture, but the creation of the best living and working conditions;
- incompetently or unknowingly used services by so-called digital illiterate people can cause much personal and systemic damage;
- cities equipped with modern technologies, e.g. housing or newly built, do not become an object of interest to the inhabitants due to high maintenance costs and lack of social relationships (e.g. Masdar city or Tianjin Eco-city built in nearby Beijing, where there are no schools, shops, transport to factories where people can work).

Complexity, diversity and uncertainty are the three key attributes of modern cities (Fernandez-Guell et al., 2016), which hinder the conceptual and technical progress in the implementation of a "smart city". In fact, this concept evolves from the simple integration of technology in the city with the development of solutions for urban challenges in a mutually connected and synergistic way (Lombardi et al., 2012; Mattoni et al., 2015). Processes that support the development, changes and everyday functioning of cities are complex and urban environments should be perceived as such as well, namely, as complex social engineering systems (Elzen et al., 2004). Many publications indicate the need to develop an integrated and holistic approach to a "smart city" (Perboli et al., 2014; Gil-Garcia et al., 2015).

2. Research methods

Considering the nature of the publication, which is a review, a bibliometric analysis was used as a research method. The results obtained using the bibliometric analysis are usually presented in the form of a map showing relationships between individual elements (Gudanowska, 2015, 2017; Siderska & Jadaa, 2018; Szpilko, 2017).

Based on the bibliometric analysis, the assessment of the dynamics of interest in the "smart city" subject was made, which is reflected in the number of publications in Scopus and Web of Science databases in the period from January 2009 to May 2019. In the next step of the research, a bibliometric map was created using the mapping technique VOS — the visualisation of similarities. VOS aims to locate items in a low-dimensional space in such a way that the distance between any two items reflects the similarity or relatedness of the items as accurately as possible (Eck & Waltman, 2011). The map was developed using the VOSviewer program, which is available from www.vosviewer.com. The created map is the reflection of the co-occurrence of words and their co-classification in publications. The size of the wheels on the map reflects the number of specific words, while the distance between the wheels depends on the number of coexistence (Halicka, 2017). The co-word analysis is based on counting the frequency of appearance in the analysed text, a few words. It allows identifying phrasemes or regularities in the coexistence of words. Co-occurrence words can signal the existence of sub-area research or identify guideline directions for further development of a given research area. Results of the co-classification analysis allow identifying the sub-areas of research both in one area, as well as in interdisciplinary fields (Dobrzyński et al., 2013). This method enabled the creation of six clusters — the sub-areas of research relating to "smart city" issues.

The basic source of data in a bibliometric analysis is bibliographic databases. A review of the publications was made in Scopus and Web of Science databases. The databases were selected because of their size and availability. In Scopus and Web of Science, it is possible to save data from bibliographic queries in the form of files that can then be directly developed using the bibliographic software VOSviewer. The formulation, based on which the database was searched, was "smart city", including in article titles, abstracts and keywords.

3. Research results

The exploration of the Scopus database resulted in finding 15744 studies registered in the database, of which the largest part were (Fig. 2) conference papers (63.4%) and articles (24.5%). In the Web of Science, authors found 5151 publications, of which the largest part, similarly to Scopus, were (Fig. 3) conference papers (55.6%) and articles (41.2%).

The great majority of publications were created in China, the United States, India, Italy, the United Kingdom, Spain, Germany and France. Numerous publications also originated in the Russian Federation, Australia and Japan.

The next step was dedicated to the analysis of the interest in the subject matter over the years. The time frame of the analysed period covered the last ten years from January 2009 to May 2019. The number of studies published in individual years is shown in Fig. 4.

Analysing Fig. 4, it can be noticed that initially — for the first five years — the interest in this subject was not significant. It is only since 2014 that interest in the "smart city" concept clearly increased, which is reflected by the number of publications in the Scopus database. Such dynamic growth in interest in this subject highlights the importance and validity of the subject area. In the next step, the identified publications were analysed in terms of research areas (Figs. 5 and 6).

In the Scopus database, over 34% of publications related to computer science and almost 19% to engineering. In the Web of Science, 37% relate to com-

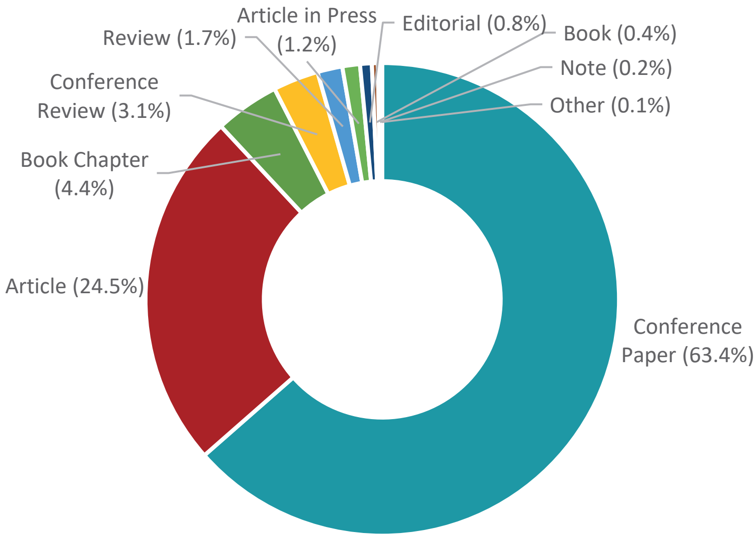

Fig. 2. Results of the search in the Scopus database — the document type criterion (indexed from January 2009 to May 2019)

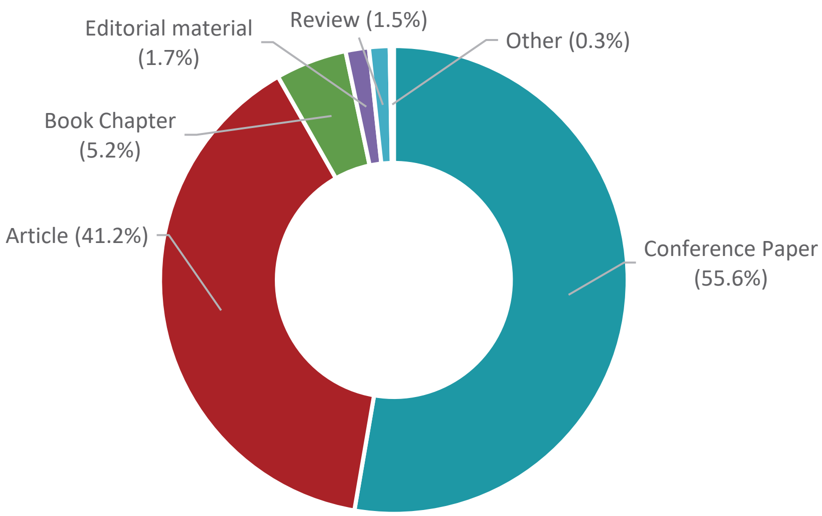

Fig. 3. Results of the search in the Web of Science database — the document type criterion (indexed from January 2009 to May 2019)

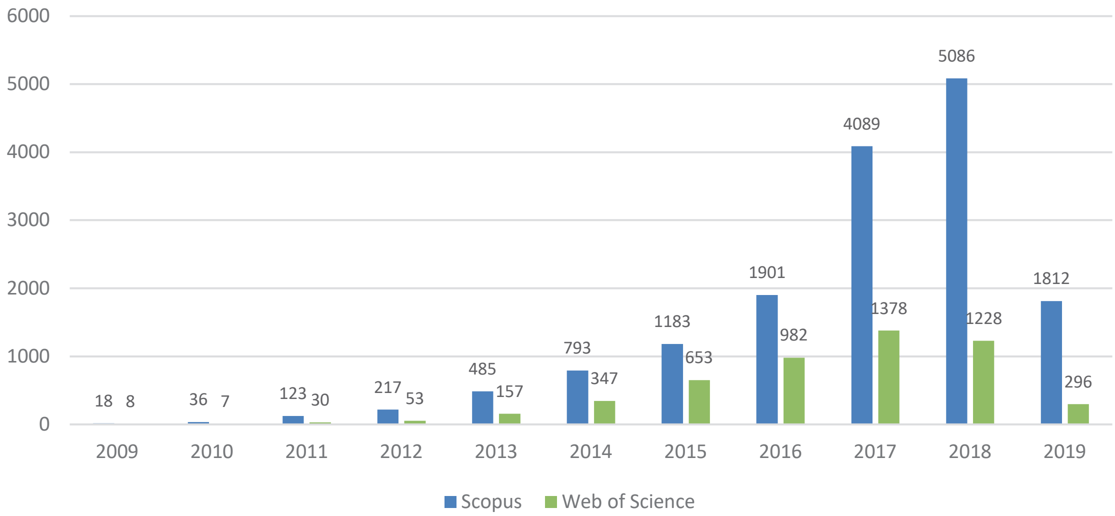

Fig. 4. Number of publications in the field of "smart city" in Scopus and Web of Science databases (indexed from January 2009 to May 2019)

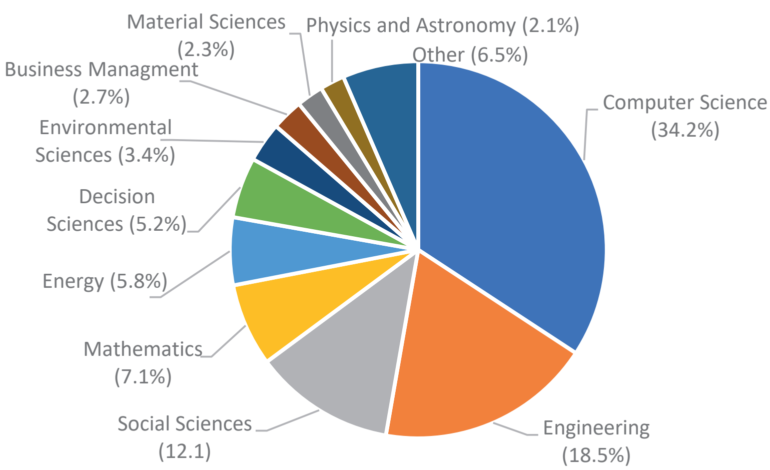

Fig. 5. Identified publications in terms of a subject area (Scopus database, indexed from January 2009 to May 2019)

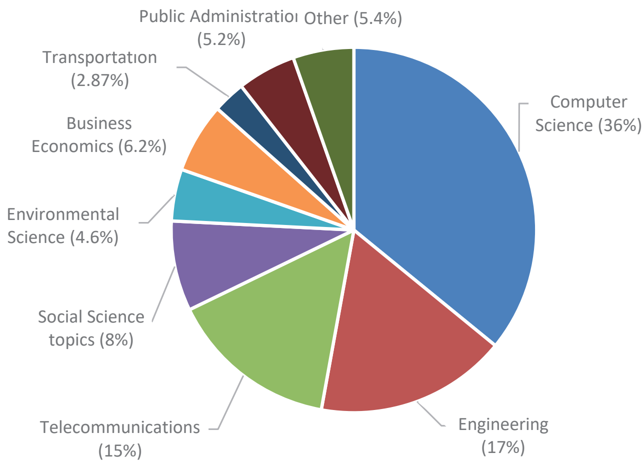

Fig. 6. Identified publications in terms of a subject area (Web of Science database, indexed from January 2009 to May 2019)

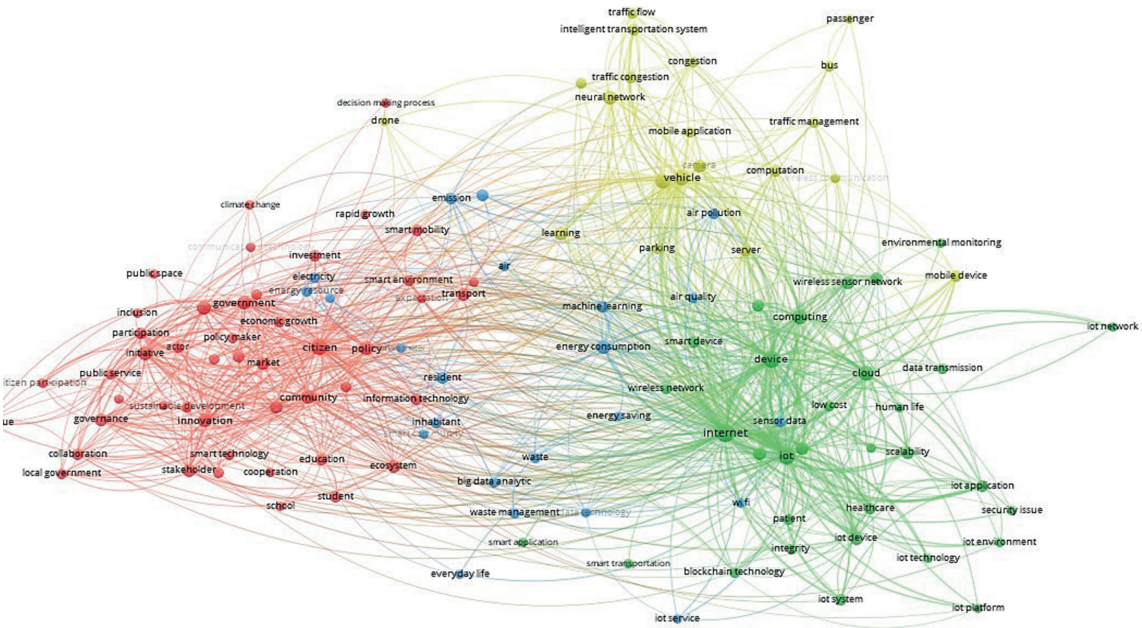

Fig. 7. Map of sub-areas related to the "smart city" concept

puter science and 30% to engineering. This proves that in most publications, the authors focus on technological aspects, where urban development is based on many IT solutions to manage the city's resources. However, more and more authors, namely, 12.1% (Scopus), indicate the importance of social aspects in the smart city concept.

In the last stage of the bibliometric analysis, a bibliometric map was developed, which is a visualisation of the results of the analysis regarding the coexistence of words using the VOSviewer software. The results of the analysis are presented in Fig. 7.

The analysis of the coexistence of words made it possible to distinguish six clusters as sub-areas related to the "smart city" concept. When analysing individual clusters, the following names were proposed:

- Cluster 1 — smart technology;
- Cluster 2 — socio-economic aspects;
- Cluster 3 — environmental aspects;
- Cluster 4 — urban logistics.

4. Discussion of the results

By making a bibliometric analysis of the smart city concept, a very dynamic increase in the interest of researchers in this field over the last five years has been noticed. The areas addressed by authors in their publications were computer science and engineering.

Tab. 1. Sub-areas and main issues of smart city research

CLUSTER	RESEARCH SUB-AREAS	MAIN RESEARCH ISSUES
1.	SOCIO-ECONOMIC ASPECTS	• the quality of social interaction (Neuroni et al., 2019; Tenney et al., 2019; Timmerman et al., 2019; Adnan et al., 2018; Vhaduri et al., 2018; Oliveira & Santos, 2018); • the engagement of citizens in public life and decision-making; the participation of local stakeholders in managing public affairs; the collaboration between the local government and residents (Novo Vázquez & Vicente, 2019; Certomà & Rizzi, 2017; Streitz, 2017; Morgado et al., 2015; Ma & Lam, 2019; Horgan & Dimitrijević, 2019; Trencher, 2019; Manchester & Cope, 2019; Kundu, 2019; Mannan & Callenes-Sloan, 2019); • healthcare (Sittón-Candanedo et al., 2019; Kumar et al., 2019; Kamel Boulos et al., 2019; Sedighian 2019; Chondrogiannis et al., 2019; Julian & Botti, 2019); • security issues (Mattos et al., 2019; Krämer et al., 2019; Sittón-Candanedo et al., 2019; Sharma & Kalra, 2019; Xie & Hwang, 2019; Vitunskaite et al., 2019); • education (Sodiq et al., 2019; Fernández et al., 2019; Panchanathan et al., 2019; Safiullin et al., 2019; Deng, 2019; Li, 2019); • the development of entrepreneurship (Grimaldi et al., 2019; Gonzaga, 2019; Perng et al., 2018; Tay et al., 2018; Indravati et al., 2018; Carè et al., 2018);
2.	URBAN LOGISTICS	• congestion (Zhao et al., 2019; Zhu & Liang, 2019; Yang & Zhu, 2019; Mishra, 2019; Reddy & Mehta, 2019; Garg et al., 2019); • traffic flow management (Zheng et al., 2019; Ferrer et al., 2019; Vranken et al., 2019; Vaida & Mouftah, 2019; Chen, 2019; Kuang et al., 2019); • autonomous vehicles (Li et al., 2019; Cantas et al., 2019; Schmitt et al., 2019; Ji et al., 2019; Xie et al., 2019);
3.	ENVIRONMENTAL ASPECTS	• incorporating sustainable development principles into the smart city concept (Bibri, 2019; Ismagilova et al., 2019; Allam & Dhunny, 2019; Zhang & Pu, 2019; Cao et al., 2019; Chakrabarty, 2019);
4.	SMART TECHNOLOGY	• IOT — the Internet of things (Mattos et al., 2019; Sittón-Candanedo et al., 2019; Heaton & Parlikad, 2019; Jan et al. 2019; Rath & Pattanayak, 2019); • cloud computing (Azhdari et al., 2019; Huang et al., 2019; Min-Allah et al., 2019; Wang et al., 2019; Del Esposte et al., 2019); • big data (Kong et al., 2019; Putra et al., 2019; Lakshmanaprabu et al., 2019; Luo et al., 2019; Ameer et al., 2019); • artificial intelligence (Khadse et al., 2019; Marcuzzi & Tonello, 2019; Wei et al., 2019; Panchamathan et al., 2019; Bui & Jung, 2019; Hu & Jiang, 2019); • wireless sensor networks (Sadeghpour et al., 2019; Chammas et al., 2019; Godoi et al., 2019; Alduais et al., 2019; Marrero et al., 2019; Alchihabi et al., 2019; Sedighian & Kashi, 2019)

This proves that in most publications, authors focused on technological aspects, where urban development was based on the integration of many IT solutions aiming to manage the city's resources. However, more and more authors in their publications indicated the importance of social aspects in the smart city concept. The analysis of the co-occurrence and co-classification of words made it possible to identify four clusters that constitute research sub-areas in the context of the smart city concept. In Tab. 1, research sub-areas of the smart city concept are indicated as well as related emerging research directions and issues.

In the cluster defined as socio-economic aspects, there are elements such as the quality of social interaction and integration with public life. The important elements are living conditions, for example, healthcare, security and education. The basis of a "smart city" is residents and their needs. In this cluster, the role of inhabitants and local stakeholders stands out, meaning their participation in managing public affairs and decisions making processes. There is a strong need for creating transparent principles of collaboration between local government and residents. Also, no smart city is possible without the well-prospering economy. The key is to develop entrepreneurship and business that would not only function on the local market but internationally as well. Another research sub-area concerns environ-

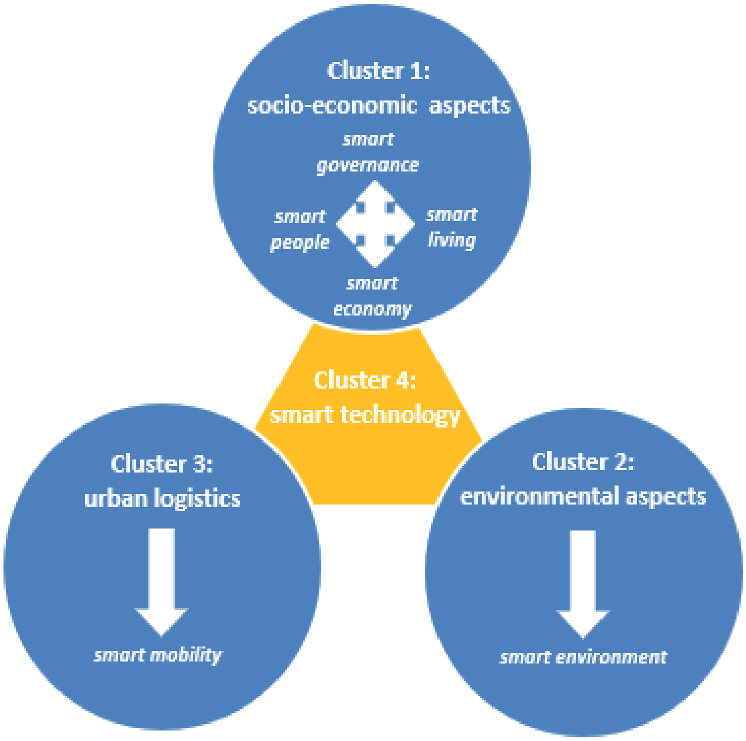

Fig. 8. Identified subareas related to smart city elements

mental aspects. A city cannot be named smart if it has no activities in the field of environmental protection and resource management methods. The care for the quality of the natural environment is of utmost importance, for example, by reducing emissions, pollution and using renewable energy sources. Generally, the principles of sustainable development should be followed. Analysing the third cluster, it can be noticed that the subject of urban logistics plays an important role in the smart city concept. In this context, urban logistics should primarily focus on planning, coordination and controlling processes related to a city or urban agglomeration, moving people and goods in a way that optimises costs, minimises congestion and improves the quality of life of the residents. The analysis of individual clusters revealed that the identified sub-areas could be related to the key elements required for a city to be called smart (Fig. 8).

Cluster 4 — smart technology — refers to a set of advanced technologies used in cities, such as wireless sensor networks, IOT, big data, cloud computing, artificial intelligence, applications, systems, mobile devices, mobile applications, wireless smartphones. The smart technology refers to each of the smart city elements. However, based on conclusions learned from the literature review and the previous difficulties in implementing the smart city concept, the real needs of people should always be placed first, and all aspects of its surroundings should be considered. The smart technology is not in the centre but is a specific background for other elements. It is a tool for achieving goals, not an end in itself. Each of the elements of the smart city concept is a wide field of research. However, it should be remembered that they constitute one integral and inseparable whole, and they should be treated as such in the practical context. For a city to be described as smart, it must have all these elements.

Conclusions

A smart city is a relatively new concept. The dynamic development of innovative technologies provides opportunities to build smart cities. However, as demonstrated by the literature review, excessive focus on the technological aspect alone leads to many problems in the implementation of the smart city concept. A city can hardly become smart only by using technology. In the current perception of the "smart city" concept, there is a return to the needs and preferences of the inhabitants. They are the focus, and technical solutions are to serve their interests.

The bibliometric map created for this publication allowed identifying six sub-areas of research related to the smart city concept. While analysing the individual clusters, it was noticed that they fit into the necessary elements of the smart city concept. For a city to be really smart, it must integrate such elements as the smart economy, smart people, smart living, the smart environment, the smart governance and smart mobility.

The literature review identified a research gap, which shows that the implementation of the smart city concept is poorly embedded in a multi-sphere and multi-variant vision of the future In the opinion of the authors, a tool that would enable the development of a vision of the future of a smart city with the involvement of a wide range of stakeholders forming a local community, could be foresight, which has been successfully used in building a vision of the future of countries, regions and businesses (Nazarko, 2013; Nazarko et al. 2013, 2015a, 2015b; Ejdys, 2014; Szpilko 2015; Ejdys et al., 2019). It, therefore, seems appropriate to develop a foresight methodology for planning the future of smart cities, in which citizens are both users and co-creators of smart cities. To develop the methodology of creating smart city development based on foresight studies, research in this field of science will be continued by the authors.

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Reduction of defects in the lapping process of the silicon wafer manufacturing: the Six Sigma application

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A B S T R A C T

Aiming to reduce flatness (Total Thickness Variation, TTV) defects in the lapping process of the silicon wafer manufacturing, it is crucial to understand and eliminate the root cause(s). Financial losses resulting from TTV defects make the lapping process unsustainable. DMAIC (Define, Measure, Analyse, Improve and Control), which is a Six Sigma methodology, was implemented to improve the quality of the silicon wafer manufacturing process. The study design and the choice of procedures were contingent on customer requirements and customised to ensure maximum satisfaction; which is the underlying principle of the rigorous, statistical technique of Six Sigma. Previously unknown causes of high TTV reject rates were identified, and a massive reduction in the TTV reject rate was achieved (from 4.43% to 0.02%). Also, the lapping process capability (Ppk) increased to 3.87 (beyond the required standard of 1.67), suggesting sustainable long-term stability. Control procedures were also effectively implemented using the techniques of poka yoke and control charts. This paper explores the utility of Six Sigma, a quality management technique, to improve the quality of a process used in the semiconductor industry. The application of the Six Sigma methodology in the current project provides an example of the root cause investigation methodology that can be adopted for similar processes or industries. Some of the statistical tools and techniques were used for the first time in this project, thereby providing new analysis and quality improvement platform for the future. The article offers a deeper understanding of the factors that impact on the silicon wafer flatness in the lapping process. It also highlights the benefits of using a structured problem-solving methodology like Six Sigma.

K E Y W O R D S

Six Sigma, quality, silicon wafer, lapping, quality control, total thickness variation, wafer manufacturing

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Introduction

The semiconductor industry consists of companies engaged in the design and fabrication of semiconductor devices, which form the foundation of modern electronics. The industry began in the 1960s and currently accounts for about 0.5% of the global GDP ($299.5 billion). It also enables the generation of approximately $1200 billion in the electronic systems business and $5000 billion in services, representing close to 10% of the global GDP, thus gaining the recognition for its critical role in the supply chain of the electronics industry (Kazmierski, 2012).

The silicon wafer manufacturing involves several stages. The semiconductor industry consists of three key sectors: silicon ingot growing, the silicon wafer manufacturing and the fabrication of integrated cir-

Tab. 1. Four key stages of silicon wafer manufacturing process

Process Flow	Description	Process Objective	Process Demerits
Slicing	Silicon ingot is mounted on the slicing machine. A web of meatl wire along with cutting slurry passes through the ingot slowly to provide disc shaped silicon wafers	To generate wafer slice structure. To achieve correct wafer thickness, orientation and warp	Poor flatness High surface damage High contamination
Lapping	Sliced wafers held in carriers are placed in between two metal plates along with abrasive slurry falling on wafers. Rotation of plates and carriers causes mechnical removal of slicon therby reducing wafer	Reduce slicing damage. Establish optimum wafer flatness	Susceptible to surface and flatness rejects
Chemical Etching	Lapped wafers are subjeted to abrasive chemicals which disolves silicon into chemical thereby thinning wafers	Reduce Previous Process Damage Reduce surface contamination	Degrades flatness wafer staining
Polishing	Etched wafers are mounted on plates. With pressure applied on these plates, the wafers are rubbed against fine abrasive polishing pads along with polishing slurry to give a mirror like finish	Establish optimum flatness. Eliminate surface damage. Minimise contamination level	High rejection rate Re-work cost

cuit (IC) chips. The silicon ingot growing process is contingent on many factors, such as size, specifications and quality, and so the ingot growing time can range from a week to a month. The next stage is the wafer production, whereby a fully-grown silicon ingot is sliced into wafers of different thicknesses. This sliced wafer is then subjected to the flattening process, and then undergoes the fabrication process producing IC chips. The focus of this research project is on the silicon wafer manufacturing.

The silicon wafer manufacturing consists of four key value-adding processes: slicing, lapping, chemical etching and polishing. The primary aim of the slicing process is to define the crystal structure of the wafer, finding the best possible shape. The wafer is subjected to high-pressure cutting, to achieve correct wafer thickness, but on the downside, it causes high surface damage and contamination. The second stage is lapping, which removes the surface damage caused by slicing. It is also critical in defining the flatness of the wafer as a failure to achieve the optimum wafer flatness can lead to complete wafer rejection. Wafers are then exposed to abrasive chemicals during the chemical etching stage that helps to remove impurities from the wafer surface. Finally, wafers that have been manufactured to the required flatness standards, with no surface damage, are polished on one side to give a smooth, mirror-like finish, on which IC chips can be fabricated. This process flow is further illustrated in Tab. 1.

The lapping process helps to achieve the maximum wafer flatness. Wafer flatness measured as Total Thickness Variation (TTV) in microns is one of critical-to-quality (CTQ) requirements for a silicon wafer. This project aimed to reduce the number of TTV rejects in the lapping process.

1. Literature review

Quality is an elusive and abstract concept (Hossain, Tasnim & Hasan, 2017; Wright, 1997). In a study by Evans and Dean (2002), managers from 86 firms in the United States were asked to define "quality". They found several definitions ranging from waste elimination, conformity to customer requirements, policy compliance, consistency in output, getting it right the first time and customer satisfaction. Broadly, quality can be understood along four dimensions: excellence, value, conformance to specifications and the extent to which expectations are met (Yong & Wilkinson, 2002). Quality as excellence is believed to be immeasurable, and control can only be exerted through the investment of maximum efforts and best skill sets. This approach has been criticised of being of little practical value to an organisation (Garvin, 1988). Quality as a value definition focuses on external effectiveness (meaning costs) and internal efficiency. This definition, once again, has been argued to lack practical and measurable parameters for organisational use (Yong & Wilkinson, 2002). A more quantifiable and objective definition of quality is conformance to specifications; which was dominant in the 20th century. It means that an outcome must not deviate from the specifications set by an organisation, and any deviations are considered as lowering the quality (Reeves & Bednar, 1994). Such conformance measures have been argued to increase the internal efficiency of the process and sale prices over time (Topalovic, 2015). Later, as the focus shifted from manufacturers to customers, a new definition of "quality" emerged, i.e. meeting or exceeding customer expectations. Anything that does not satisfy the customer was considered to be of low quality (Yong &

Wilkinson, 2002). However, customer requirements are variable and subjective, which makes them difficult to satisfy. These intricacies associated with the concept of quality, highlight the need to have a management system that ensures the manufacturing of good-quality products resulting in monetary profits and customer satisfaction. This leads to the concept of quality management.

The revolution in quality management began in Japan during the 1950s and gradually gained momentum in the rest of the world during the 1970s and the 1980s (Foley, 2004). One of the most influential quality movements during this era was the total quality management (TQM), which again owes its origin and conceptual developments to Japan (Cole, 1998; Esaki, 2016; Juran, 1995). TQM eliminated the weaknesses of previous quality improvement techniques, which makes it an efficient quality management tool. TQM is an integrated approach that stresses the top-down approach, staff engagement in the process, evidence-based decision-making and the consideration of customer requirements (Tobin, 1990). Despite its influential and successful reputation, many publications have documented unsuccessful implementation stories of the TQM concept in the manufacturing industry (e.g., Brown et al., 1994; Eskildson, 1994; Cao et al., 2000; Nwabueze, 2001). Based on the evidence from independent publications by consulting firms, it can be argued that two-thirds of TQM implementation efforts failed to produce any significant improvements in the overall quality of the product, financial gains or the company's competitive situation in the industry (Jimoh et al., 2018). This is partly due to the ever-changing and evolving definitions of TQM, which can mean different things to different people, making its implementation insufficiently consistent and reliable (Andersson et al., 2006; Boaden, 1997; Talapatra, Uddin & Rahman, 2018).

Two other branches of quality management were introduced during the 1960s: reliability engineering and zero defects. The reliability engineering technique has roots in the disciplines of pure probability and statistics. It was mostly used in the USA and aimed to apply principles of probability to reduce defect rates of durable products (Dimitri, 1991). The zero defects strategy, which originated in the USA

Tab. 2 Overview of key quality management concepts

Concept	Origin	Aim	Focus	Methodology and Tools	Criticisms
Total Productive Maintenance	Japan (the 1950s)	Increase process capability by reduction of unplanned failures, accidents and defects	Preventive and predictive maintenance of processes	Gap analysis of historical records, cause-effect analysis	Skilled workers required to implement, resource demanding and long-term
Total Quality Control	Japan (the 1960s)	To coordinate quality maintenance and improvement from all groups to achieve the most economical process	To reduce rework and achieve maximum customer satisfaction	Methodology: Plan Do Study Act Tools: Statistical techniques	Vague and difficult to coordinate
Total Quality Management (TQM)	Japan (the 1990s)	Improve the quality and consistency of processes	Customer satisfaction	Methodology: Plan Do Study Act Tools: Statistical techniques	Vague and inconsistent conceptualisation, excessive resource consumption, unsatisfactory resu lts
Zero Defects	Denver Division of the Martin Marietta Corporation (the 1960s)	To enhance the quality of a process outcome through the elimination of any defects in the production process	Defect elimination	Extra attention and care devoted to each step of the production process ensuring no mistakes	Expensive
Reliability engineering	Shewart during the 1920s and the 1930s: cited in Kapur and Lamberson (1977)	To reduce failure modes	Longevity and dependability of parts, products and systems	Reliability-Centred Maintenance, failure modes and effects, root cause analysis, condition- based maintenance	Technical and requires skilled staff. Expensive and demands long term commitment

during the 1960s, was considered to be the most optimistic approach in the quality management field as it aimed to achieve the complete elimination of defects and process failures (Crosby, 1979). Both concepts, however, received criticism for being impractical and expensive (Crosby, 1984). It can, thus, be argued that the different quality management concepts differ in their origin, aim, definitions, methodology and focus, thereby confusing rather than informing the readers. Furthermore, each of the techniques cited above has limitations that reduce their applicability and anticipated benefits (Kedar et al., 2008). Many organisations have reported difficulties in the implementation of quality management programmes (Brown et al., 1994; Eskildson, 1994; Harari, 1997; Nwabueze, 2001); they suggested the lack of inherent connectivity between parts and also reported some missing information about some of the relevant sections, as shown in Tab. 2.

None of the quality management tools discussed so far had global success, and quality managers were still in search of a complete quality management programme when Six Sigma arrived. Six Sigma is a systematic set of guidelines that aims to significantly improve the quality of a manufacturing process and reduce costs by minimising process variation and reducing defects. It utilises statistical tools that can either be applied to facilitate a new product development or strategic process improvement (Breyfogle et al., 2001). Six Sigma is the edge that helps win the market competition as it provides financial, business and personal benefits; financial — by optimal and efficient use of resources; business — through ensuring maximum customer satisfaction; and personal — enhancing skills of an individual and, thereby, increasing their employability. In the last decade or so, there has been a rapid uptake of the Six Sigma technique as a process change, management and improvement strategy by global industries. This helped them beat market competition and maximise yearly savings (Su & Chou, 2008; Yang & Hsieh, 2009).

Besides, in the last decade or so, there has been a massive uptake and implementation of the Six Sigma technique as a process change, management and improvement strategy by global industries, which include the manufacturing process (Al-Aomar, 2006; Gangidi, 2019; Valles et al., 2009), financial organisations (Brewer & Eighme, 2005), engineering firms (Bunce et al., 2008), hospitals and intervention clinics (Craven et al., 2006), banking, hospitality, pharmaceutical companies (Cupryk et al., 2007), chemical industries (Doble, 2005), educational institutions (Bandyopadhyay & Lichtman, 2007), software industry (Arul & Kohli, 2004), call centres (Schmidt & Aschkenase, 2004), utility service providers (Agarwal & Bajaj, 2008), the automobile sector (Gerhorst et al., 2006), information technology (Edgeman et al., 2005), human resources departments (Wyper & Harrison, 2000), military administration units (Chappell & Peck, 2006) and even government departments (Furterer & Elshennawy, 2005). A summary is presented Tab. 3.

The origins of Six Sigma can be found in statistics. The term Six Sigma owes its origin to the terminology employed in the statistical modelling of manufacturing processes. A Six Sigma process is the one that produces 3.4 defects or non-conformances per million opportunities (DPMO). A defect is anything that does not conform to the manufacturer's guidelines or customer's specifications, and an opportunity is any chance for this defect to happen. The sigma level, also known as a Z-value, is used as a capability index for the process, which indicates how well that process can meet the customer's requirements (Bothe, 2001; Da Silva et al., 2019). Each sigma level corresponds to a certain number of defects/non-conformances that are associated with the process, as shown in Fig. 1.

Sigma (σ) Level	Defects / Non-Conformances per Million Oppurtunity (DPMO)
2 σ	308,537
3 σ	66,807
4 σ	6,210
5 σ	233
6 σ	3.4

Fig. 1. Sigma levels depending on DPMO

Tab. 3. Selected success stories of the Six Sigma implementation in industries

Authors	Name of an organisation	Benefits of implementing the Six Sigma technology
Financial sector		
Rucker (2000)	Citibank group	Numerous benefits have been reported across different organisations of this group. They successfully halved their credit processing time and reduced internal call-back time by 80% and external by 85%. Reduced the time between a customer first placing an order till the actual service delivery and the credit decision cycle from 3 days to just 1 day. The time taken to process a statement was also decreased from 28 days to 15 days only
	JP Morgan Chase (Global Investment Banking)	Improved customer experience in using bank's services such as account opening, balance enquiry, making transfers and payments via online or cheque mode; leading to increased customer satisfaction and a reduction in process cycle time by more than 30%
Antony (2006)	British Telecom wholesale	Financial benefits of over $100 million, greater customer satisfaction, error reduction
Roberts (2004)	Bank of America	24% reduction in customer complaints and a 10.4% increase in customer satisfaction
	Sun Trust Banks	Significant improvement in customer satisfaction
Bolt et al. (2000)	American Express	Improved the external vendor related processes and reduced the numbers of non-received renewal cards
Manufacturing sector		
Antony (2006)	Motorola (1992 and 1999)	1992: Achieved dramatic reduction in the defect levels of their process by about 150 times 1999: Huge financial gains of about $15 billion over 11 years
	Honeywell	Profit of $1.2 billion
	Texas Instruments	Achieved a financial gain of over $ 600 million
	Johnson and Johnson	The financial gain of about $500 million
	Telefonica de Espana (2001)	Whooping increase in revenue by about 30 million in the first 10 months and gain in savings too
	Dow chemical/rail delivery project	Reported substantial savings in capital expenditures: of over $2.4 million
McClusky (2000)	AlliedSignal/ Bendix IQ brake pads	The cycle time of their production-shipment process decreased by 10 months (18 to 8 months)
	AlliedSignal/ Laminates plant in South Carolina	Reaped a range of benefits: their capacity almost doubled, and punctuality in delivering goods reached 100% threshold level. Their cycle time and inventory had a reduction of 50% each
	DuPont/Yerkes plant in New York (2000)	Increase in yearly savings of over $25 million
	Seagate Technology	Gained financial profits of about £132 million in just 2 years
	General Electric	Increase in yearly financial savings by about $2 billion
	Hughes Aircraft's Missiles Systems Group / Wave soldering op.	The quality of their yields improved by about 1000% and productivity by 500%
	Raytheon/ Aircraft Integration Systems	Achieved a significant reduction (approx. 88%) in the inspection time spent on the depot maintenance process
McClusky (2000)	GE/ Railcar leasing business	Achieved a 62% reduction in the time spent at repair stops
Healthcare sector		
Benedetto (2003)	Radiology film library, Anderson cancer centre Outpatient CT exam lab at the University of Texas	Service quality improved Preparation and waiting times for patients reduced from 45 min to 5 min Dramatic increase by 45% in daily numbers of examinations without an increase in workforce/ equipment
Engineering and Construction sector		
Byrne(1998)	General Electric	1997: made a profit of $320 million which was more than double their goal of $150 million, further in 1999, annual savings of 2 billion
Magnusson et al. (2003)	Volvo cars (Sweden)	Profit of over 55 million euro in the years 2000 and 2002
Anderson et al. (2006)	Business Unit of Transmission and Transportation Networks at Ericsson	Savings of over 200 million euro between the years 1997-2003

Each manufacturing process has set specification limits for a process and product quality. If six standard deviations can be managed between the statistical mean of a process and its nearest specification limits, then all aspects of that process would meet the specification criteria. This distance between the process mean and the specification limit is measured in sigma units and is known as the process capability. The process capability measurement index is the process performance index (Ppk). Once a process has been brought under statistical control through the implementation of a Six Sigma project, Ppk estimates how stable these improvements would be in the long-term and how closely they would meet customer expectations. The larger the Ppk value, the less is the process variability and the higher the long-term stability. To satisfy customers, the Ppk value should be greater than 1.67 (Kotz, 1993; Raman & Basavaraj, 2019).

The literature indicated that even if a process achieved a high sigma level over short-term, its performance could have declined over long-term; and a common research finding is that it might fall from Six Sigma to the 4.5 sigma level (Alexander, Antony & Rodgers, 2015; Pandey, 2007). This could happen because the process may 'drift' over time. Such shifting can further lead the process mean to move away from the target, thus reducing the number of standard deviations that can fit between the process mean and the closest specification limit. This is commonly known as a 1.5 sigma shift. So, the standardised definition of the Six Sigma quality considers this shift and guarantees that a six-sigma process will produce no more than 3.4 DPMO (Antony, Snee & Hoerl, 2017; Harry, 1988).

Some previous attempts to resolve the problem of high TTV failed. The problem of obtaining high TTV rejects had been a recurrent issue at the current organisation, for a significantly long time. Earlier, the traditional problem-solving technique called One Factor At a Time (OFAT) had been applied in an attempt to reduce TTV rejects. OFAT is an experimental technique that evaluates the impact of potential factors on the process outcome, one at a time while keeping other factors constant. However, these attempts failed to identify the root cause of the current problem. Further expert consultations and systematic research review indicated a better potential of the technique called Factorial Experimental Design (FED), as compared to the OFAT strategy. FED evaluates the effect of more than one factor together with their interactions, simultaneously on the process outcome. This gives FED an edge over the OFAT technique, wherein only one factor can be evaluated at one time.

Many studies have compared OFAT and FED — the two problem-solving techniques — and FED is considered to be more effective than OFAT for the following reasons (Czitrom, 1999):

- In FED, investment of comparatively fewer resources (time, money and material) results in greater and more accurate information. This makes it extremely useful in industries, where time and financial costs of running a process are extremely high;
- Interactions between factors cannot be identified using OFAT technique, which uses trial and error method; whereas the FED technique provides a systematic procedure for estimating interactions between several factors;
- Each observation carried out during a factorial experiment considers all the factors and their interactions, which estimate the effect of factors much more precisely. In contrast, OFAT typically uses only two observations to measure the effect of one factor; these estimations are subject to greater variability.

The current study used the FED technique to address the problem of high TTV rejects in the lapping process. At a broader level, the Six Sigma methodology was applied for improving the output quality of the lapping process. Six Sigma emphasises the need to identify and clearly define customer requirements and internal industrial factors for setting goals. The data-driven rigour component of the Six Sigma approach delineates objective decision-making purely guided by the statistical analysis of data to determine process strengths and weaknesses. It is crucial to this approach that a solution is not offered until the problem has been clearly and completely defined (Ishikawa, 1985; Kume, 1985, 1995; Hoerl, 1998; Sreedharan et al., 2019).

2. Research methods

The Six Sigma methodology was applied to resolve the issue of high TTV rejects in the wafer lapping process, of the semiconductor manufacturing industry. The problem of the current project was formulated as follows: the mandatory replacement of slurry in the lapping process results in poor wafer flatness causing TTV rejects to increase from 0.1% to 4.43% or a loss of £58k/month.

The overall aim of this research was to evaluate the effectiveness of Six Sigma aiming to improve the quality output of the lapping process in the silicon wafer manufacturing industry.

Specific research objectives were to test the utility of the Six Sigma methodology in:

- Identifying the factors responsible for high TTV defect rates;
- Implementing sustainable long-term process improvements that will reduce the defect rate to <0.1%;
- Increasing the Lapping Process Performance index (Ppk) to >1.67;
- Delivering at least a £25k saving to the company by the end of the project.

The rationale for the project selection was based on the experience of one of the authors of this paper, who worked as a process engineer in the world's leading semiconductor wafer manufacturing company and received black belt level in-service training in the Six Sigma methodology. The issue of high TTV rejects had been causing huge financial losses (> £50k/month) to the organisation and was topping the priority list of the senior management. It was, thus, considered necessary to apply the statistically validated, well-known, effective strategy of Six Sigma to address this problem. A team of the appropriately qualified technical staff was delegated to undertake this task, under the leadership of a trained Six Sigma black belt specialist, the first author of this article.

DMAIC, which is a Six Sigma process, was employed for achieving the above stated objectives.

Six Sigma, inspired by Deming's Plan-Do-Check-Act cycle, has two popular methodologies, namely, DMAIC and DFSS. The DMAIC methodology is utilised for improving an existent process whereas DFSS — for the development of a new product. The current investigation followed the DMAIC principles, following the five stages:

- Define is the most important and critical stage of the Six Sigma process. First and foremost, project scoping and mapping is carried out that helps explain the basic problem to all the team members. Then, current process defects are defined according to customer's preferences, these are known as Critical to Quality (CTQ) metrics;
- Measure: at this stage, in accordance with the set goal and CTQ specifications, further measurements of key elements for the concerned process are carried out;
- Analyse: this stage includes an in-depth and scientific investigation of collected data, statistical tools are utilised to identify and assess the statistical significance of associations between various aspects of a process. Any findings should be objective, valid and justifiable by means of data. Analyses results help reveal the root cause of the defect in the manufacturing process. Results from the Analyse stage may also be treated as pilot results which are documented to facilitate replication of the same process design in the future;
- Improve: the results from the analyses were applied to eliminate the root cause of defects in a process, thereby improving the overall quality of the outcomes;
- Control: the methodology and results of each stage are clearly spelt out in sufficient detail to allow the replication in future processes to identify and correct early errors and prevent a financial loss due to defects in the yield. At this stage, Six Sigma tools of poka yoke, statistical process and quality control charts, and control plan were used.

3. Research results

Stage 1 — Define: the key aim of this phase was to mutually agree on a clear and concise problem statement, gain a fuller understanding of the process and identify the manageable focus area.

To clearly define and communicate the issue at hand, the following problem statement was developed based on IS-IS Not Analysis: the mandatory replacement of slurry in the lapping process is resulting in poor wafer flatness causing TTV rejects to increase from 0.1% to 4.43% or a loss of £58k/month.

Tab. 4. Critical to Quality metrics of the lapping process

Type[E]	Name	VOC	CTQ
External	Polishing	No sharp roll-off at the edge of wafer	For Loose Spec TTV < 3.5 µm
			For Tight Spec TTV < 2.0 µm
Internal	Lapping	Comparable yield to old active agent	TTV reject < 0.10 %
		Good Flatness	For Tight Spec TTV < 2.0 µm

Process mapping: all the essential components and steps of lapping were outlined in detail, such as material flow, operational activities, resources and material required; and the desired standards of the outcome were established. The aim is to provide all the team members with the understanding of the internal requirements of the process to allow for effective and quicker reviews in the case of any errors.

Critical to quality metrics: in Six Sigma, customer requirements are expressed through the Voice of Customer (VOC), which is converted into quantifiable Critical to Quality (CTQ) metrics. Tab. 4 displays the results on VOC and CTQ characteristics for both internal and external customers in the context of the current project. As lapping supplies two different products to polishing, there were two different CTQs for the same customer requirement (VOC). These CTQs were used throughout the project to assess improvements made to the lapping process.

Cause and Effect (C&E) Diagram is also known as the fishbone, 6M or Ishikawa diagram (Ishikawa, 1968). It is a tool to facilitate brainstorming, identifying the causes for an effect under six broad categories of Measurements, Material, Man, Environment, Methods and Machines. In the current project, poor flatness or TTV reject (CTQs) was the effect and a potential factor responsible for poor flatness. The initial project scoping identified over one hundred of potential causes for TTV rejects. It would have been excessively time consuming to analyse all these factors. So, it was important to prioritise potential causes and reduce the project scope to a manageable extent, which was achieved by using the Y=f(x) cascade tool as shown below in Fig. 2.

All causes identified during the making of the C&E diagram were combined in broad categories to form clusters. These clusters (five in the current scenario) formed the highest level in the Y=f(x) cascade, which was drilled into lower levels till it reached a manageable scope, as shown in Fig 2. Key input variables to be investigated are highlighted in blue and green.

It should be noted that Six Sigma is an iterative process, and it must continue running until the desired results are achieved. So, in this case, if the chosen experimental variables did not result in any improvement, remaining inputs were selected for the next iterative cycle.

Stage 2 — Measure: from the define stage, fourteen input variables were identified, for which the data collection plan using the Kipling's checklist was developed, as shown in Tab. 5.

MSA — the measurement systems analysis — was conducted on all the measurement devices used for data collection, which aimed to identify sources of variations, induced due to the measurement process. It included checks on measurement devices, personnel engaged in the data collection process, their skill sets, adequacy and accuracy of specifications, raw material and the measurement procedure. In the current study, two MSA tools of Gage R & R and Gage Bias & Linearity Study were used. Results from both studies suggested that all measurement tools were fit for purpose.

Establish the Baseline DPMO: first and foremost, the starting line for the process was established with the help of DPMO and process capability (Ppk). Key CTQ was TTV based on loose and tight specifications. The process capability for both types of materi-

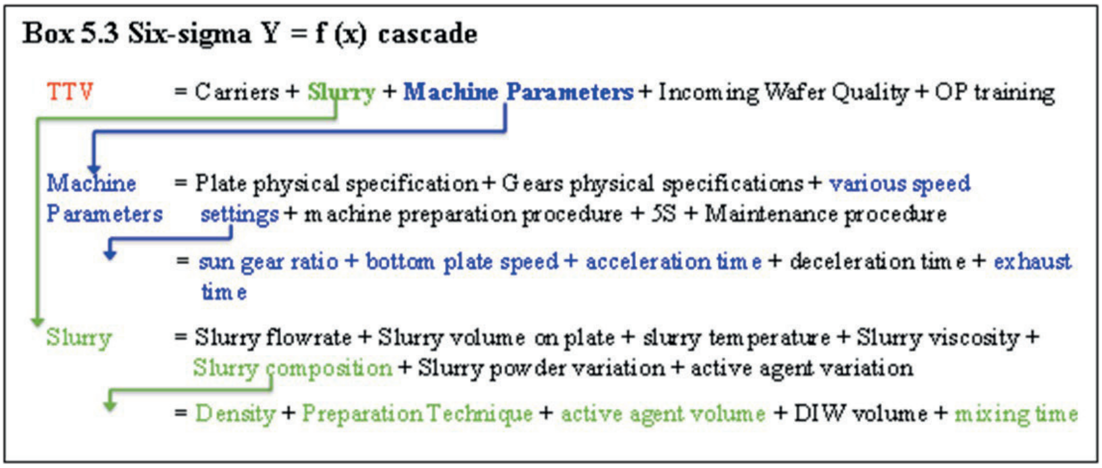

Fig. 2. Y = f (x) cascade

Tab. 5. Data collection plan

Item No.	What	Why	When	How	Where	Who
1	Wafer Traceability	To correlate poor TTV with different	Every Lot	Data capture application	Central Database Browser	- Lapping Op
2	TTV	KPOV, CTQ	Every wafer	Lapping ADE, Data upload	Central Database	CW Insp. Op
3	Slurry Mixing Time	KPIV	Every time fresh slurry prepared	Machine Setting (SOP)	Slurry Sheet	Lapping Op
4	Slurry Density	KPIV	Every time fresh slurry prepared	Manual Measurement	Control Charts	Lapping Op
5	Machine flowrate	KPIV	Every time loop was changed	Manual Measurement	Control Charts	Lapping Op
6	Plate Shape	KPIV (can affect wafer shape)	Every 40 hr of Opertion Time	Using dial gauge	Plate Shape Sheet	Lapping Op
7	Recycle Slurry Status	To evaluate impact of different slurry	Every 5 mins	Data capture application	BMS Database	PSE Op
8	Active Agent Volume	KPIV (can affect slurry viscosity)	Every time fresh slurry prepared	Machine Setting (SOP)	Slurry Sheet	Lapping Op
9	Sun Gear Ratio	KPIV (can affect wafer rotation)	Any time changed by engineer	Machine Setting (SOP)	QA Records	Engineer
10	Bottom Plate Speed	KPIV (can affect wafer rotation)	Any time changed by engineer	Machine Setting (SOP)	QA Records	Engineer
11	Exhaust Timer	KPIV (can affect wafer rotation)	Any time changed by engineer	Machine Setting (SOP)	QA Records	Engineer
12	Acceleration Timer	KPIV (can affect wafer rotation)	Any time changed by engineer	Machine Setting (SOP)	QA Records	Engineer
13	Slurry Temperature	KPIV (can affect slurry viscosity)	Every time fresh slurry prepared	Machine Setting (SOP)	Slurry Sheet	Lapping Op
14	Plate Temperature	KPIV (can affect slurry viscosity)	At the start of shift	Digital thermometer	Lot Processing Sheet	Lapping Op

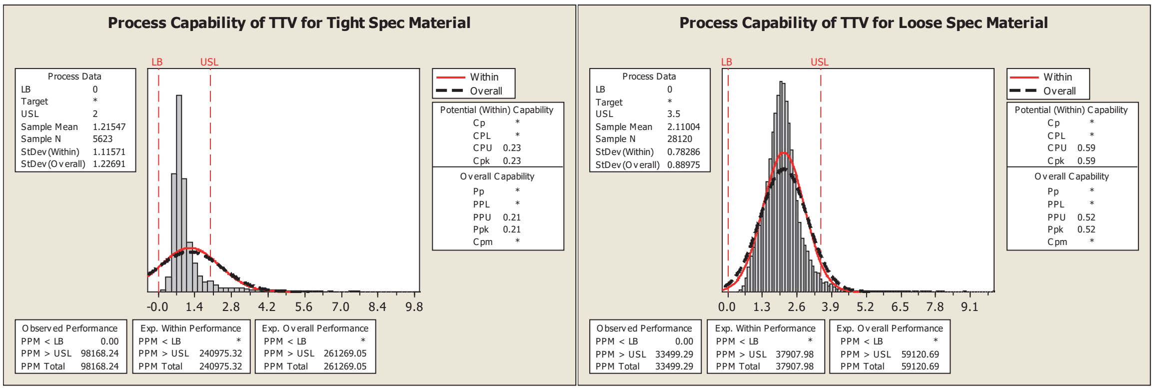

Fig. 3. Process capability of TTV for Tight and Loose Spec Material

als was calculated using Minitab Software, which is shown in Fig. 3 and Tab. 6.

As shown in Tab. 6, the combined TTV reject was very high at 4.43%, with TTV rejects for tight flatness specification being higher than that of loose flatness specification. For a Six Sigma project to be successful, it should be able to reduce DPMO to 1/10th, which means the combined TTV DPMO should be less than 4428.

Stage 3 — Analyse: during this phase, the collected data was analysed through a systematic application of statistical and graphical tools.

Control charts, also known as Shewhart charts, were used to identify key trends and generate clues.

Tab. 6. Key results from process capability charts

Parameters	Tight Flatness Spec	Loose Flatness Spec	Combined
Wafer Qty	5,623	28,120	33,743
TTV Reject %	9.82	3.35	4.43
DPMO	98,168	33,499	44,282
Process Capability (Ppk)	0.21	0.52	-NA-

Although there are different kinds of control charts, in the current study, Xbar-S and I-MR charts were used together with boxplots. The further investigation into out-of-control lots gave more clues, from which a number of Multi-Vari charts were generated but only two charts displayed a significant trend (Fig. 4).

Avg TTV refers to the mean of TTV for a lot; and it should be noted that a lot can have a wafer quantity from 100 to 320. Then, this mean of Avg TTV is further split by three factors: Lapping Machines, lots with Line Saw Mark (LSM) Rejects and Run Order of lots during the shift. The right-hand side graph is exactly the same, except for Std Dev of TTV on the Y-Axis. In summary, the following inferences could be extracted from the Multi-Vari charts (Fig. 4):

- The green trend line in Fig. 4 shows that generally, Avg TTV for the first lot of the shift was comparatively higher than the rest of the lots processed during the same shift. It means that something at the start of the shift was not correct, which was resulting in high Avg TTV. Factors that were different at the start of the shift and got stabilised during the shift were the slurry temperature, slurry mixing time and plate temperature;
- Generally, the wafers with Line Saw Mark (LSM) reject have a higher Avg and Std Dev TTV than the wafers without LSM reject. This is an important finding as it indicates that due to the poor quality of an incoming wafer, the wafer was unable to rotate freely at lapping. Wafer rotation could be affected by factors like sun gear ratio, plate speed, acceleration time and exhaust time;
- Generally, lapping machines have no significant impact on Avg and Std Dev TTV. It means that the problem is global and related to something that was common to all lapping machines, like slurry composition, slurry type etc.

Stage 4 — the Improve phase: based on enhanced learning gained from the Analyse phase, a list of factors that can influence TTV, was generated by the team using the brainstorming technique. To characterise the impact of these input variables on TTV, Design of Experiments were used. As part of DoE planning, a CNX diagram was generated, as shown in Fig. 5.

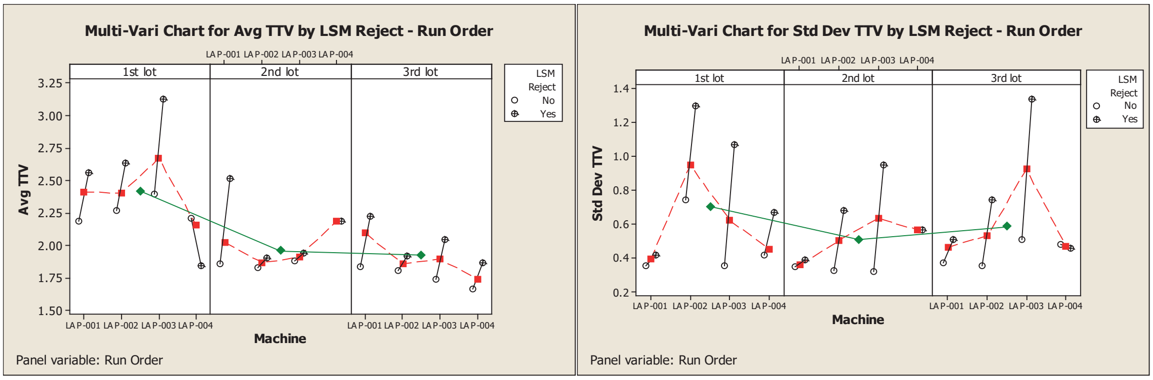

Fig. 4. Multi-Vari charts for Avg and Std Dev TTV by LSM reject — Run order

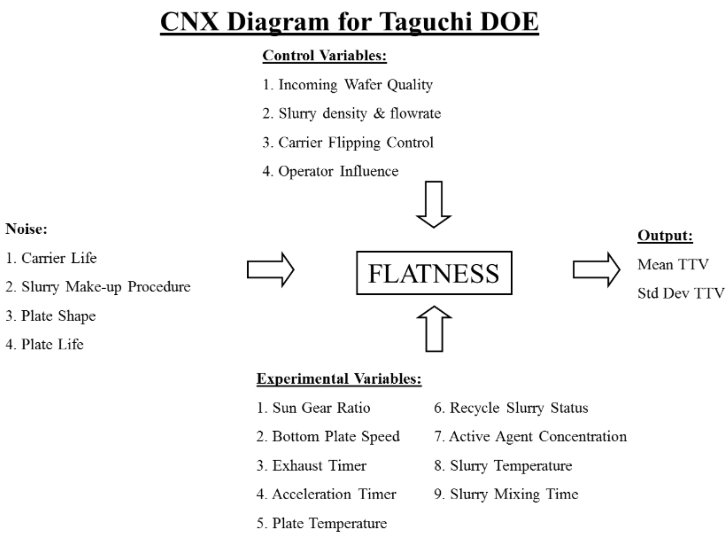

Fig. 5. CNX Diagram for DOE

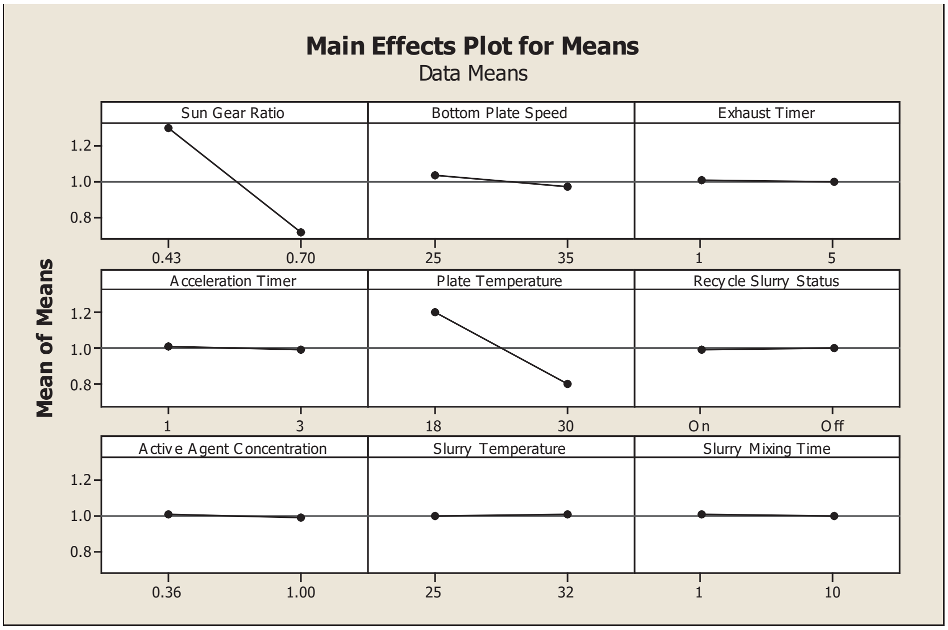

Fig. 6. Main effect plots for means

Tab. 7. Response Table for Means

Level	Sun Gear Ratio	Bottom Plate Speed	Exhaust Timer	Acceleration Timer	Plate Temp.	Recycle Slurry Status	Active agent concentration	Slurry Temp.	Slurry Mixing Time
1	1.2893	1.0338	1.0053	1.0092	1.1997	0.9940	1.0120	0.9957	1.0062
2	0.7123	0.9678	0.9963	0.9925	0.8020	1.0077	0.9897	1.0060	0.9955
Delta	0.5770	0.0660	0.0090	0.0167	0.3977	0.0137	0.0223	0.0103	0.0107
Rank	**1**	**3**	9	5	**2**	6	4	8	7

The list of experimental variables was still too long, and only screening DOE was feasible. Taguchi L12 design was used to rank the factors in the order of their impact on TTV. Taguchi L12 implied that by performing 12 lapping batches, nine experimental factors at two different values were evaluated for their impact on TTV, as shown in Fig. 6 and Tab. 7.

From Taguchi DOE, the top two ranked factors (the sun gear ratio and plate temperature) seemed to have a significant impact on TTV. Although the factor ranked third (the bottom plate speed) did not seem significant, it was still chosen for further analysis. As Taguchi is only a screening DOE, it is always recommended to perform a more comprehensive DOE to confirm the results of any screening DOE. So, three factors of the second level of the full factorial design of experiment (DOE) were designed with three centre points to characterise and optimise the three experimental factors.

DoE results in the Pareto chart represent the relative impact of differences between different factors on the process outcome. As shown in Fig. 7, factor A (sun gear ratio) had the biggest impact on TTV. This was followed by factor B and an interaction effect between factors A and B. The Pareto chart was also used to determine statistically significant factors and the effect of their interactions on the output. The factors above the red line were significant, and the factors below were non-significant.

T main effects plot (Fig. 8) indicated that an increase in the sun gear ratio, plate temperature and the bottom plate speed resulted in reduced TTV. Further, as centre points (marked red) for all the three factors were not on the line, the impact of these factors on TTV was not linear. In simple terms, the increase in the plate temperature to 24 °C did not result in any reduction in TTV; however, a plate temperature closer to 30 °C was most likely to reduce the TTV reject rate.

To make things simple, Minitab's response optimiser function could be used, which calculated values for input variables to achieve the optimum output. Results are shown in Fig. 9, suggesting that to achieve the minimum TTV (0.462), inputs should be set to the following parameters (highlighted in red):

- Sun Gear Ratio = 0.7;

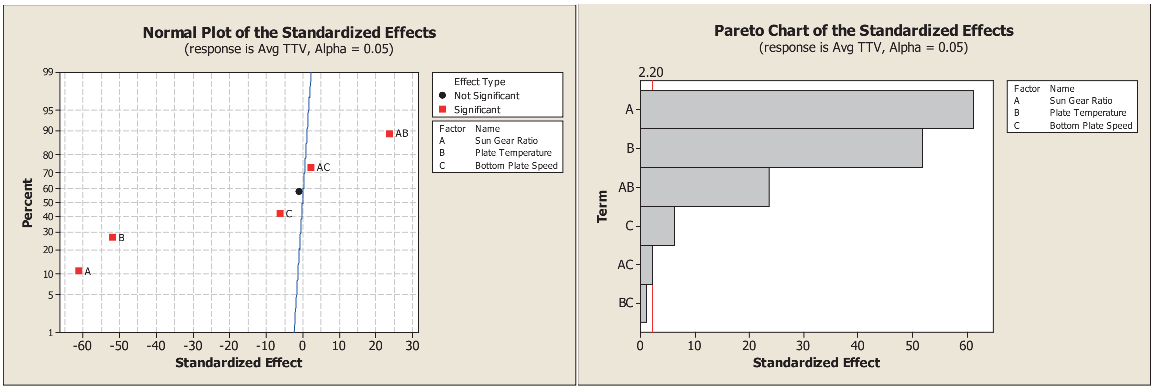

Fig. 7. Normal and standardised effects for Pareto charts

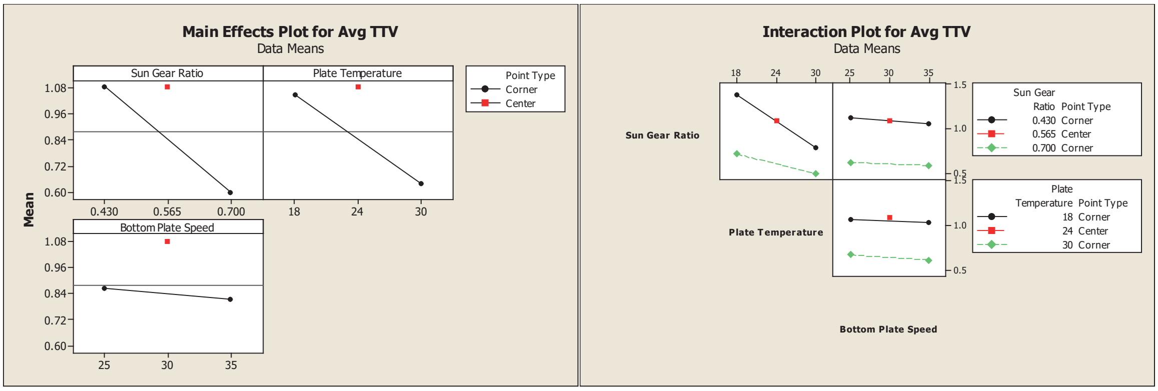

Fig. 8. Main effects and interaction plots for avg TTV

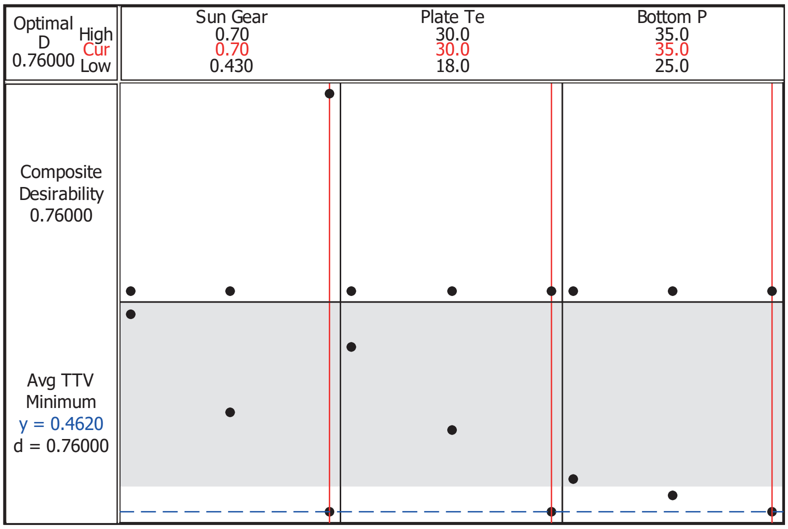

Fig. 9. Response optimiser result

- Plate Temperature = 30 °C;
- Bottom Plate Speed = 35 rpm.

To validate the theoretical predictive DOE model, a confirmation run should be conducted using the recommended input values. A confirmation run was carried out with six lapping batches, and the results are presented in Fig. 10.

Using the recommended input values, Response Optimiser predicted Avg TTV to be around 0.462 μm, which is exactly the same as the confirmation run result of 0.460 μm (see Fig. 10). The confirmation test, thus, confirmed the validity of the theoretical model.

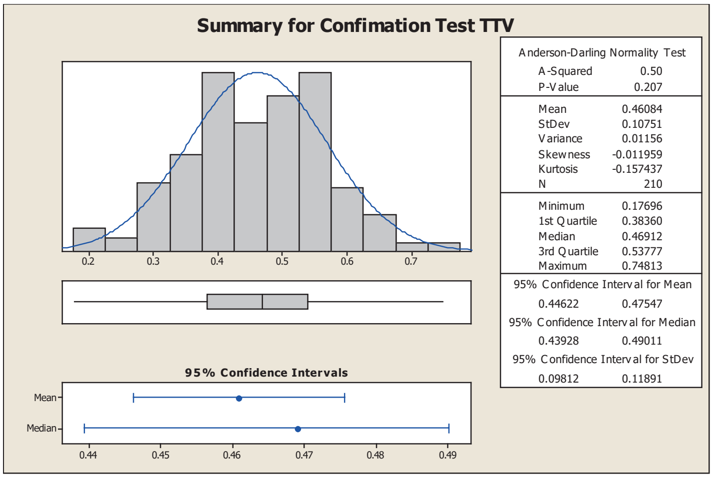

Fig. 10. Graphical Summary of Confirmation Test Run Results

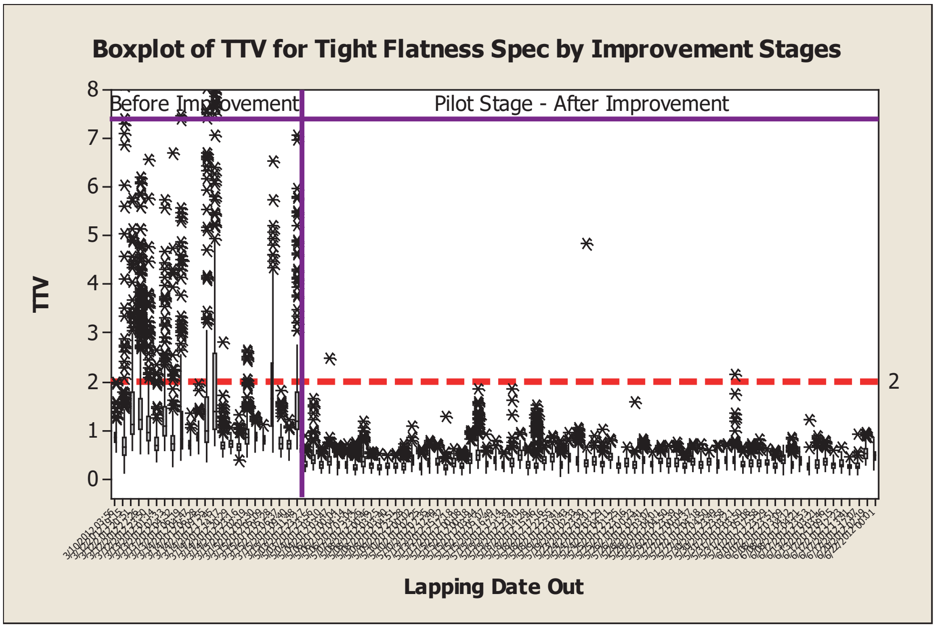

Fig. 11. Boxplot of TTV for tight flatness spec by improvement stages

Pilot testing was used for the validation of the results found during the improvement stage by implementing it on larger sample size. The incremental implementation with a continuous review of results was conducted to reduce the risk of large rejects. Loose TTV spec materials were run on one lapping machine for a limited period of one week, and then, the results were awaited. Since results from this initial phase were as expected, this optimum condition was expanded to other machines, one at a time. Boxplot results from the pilot stage for loose spec material are shown in Fig. 11.

There were rather a few wafers with TTV > 3.5 microns (spec limit) before improvement. However, a noticeable difference was visible after the introduction of the improved condition. It was found that TTV had become stable; and few wafers were above the spec limit. This improvement was statistically significant (W=1367172420.0 and p< 0.01). This data provided sufficient evidence in support of the improved condition for loose spec material. These conditions were then transferred to tight spec material, and the improvement in TTV was again statistically significant according to the Mann Whitney test (W=124139220.0 and p= 0.00).

The Establishing Process capability and DPMO were the next step, aiming to quantify and validate the new improved results. At the start of the process, the baseline for the lapping process was established using DPMO, which was now repeated for the improved process. The process capability charts are

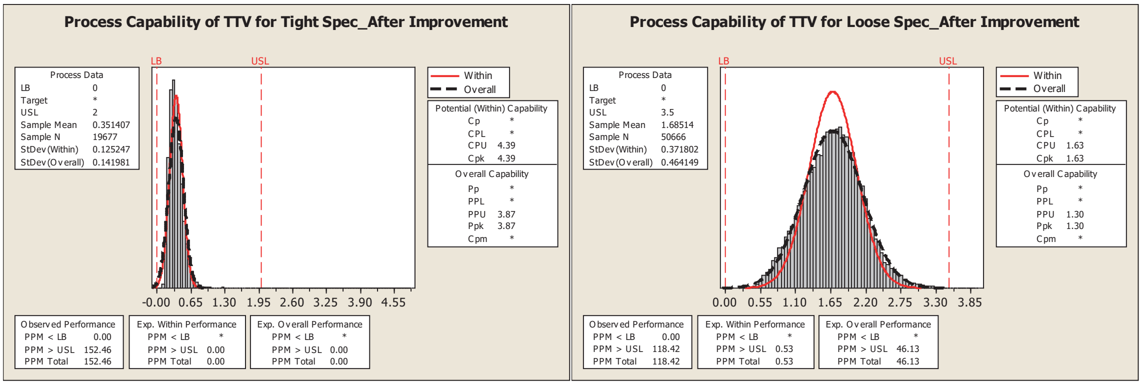

Fig. 12. Process capability of TTV for tight and loose spec after improvement

Tab. 8. Displaying the impact of improvements on TTV rejects

Parameters	Before Improvement			After Improvement		
	Tight Flatness Spec	Loose Flatness Spec	Combined	Tight Flatness Spec	Loose Flatness Spec	Combined
Wafer Qty	5,623	28,120	33,743	19,677	50,666	70,343
TTV Reject %	9.82	3.35	4.43	0.02	0.01	0.01
DPMO	98,168	33,499	44,282	152	118	127
Process Capability (Ppk)	0.21	0.52	-NA-	3.87	1.30	-NA-

shown in Fig. 12. The key results from Fig. 12 and from the start of the project are summarised in Tab. 8.

As shown in Tab. 8, there was a massive reduction in TTV rejects from 9.82% to 0.02% for tight flatness spec; from 3.35% to 0.01% for loose flatness spec; and from 4.43% to 0.01% for the combined materials. This is also reflected in the DPMO values. The initial target of the project was to reduce TTV rejects to less than 0.1%; and after the improvements, TTV reject for both specs was found to be less than 0.03%. Process capability charts clearly demonstrated that the mean and variation for loose spec material was comparatively higher than that of the tight spec material. Loose spec material went through other manufacturing processes that increased its TTV value, whereas tight spec material went straight to the TTV measurement stage. Hence, a true reflection of the lapping process capability could be evaluated by tight flatness spec material only. The process capability index increased from 0.21 to 3.87, suggesting a significant improvement in the output quality of the process, as well as sustainable long-term stability of the lapping process, in terms of controlling TTV of wafers.

Stage 5 — the Control phase: poka yoke. This term, commonly referred to as "mistake proofing", originated from Japanese words "poka" meaning "avoid" and "yokeru" meaning "mistakes". In the current scenario, the sun gear ratio and the bottom plate speed were identified as two key input variables for TTV control in the lapping process. So, the poka yoke method was exercised on the lapping machine, which would automatically prevent the machine from running if any of these two parameters were set incorrectly. This was achieved using continuous, automatic measurement of these parameters by the machine, and as soon as incorrect values were identified, an alarm went-off and the machine stopped running.

The Statistical Process Control (SPC) Chart: the underlying principle of Six Sigma is to reduce the process output variation by controlling key process input variables (KPIV's), which is done with the help of SPC charts. As discussed earlier, the second most critical parameter for good TTV is the plate temperature, where poka yoke cannot be applied. However, it is imperative to control it using SPC charts. The most appropriate SPC chart for this purpose is the Individual – Moving Range (I-MR) control chart.

Statistical Quality Control Chart is used to control the key process output variables (KPOV). In this project, the KPOV was TTV, which could be controlled using the Mean and Std. Deviation (Xbar-S) chart.

Control Plan is the master document, which lists all the parameters of the process that should be monitored and controlled to achieve the desired results. It is of utmost importance to communicate the control procedure amongst various stakeholders. Maintaining timely updates to the lapping process control plan was also important. Proper control and vigilance mechanisms for the key input parameters impacting the identified output and placing adequate controls for achieving quantifiable improvements were crucial.

4. Discussion of the results

The current implementation of the Six Sigma methodology to reduce flatness defects in lapping was successful. The silicon wafer flatness was found to be dependent on several and their interaction. This project presented an interesting revelation regarding the key input variables that can affect lapping TTV. Based on the controlled design of experiments, it can be concluded that the sun gear ratio and the plate temperature were the two most critical input variables affecting TTV. The interaction between these two factors was also statistically significant. The sun gear ratio of 0.7 and the plate temperature of 30 °C were the optimum setting to minimise TTV. However, care must be taken as these were optimum settings for one manufacturing plant location and were completely different from other locations using a similar manufacturing set-up.

The bottom plate speed was a statistically significant input factor. However, its impact on TTV was not as high as the other two significant factors (the sun gear ratio and the plate temperature). It was found that the bottom plate speed should be optimised at 35 rpm. The wafer rotation was critical for achieving the optimum TTV: Lapping is a closed process, which makes it difficult to see what is going inside the machine. As per the results of the test, which were discussed earlier, the increasing sun gear ratio and the bottom plate speed helped with wafer rotation. Further, the increasing plate temperature reduced the viscosity of lapping slurry, thereby aiding the wafer rotation as well. This suggested that if silicon wafer does not receive enough rotation in the lapping carrier, it can result in uneven lapping removal, thereby high TTV.

Detailed scoping of the problem at early stages helped to generate the following solutions. As part of the Six Sigma approach, a clear statement of the problem was drafted at the start of the project. Consistent with evidence of previous research (Mishra, 2018; Pyzdek, 2003), the scoping exercise largely consisted of ensuring that team members understand the nature of the problem and what is expected of them. A clear and shared understanding of the problem and the process at the early stages enabled working towards a common goal and channelling of team members' efforts in the right direction, avoiding any ambiguity or confusion. Following which, a detailed breakdown of the components of the problem facilitated a productive brainstorming session, resulting in a list of possible causes and solutions. For example, initially, a long list of over 60 potential causes was generated. It was practically impossible to evaluate all of them at the same time. However, it did not take very long for the Six Sigma experts in the team to suggest solutions for dealing with such situations, which was only possible due to a clear and detailed written statement of the problem. Six Sigma tools of project framing, cause and effect diagram and Y=f(x) cascade helped to shorten the long list of identified potential causes, thus making it easier to reduce the scope of the project to a manageable extent and providing the necessary focus to the evaluation.

A seamless, systematic roadmap of statistical thinking was ensured. Six Sigma is a step-by-step procedure for problem solving or process improvement. Previously, at this organisation, all the efforts to identify the root cause for high TTV rejects had failed. Whereas, with the help of Six Sigma methodology, wherein every step was clearly laid out in sufficient detail, the problem-solving process was much more straightforward. Whenever the project met a roadblock, a range of statistical tools was available to facilitate the problem-solving process. For example, after using several statistical and graphical analysis techniques, such as Multi-Vari charts, there were still nine potential factors whose impact on wafer flatness was unknown. At that stage, Taguchi screening DOE helped reveal that causal relationship. The learning point here is that since there are a wide number of tools and techniques listed at every step of the five phases of the Six Sigma process, at least one of them is likely to work for the concerned process.

Statistical tools were used to validate the engineering models. Statistical knowledge forms the core of the Six Sigma methodology, which is yet another important learning point gained from the current project. The implementation of the Six Sigma methodology in the current project can be argued to be a creative interplay between three components of managerial objectives, the expansion of engineering knowledge and the application of statistical techniques. Statistical analyses were used to validate the theoretical engineering models.

The full factorial DOE technique gives the Six Sigma methodology an edge over traditional problem-solving techniques. Full factorial DOE tool, which also belongs to Six-Sigma, was particularly useful in identifying key factors that were responsible for causing TTV rejects. Previous studies have also shown that the application of Taguchi and full factorial DOE technique helps to identify sources of variation in the process (Ghosh & Rao, 1996). Previous attempts at this organisation involved the use of One Factor at a Time (OFAT) technique. This technique had repeatedly failed to identify the underlying cause in the current scenario. In hindsight, it is now logical to understand why traditional problem-solving techniques had failed. In the current project, an interaction between more than one factors (plate temperature and sun gear ratio) was responsible for high TTV rejects. Such an evaluation of the interaction between more than one input factor would have been impossible to perform through traditional problem-solving techniques, such as OFAT. The use of Full factorial DOE technique revealed not only the impact of all three significant factors but also imparted new insights on the interaction between these factors. It was found that unless these factors are set at their respective optimum levels simultaneously, inputting of individual optimum values of these factors will still result in poor TTV values.

Implementation and control were also carefully considered. It had been argued in previous research (Sreedharan et al., 2019; Raman & Basavaraj, 2019) that after the desired results through the Six Sigma methodology are achieved, if appropriate monitoring and control procedures are not established, then most likely the process would regress back to its original, flawed state (Antony & Coronado, 2002; Muraliraj et al., 2018). A similar phenomenon had been observed in this organisation, where an effective solution had temporarily fixed a problem, but a lack of appropriate control systems caused the re-appearance of the same issue. For such reasons, in the current project, much emphasis was put on the control stage of the Six Sigma methodology, which was a new experience for the entire team and, probably, the organisation too.

Limitations

How stable are the improvements in the lapping process? It has been shown that despite noticeable improvements achieved by a project in the short-term, its sigma level and performance can decline over time by 1.5 sigma. The standardised six-sigma level accounts for such variations in the long-term. Since the current process did not achieve the full six-sigma level, it is likely that in case of a 1.5 sigma shift occurring, the process capability might regress to its original state. Nevertheless, another measure of long-term stability of an improved process achieved through the implementation of Six Sigma methodologies is the process capability (Ppk) index. The Ppk index of the current process was found to be 3.87, which indicates that a sustainable solution to the problem has been identified and implemented. It also ensures that correct factors responsible for poor wafer flatness have been identified and that adequate control has been exerted to maintain a long-term process stability. Any decline in the process capability or quality over long term should, therefore, be unlikely.

Conclusions

This study aimed to reduce flatness rejects in the lapping process of silicon wafer manufacturing using the Six Sigma methodology. It is a novel application of Six Sigma as previously it has been implemented in several industries, such as finance, service, manufacturing and non-manufacturing but not for the lapping process of silicon wafer manufacturing in the semiconductor industry. A significant reduction in rejects from 4.83% to 0.02% was achieved through the implementation of the Six Sigma methodology, resulting in the savings of £57.5k/month. A significant increase in the capability index (Ppk) of the lapping process also occurred, which is indicative of the enhanced product quality and efficiency, thereby increasing customer satisfaction. In the current project, three factors (the sun gear ratio, the plate temperature and the bottom plate speed) and the interaction between the sun gear ratio and the plate temperature were statistically significant. The optimisation and tighter control of these variables were key for the successful reduction in TTV rejects.

On a large scale, dealing with such complex processes as lapping, it is often difficult to agree on a starting point and contain the scope to a manageable extent. The Six Sigma techniques of define and measure provided a much-needed direction and structure to the problem-solving process, at an early stage. Previous attempts using traditional problem-solving techniques had failed since several potential factors and their complex interactions were responsible for high TTV rejects. On the other hand, the Six Sigma technique could quantify and rank order several factors with their interactions in terms of their relative effect on the process outcome. Other Six Sigma pointers, such as the commitment of the top management, the interim publication of success stories and open communication, also helped to maintain the motivation and focus throughout the project.

Overall, Six Sigma was shown to be an effective problem solving and quality improvement statistical technique for the semiconductor industry, which lead to a series of other benefits (such as the increase in the process efficiency, the reduction in time and financial costs, the enhanced satisfaction of customers and employees as well as the provision of innovative team building and networking opportunities), in addition to the defect rate reduction in the lapping process. The relevance of Six Sigma in the manufacturing industry is irrefutable, but there may be a need to conduct further rigorous research on its utility across non-conventional sectors and the practicalities in terms of incurring costs and resources.

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Performance of an automated process model discovery – the logistics process of a manufacturing company

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ABSTRACT

The simulation and modelling paradigms have significantly shifted in recent years under the influence of the Industry 4.0 concept. There is a requirement for a much higher level of detail and a lower level of abstraction within the simulation of a modelled system that continuously develops. Consequently, higher demands are placed on the construction of automated process models. Such a possibility is provided by automated process discovery techniques. Thus, the paper aims to investigate the performance of automated process discovery techniques within the controlled environment. The presented paper aims to benchmark the automated discovery techniques regarding realistic simulation models within the controlled environment and, more specifically, the logistics process of a manufacturing company. The study is based on a hybrid simulation of logistics in a manufacturing company that implemented the AnyLogic framework. The hybrid simulation is modelled using the BPMN notation using BIMP, the business process modelling software, to acquire data in the form of event logs. Next, five chosen automated process discovery techniques are applied to the event logs, and the results are evaluated. Based on the evaluation of benchmark results received using the chosen discovery algorithms, it is evident that the discovery algorithms have a better overall performance using more extensive event logs both in terms of fitness and precision. Nevertheless, the discovery techniques perform better in the case of smaller data sets, with less complex process models. Typically, automated discovery techniques have to address scalability issues due to the high amount of data present in the logs. However, as demonstrated, the process discovery techniques can also encounter issues of opposite nature. While discovery techniques typically have to address scalability issues due to large datasets, in the case of companies with long delivery cycles, long processing times and parallel production, which is common for the industrial sector, they have to address issues with incompleteness and lack of information in datasets. The management of business companies is becoming essential for companies to stay competitive through efficiency. The issues encountered within the simulation model will be amplified through both vertical and horizontal integration of the supply chain within the Industry 4.0. The impact of vertical integration in the BPMN model and the chosen case identifier is demonstrated. Without the assumption of smart manufacturing, it would be impossible to use a single case identifier throughout the entire simulation. The entire process would have to be divided into several subprocesses.

KEY WORDS

process mining, automated process discovery, simulation, agent-based simulation, ABS

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Introduction

In today's world, various industries and economic sectors are changing as a result of the digital transformation, which is part of fourth industrial revolution called "Industry 4.0" (Slusarczyk, 2018; Qin et al., 2016). The shift from simple digitisation of the previous industrial revolution is going to force companies across the supply chain to re-examine the way they do business. The concept of Industry 4.0 was introduced by the German government in 2011 in the context of its hi-tech strategy aimed at the industrial sector and was quickly adopted all around the world. Industry 4.0 is closely linked to the Internet of Things (IoT) and represents the ability of industrial components to communicate with each other (Roblek et al., 2016; Piccarozzi et al., 2018). However, Industry 4.0 does not relate only to the digitalisation of the industrial sector but considers the entire value-added chain, including sub-systems like, for example, research and development, retailers, suppliers, customers etc. The main idea of the Industry 4.0 concept is aimed at preserving the competitiveness in the light of increasingly more demanding customers. Several concepts and technologies are available for the fulfilment of the main objective of Industry 4.0. Firstly, the literature specifies three types of integration: horizontal, vertical and end-to-end integration. Vertical integration considers processes within an organisation, while horizontal integration emphasises cross-organisational processes within a value chain (Sony, 2018). End-to-end integration assumes the involvement of the product itself within both the horizontal and vertical integrations (Wang et al., 2016). Secondly, the particular integrations are joined by concepts of smart factories, smart product, new business models and new customer services (Qin et al., 2016). Thirdly, there are several leading technological solutions with a major impact on production and services: Cyber-Physical Systems (CPS), big data analytics, cloud computing, autonomous machines, simulations, augmented reality, IoT etc. (Pan et al., 2015; Kolberg & Zühlke, 2015), where the use of all of such technologies leads towards further digitisation and computerisation of production, service and market processes. Thus, in the future of manufacturing, the particular sub-systems of a value-added chain will be connected into an intelligent network with the use of CPS to relate physical and virtual spaces. This paradigm shift means that an information system manages an intelligent network while considering physical factors to allow independent process management, which represents a fundamentally new aspect of the production process leading towards reshaping of production, consumption, transportation and delivery systems (Rodič, 2017). As it is obvious from the literature regarding the Industry 4.0, there will be significant requirements for the management of business processes across the entire value-added chain.

Thus, the subject of this study is big data analytics and simulations, or, to be more precise, process mining and agent-based modelling and simulation (ABS) because of their potential to enhance process management of the network of sub-systems within the Industry 4.0 concept. The further digitisation and computerisation of business processes within the Industry 4.0 mean that less common approaches within the business practice, like ABS, are becoming trendy, and it is expected that in the near future, they will become common in many areas of business. One of the conditions of successful ABS employment is the ability to automatically produce appropriate process models that can be exploited by ABS. The idea is supported by other requirements for Industry 4.0, such as self-organisation, self-adaptation, reconfigurability, self-awareness etc. (Pisching et al., 2018; Dinardo et al., 2018; Wan et al., 2017). They will be part of the process management of an intelligent network of a value chain. And the automated discovery of process models will be necessary not only with regards to the use of ABS within Industry 4.0 but also within the Industry 4.0 concept in general. Thus, the objective of this research paper is to benchmark the automated process discovery techniques on the realistic simulation models of supply-chain elements. The design of supply chain and operations play a significant role in the success or failure of a company (Kozma, 2017). As it is crucial for a simulation model to work with the most precise model possible to ensure that the following analysis brings the best outputs in terms of enhancement, the prediction and understanding of the investigated system were based on the data produced by the system. If the business processes are poorly designed or contain errors, then customer needs are not fully satisfied due to the insufficient performance of the process. Similarly, if, using the simulation modelling at both operational and strategic level, the decision-making process is based on unprecise process models, the impacts will be equivalently bad.

Simulation modelling is used for the representation of real or imagined systems or processes for the purpose of its analysis and understanding. Today, the use of simulation modelling is well established in science, engineering etc. (Abar et al., 2017). It is used for prediction, performance analysis, process discovery, etc. In business practice, modelling is used mainly as a tool for operational and strategic management and decision making in many of its areas like marketing, management, logistics, scheduling, etc. Simulation modelling is powerful because it allows investigating the influence of random variables on a dynamic system using both quantitative and qualitative views

(Doomun & Jungun, 2008; Hlupić & Vukšić, 2004). There are many approaches to simulation modelling, such as analytical modelling, based mostly on mathematical theories (Gries et al., 2016), system dynamics (Macal, 2010; Borshchev & Filippov, 2004), discrete event simulation (Siebers et al., 2010; Chan, Son & Macal, 2010). However, ABS is becoming increasingly more popular for several reasons. Firstly, it offers a broad scope of analysis in terms of levels of the used abstraction of complex modelled systems, thus allowing the analysis of much greater detail than is possible using other paradigms. Active elements of the system are represented by software agents with defined behavioural patterns replicating the complexity of the system (Kelly et al., 2013; North & Macal, 2008). Secondly, evidence is available showing that ABS work well with the most crucial technologies and concepts of Industry 4.0, be it IoT or smart products (Savaglio et al., 2017), smart manufacturing (Bannat et al., 2011), vertical integration (Hsieh, 2015), CPS (Leitao et al., 2016), autonomy and related self-organisation, self-awareness, machine-human and machine-machine interaction etc., (Boes & Migeon, 2017; Pomarlan & Bateman, 2018; Claes et al., 2017).

Several research papers attempt to evaluate the performance of automated process discovery techniques, for example, Augusto et al. (2018) and Weerdt et al. (2012). This paper is organised as follow: the following section presents a literature review of process mining techniques with a focus on the automated process discovery. The third section details the methodology of the research. The fourth section comments on the results of the benchmarking of the chosen process discovery techniques. Finally, the results are summarised and discussed.

1. Process mining

Process mining is a group of techniques combining the data-based point of view of data science with the process-oriented one. Process mining is related to the general domain of knowledge discovery in databases (KDD) as it has a similar approach to the analysis of large repositories of data and learning from them. Similarly to KDD, within the process mining domain, researchers developed numerous quantitative techniques and approaches to allow examining the execution of traces of business activities from the process-oriented perspective. In that sense, the focus of process mining is on processes and makes the distinction between process mining and KDD or business intelligence (BI) tools, eminent as the BI tools, focus primarily on key performance indicators (KPIs) and, thus, lack the ability to provide insight into the root causes of process inefficiency and erroneousness (Weerdt et al., 2012). Process mining can be defined as a group of techniques that search for hidden information and patterns in the data allowing for the performance analysis of the actual processes based on data produced by processes itself (Aalst, 2016; Aalst et al., 2011). This data is stored by information systems supporting such processes and recording execution events of processes, such as the start of the case, the execution of the task within a case, and others. There are various properties of an event that can be tracked and recorded, such as timestamps, costs, prices etc. The sequence of all events related to a particular case is called a trace, and the collection of such records is referred to as an event log. Thus, an event log has to carry certain minimal information to be applicable for a process mining analysis. Firstly, it has to distinguish between particular process instance or cases. Secondly, events within cases have to be ordered and, lastly, there has to be a function that assigns actions to events within the log (Aalst, 2015). As there are information and communication technologies in the background of the main driving forces of Industry 4.0, there will be a considerable amount of event logs produced by information systems supporting the processes of Industry 4.0, such as CPS, enterprise information systems, enterprise resource planning systems etc.

As of now, there are five significant areas of research within the process mining domain. The automated process discovery focuses on building process models from real data using various algorithms and approaches (Aalst, 2016). Next, conformance is checked using the evaluation and comparison of process models and event logs based on different criteria to identify commonalities and discrepancies between behaviour of process models, process model and event log or event logs (Buijs, Dongen & Aalst, 2014; Buijs, Dongen & Aalst, 2012; Aalst, 2005). The enhancement of the process means the extension or improvement of an existing process model using the information about an actual process in some event log (Aalst, 2016). Further, operational support focuses on particular processes online and in real time. This means that operational support not only uses post-mortem data but also pre-mortem data from unfinished process instances (Aalst et al., 2011). Lastly, there is deviance mining, which is a group of techniques used to analyse deviances of different variants of processes (Nguyen et al., 2016). The process mining techniques are briefly introduced for the sake of completeness, and the focus of the rest of this section is on automated process discovery techniques.

1.1. Automated process discovery

Throughout the process mining literature, out of the previously mentioned areas, the automated process discovery is the most widely researched. As input, automated process discovery techniques take an event log containing the information about the behaviour of the analysed process, and then produce a process model representing control-flow containing relations between tasks observed or implied in the event log (Aalst, Weijters & Maruster, 2004). However, for discovered process models to be useful, they have to find an appropriate balance between several properties (Aalst, 2016; Buijs, Dongen & Aalst, 2014), such as fitness, precision, generalisation and simplicity. The fitness quality dimension describes the fraction of the behaviour in the event log that can be replayed by the process model, essentially meaning that the discovery method generates traces that are present in the log or are similar to a trace in the log. On the other hand, the precision quality dimension estimates the behaviour unseen in the event log but allowed by the process model, essentially meaning that the discovered model should not generate traces that are too different from the behaviour seen in the log. The generalisation quality dimension is indicated if the event log is not overfitting the behaviour present in the event log as the event log itself may contain only partial behaviour of the analysed system, essentially meaning that the discovery method generates traces not seen in the model which have similar behaviour to the traces seen in the event log. Finally, the simplicity quality dimension states that the discovered process model should be as simple as possible. As criteria go against each other, it is necessary to find the appropriate balance between them; however, this is not an easy task, especially considering real-life event logs. Thus, according to Augusto et al. (2018), there are two major problems which occur during the application of automated process discovery methods on real-life event logs: 1) the discovery method produces large spaghetti-like models (Fig. 1), which are incomprehensible, unstructured and very hard to analyse and work with (Aalst, 2016; Aalst, 2011); and 2) they produce models with unsatisfactory quality dimensions, be it poor fit of the log or ever-generalised model.

According to Tiwari, Turner & Majeed (2008), pioneering work in the area of the automated process discovery and process mining discipline, in general, was done by Agrawal, Gunopulos & Leymann (1998) and Cook & Wolf (1998) and their foundational approaches. Agrawal, Gunpulos & Leymann (1998) focused on mining models from workflow systems with the main focus on the appropriate ordering of

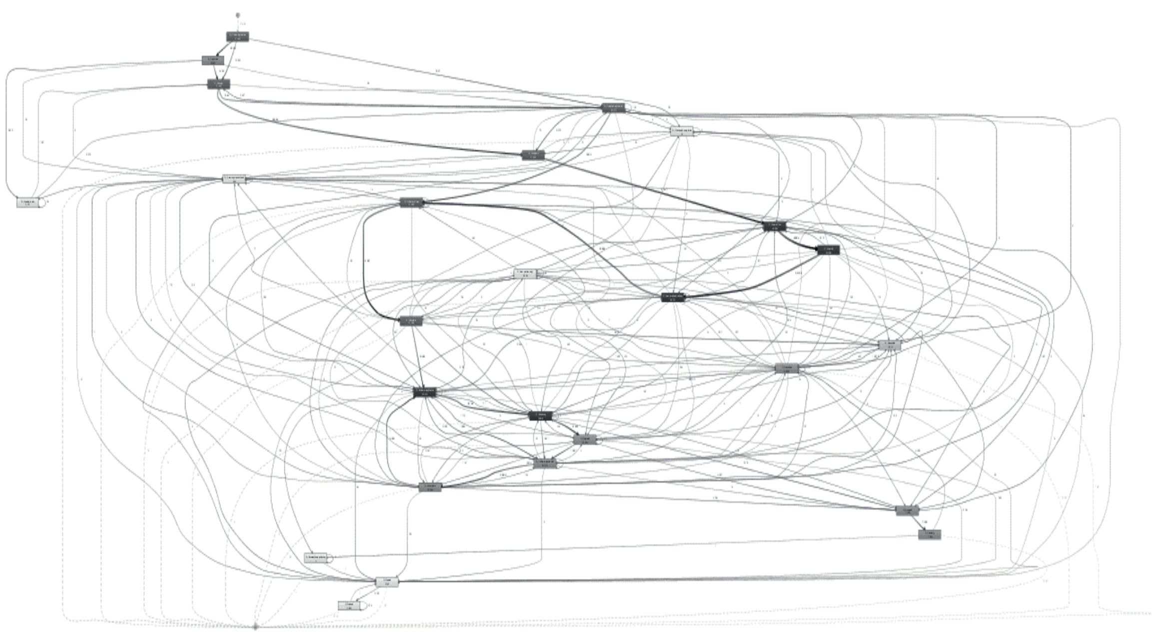

Fig. 1. Example of a spaghetti-like process model

activities and the successful termination of the process. Cook & Wolf (1998) described the application of Markov method within the process mining domain in addition to RNet and Ktail methods and evaluated the three proposed approaches to the automated process discovery: algorithmic, statistical and probabilistic. As was predicted by Cook & Wolf (1998), the most popular approach to the automated process discovery will be the algorithmic approach. This prediction turns out to be true and algorithmic approach to the automated process discovery is by far the most popular approach among researchers of the field (Tiwari, Turner & Majeed, 2008; Augusto et al., 2018).

One of the most influential techniques of the automated process discovery was introduced by Aalst, Weijters & Maruster (2003) and called α-algorithm. In their work, Aalst, Weijters & Maruster proved that α-algorithm is capable of discovering structured workflow-nets, which are an important class of Petri nets in the area of business processes, from complete event logs, assuming that they do not contain any noise. However, the original α-algorithm had several shortcomings in the form of short loops, invisible, duplicate or implicit tasks and non-free-choice constructs (Medeiros, Aalst & Weijters, 2003). Thus, the α-algorithm was extended several times. Firstly, Medeiros et al. (2005) introduced so-called α+-algorithm, so it was able to deal with short loops using the pre-processing of patterns specific to short loops. Next, Wen et al. (2007) and Wen, Wang & Sun (2006) introduced α++-algorithm that was able to detect non-free-choice constructs by considering a new relation called the implicit dependency. Wen et al. (2010) introduced α#-algorithm, capable of mining invisible tasks by considering the relation called the mendacious dependency. The latest version of an α-algorithm, so-called α$-algorithm was introduced by Guo et al. (2015). The algorithm uses improved mendacious and implicit dependency relations, and besides invisible and non-free-choice constructs, it is also able to mine invisible tasks in non-free-choice constructs.

HeuristicsMiner is another influential approach to the automated process discovery, which was introduced by Weijters, Aalst & Medeiros (2006). HeuristicsMiner was introduced to deal with noise and incompletion of event logs, where noise means events recorded in the log that are not supposed to be there and that do not represent the behaviour of the analysed process. On the other hand, an incomplete event log means missing data. It is an extension of α-algorithm in a sense that it considers frequencies, by which activity relationships occur (Aalst, Weijters & Medeiros, 2003) in the event log. In addition to robustness of an event log, HeuristicsMiner is also capable of dealing with short loops and non-local dependencies. Broucke & Weerdt (2017) introduced the discovery technique Fodina that is based on HeuristicsMiner and which handles the noise in the log and discover duplicate activities. Flexible Heuristics Miner (Weijters & Ribeiro, 2011) is yet another discovery technique based on HeristicsMiner. Similarly to previous techniques, Flexible Heuristics Miner can also deal well with noise in event logs.

In a series of papers, Leemans et al. (2013a, b; 2014) introduced the so-called inductive mining. Later versions focused on infrequency and incompleteness. Inductive mining produces process models in the form of process trees. The advantage of inductive mining is that it does provide guarantees in terms of soundness and re-discoverability of discovered process models. Leemans, Fahland & Aalst (2015; 2016) introduced the framework based on inductive mining that adds the advantage of scalability, while still guaranteeing the soundness and re-discoverability. Evolutionary Tree Miner introduced by Buijs, Dongen and Aalst (2012; 2014) belongs to the group of genetic algorithms and extracts process models from event logs in the form of a process tree.

Split Miner proposed by Augusto et al. (2017) is a technique with consistently high and balanced fitness, precision and generalisation that guarantees the deadlock-freedom for cyclic process models and the soundness for the acyclic. It merges an innovative approach to filter the directly-follows graph induced by an event log, with an approach to identify combinations of split gateways that accurately capture the concurrency, conflict and causal relations between neighbours in the directly-follows graph.

Günther & Aalst (2007) introduced Fuzzy Miner to tackle with unstructured processes. Fuzzy Miner is an adaptive simplification and visualisation technique based on significance and correlation measures to visualise the behaviour in event logs at various levels of abstraction (Weerdt et al., 2012). Previously mentioned algorithms use Petri nets as a representation of discovered process models. However, the discovered fuzzy model cannot be translated to the Petri net, which is a severe disadvantage to the Fuzzy Miner approach as it limits the comparability of Fuzzy Miner to other techniques. The same problem is characteristic of many more techniques.

Applying the genetic algorithm to process discovery, Medeiros, Weijters & Aalst (2007) introduced the so-called genetic process mining. An effort of the genetic process mining was to overcome problems related to non-free-choice constructs, and furthermore, invisible and duplicate task. Previously mentioned discovery techniques are limited by a local search, which is causing problems in discovering non-free-choice constructs or invisible and duplicate task. Thus, the global approach of genetic process mining comes into play, enabling the discovery of non-local behaviour (Weerdt et al., 2012). The advantage of the genetic process mining is that while most of other process discovery techniques focus only on one or two quality dimensions at the same time (Buijs, Dongen & Aalst, 2012), the genetic process mining can address all four quality dimensions.

Furthermore, several authors, for example, Werf et al. (2009), Aalst et al. (2010), based their automated discovery techniques on the principles of the theory of regions and integer linear programming (ILP). One of the main goals of automated discovery algorithms based on the theory of regions and ILP was to address the issue related to the assumption of completeness of the event log and the related problem of overfitting or underfitting the discovered process model by solving a series of ILPs. ILP was also used by Zelst et al. (2018) in their approach to automated process discovery. HybridILPMiner by Zelst et al. (2018)'s is based on the theory of regions and discovers relaxed sound workflow nets built on hybrid variable-based regions. Dongen & Aalst (2004) introduced the multi-phase process mining to mine instances of processes that can be later translated into other models, such as Petri nets of Event-driven Process Chains (EPCs). Correspondingly to techniques based on the theory of regions, the multi-phase process mining addresses the assumption of completeness of the log. The divide and conquer framework (Verbeek, Aalst & Munoz-Gama; 2017, Verbeek & Aalst, 2015) decomposes the process model discovery into smaller parts working with discovery techniques, and in this study, with ILP.

2. Methodology

The methodology section is divided into the following subsections: the first subsection describes the procedure of the acquisition of event logs from hybrid simulation models in AnyLogic framework. The second subsection describes business processes captured in a simulation model. The third subsection describes automated process discovery techniques used to benchmark and the use of metrics.

2.1. Procedure of the acquisition of event logs

To evaluate different automated process discovery techniques and assess their performance with ABS, a hybrid simulation was chosen from the AnyLogic framework (2019), based on which synthetic event logs were generated by replaying the process model. Hybrid simulation means that the simulation model consists of two or more approaches, meaning that the simulation model combines characteristics of two approaches, for example, ABS and discrete-event simulation, which was also used for the purpose of this study. The AnyLogic framework does not directly produce event logs needed for the process mining analysis. Thus, first, it is necessary to acquire such event logs. For this purpose, the BPMN 2.0 notation and the business process simulator (BIMP, 2019) were used. First, based on flowcharts and statecharts of business processes contained in the chosen hybrid simulation, models were transformed into BPMN process models. Then, the BPMN process models were simulated using the BIMP software that can produce an event log in the form of an MXML file. The BPMN notation is expressive enough to reproduce the control flow of a hybrid simulation model without any sacrifices (Fig. 2).

Furthermore, as stated in the Introduction section, the main advantages of ABS are the autonomy of agents, the complexity of the models etc. The autonomy of agents allows them to make decisions and, thus, determine the control-flow in particular process instances through such decisions. However, automated process discovery techniques are mainly focused on relations between occurring events and their sequence, and not necessarily on the reasons why the behaviour occurred. Thus, by expressing the behaviour of the modelled system using the BPMN notation, all the information relevant to automated process discovery techniques is preserved. While simulating the BPMN model in the business process simulator BIMP to acquire an event log, each event has to have a timestamp, so it can be ordered within the trace and, thus, processing times and arrival distributions of process tasks have to be defined for the purpose of generating an event log in the BIMP simulator. Where possible, parameters were used from the hybrid simulation model; otherwise, they were made artificially. However, it is necessary to keep in mind

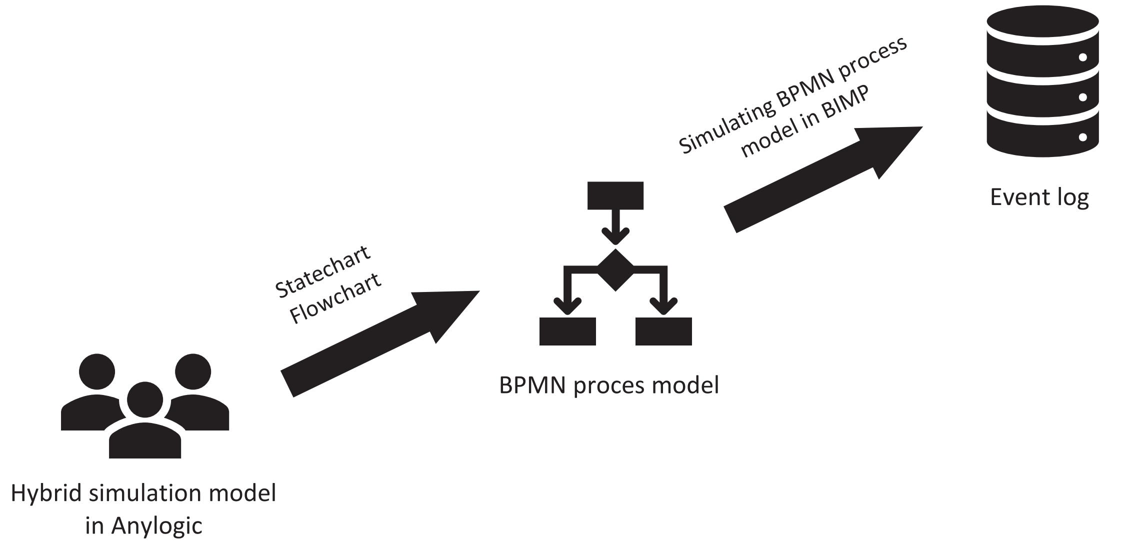

Fig. 2. Procedure of the acquisition of event logs from AnyLogic

that this does not pose a problem to the validity of the event log because the interest is not in the performance of the process itself and, thus, particular timestamps, but rather in the control flow of the process.

2.2. Description of a simulation model

A simulation model simulates the logistic process in a small job shop. Specifically, it is a logistics process describing the import of raw material, its storage, transformation into a product and its export. The overall process of the job shop simulation is as follows: the raw material is delivered to the receiving dock, where it is placed into storage until the processing occurs at the machine. Finished products are palletised and then moved to storage at s shipping dock until the completed pallets can be loaded on a truck.

The BPMN process model of the hybrid simulation is provided in Fig. 3 and is as follows: the start event in the business model is represented by the arrival of a truck with raw material. When the truck arrives at the docks, the system checks if the forklift is available. In the case that a forklift is available, it is assigned, pallets are unloaded from the truck and simultaneously assigned. In another case, the system automatically checks for an available forklift again until the forklift is assigned. After the pallets are unloaded, they are transferred into docks and stored. When the time comes, the pallets are assigned to particular machines for processing and transported to the assigned machines. This job used the second group of forklifts. Once the pallets are transferred to the machines, the raw material is processed. After the processing, the finished products are collected and put into storage. This processing part of the logistics process lies inside the big XOR gate. When the time comes, the system schedules a truck and finished products are prepared for export. When the truck arrives, the finished products are loaded, and the process ends when the loaded truck leaves. Fig. 4 basically represents the same model, but with 4 added

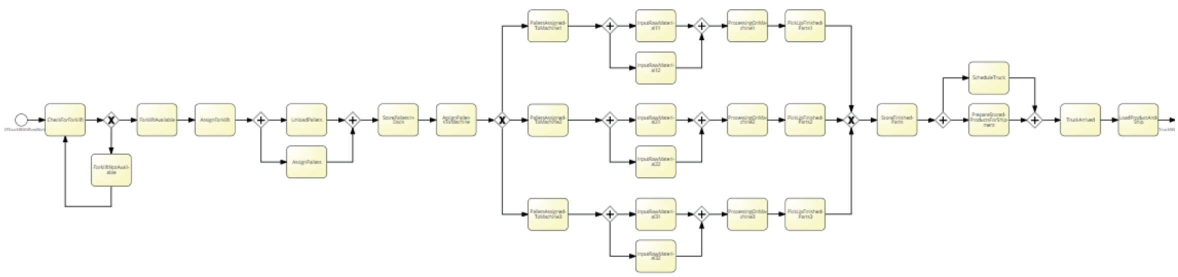

Fig. 3. BPMN process model of the hybrid simulation model

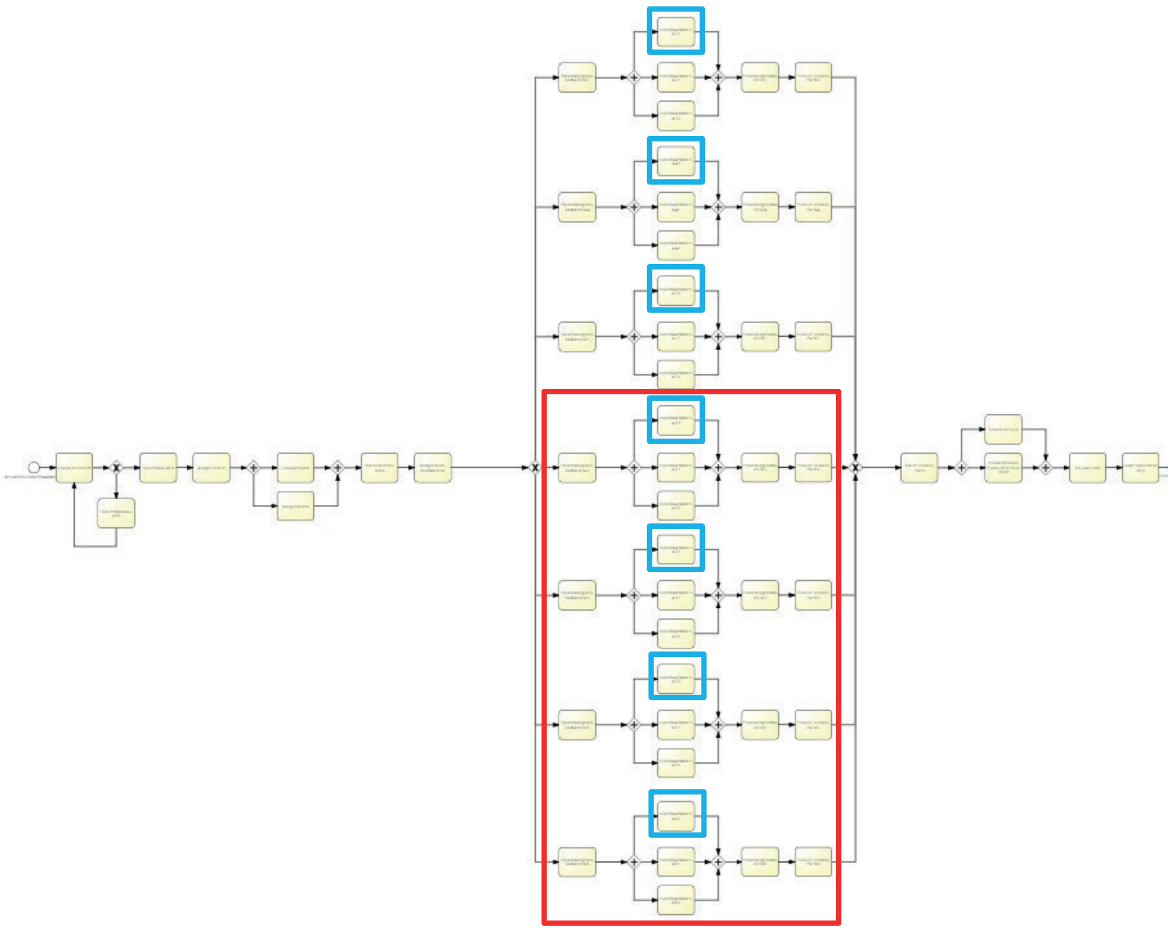

Fig.4. Extended BPMN process model of the hybrid simulation model

machines (red rectangle in Fig. 4) and one additional input of raw material (blue rectangles in Fig. 4) per each work line as parallel work lines are common in manufacturing. Finally, particular products made in the job shop were chosen as the case identifier for the simulation. The idea behind the case identifier being equal to a particular manufactured product is based on one of the pillars of Industry 4.0, where the product and even material are equipped with chips and thus, trackable in the cyber-physical environment.

Tab. 1. Selected automated process discovery techniques

Automated process discovery technique	Related studies
Structure HeuristicsMiner (sHM6)	Augusto et al. (2018)
Split Miner (SM)	Augusto et al. (2017)
Inductive Miner (IM)	Leemans et al. (2014)
Fodina (FO)	Broucke and Weerdt (2017)
α$	Guo et al. (2015)

2.3. Automated process discovery techniques and metrics

The focus regarding the evaluation of automated process discovery techniques is mainly on two previously mentioned quality dimensions: fitness and precision. Simply put, fitness measures the ability of the model to reproduce behaviour contained in the log. The range of the fitness function is the interval [0,1], where the value of fitness equal to 1 means that the process model can replay every trace in the event log. Precision, on the other hand, measures the ability of a model to generate the behaviour present in the event log. Similarly to fitness, the range of the precision function is the interval [0,1], where the value of precision equal to 1 means that any trace produced by the process model is found in the event log. Both quality dimensions can be combined into one index called the F-score, which is the harmonic mean of the two measures. For the purpose of this study, Markovian fitness and precision are used (Augusto et al., 2019).

It is necessary that the used modelling language has executable semantics so the quality dimension of

Tab. 2. Fitness and precision values for the process model depicted in Fig. 3 – 100 cases

Algorithm	Fitness	Precision	F-score	Soundness	Struct.
sHM6	1.0000	0.0763	0.1418	Sound	1.0000
SM	1.0000	0.0763	0.1418	Sound	1.0000
IM	1.0000	0.0763	0.1418	Sound	1.0000
FO	0.5918	0.0810	0.1425	Sound	1.0000
A$	1.0000	0.2269	0.3698	Sound	1.0000

Tab. 3. Fitness and precision values for the process model depicted in Fig. 3 – 8000 cases

Algorithm	Fitness	Precision	F-score	Soundness	Struct.
sHM6	1.0000	0.1002	0.1821	Sound	1.0000
SM	1.0000	0.1002	0.1821	Sound	1.0000
IM	1.0000	0.1002	0.1821	Sound	1.0000
FO	1.0000	0.1002	0.1821	Sound	1.0000
A$	1.0000	0.1002	0.1821	Sound	1.0000

Tab. 4. Fitness and precision values for the process model depicted in Fig. 4 – 100 cases

Algorithm	Fitness	Precision	F-score	Soundness	Struct.
sHM6	0.9488	0.0385	0.0739	Sound	1.0000
SM	-	-	-	-	-
IM	1.0000	0.0134	0.1775	Sound	1.0000
FO	0.7628	0.0130	0.0264	Sound	1.0000
A$	-	-	-	-	-

Tab. 5. Fitness and precision values for the process model depicted at Fig. 4 – 8000 cases

Algorithm	Fitness	Precision	F-score	Soundness	Struct.
sHM6	1.0000	0.1105	0.1990	Sound	1.0000
SM	-	-	-	-	-
IM	1.0000	0.1105	0.1990	Sound	1.0000
FO	1.0000	0.1105	0.1990	Sound	1.0000
A$	-	-	-	-	-

fitness and precision are computable. Petri nets are popular in many different areas of system modelling, while simultaneously having executable semantics. Furthermore, Petri nets are used by a relatively large number of automated process discovery techniques for representation of discovered process models. Thus, it is required that discovery techniques selected for the benchmark use Petri nets for the representation of the discovered process model. Also, those techniques were included that produce models which are convertible into Petri nets (Process Trees, BPMN models). Secondary criteria for the selection of the automated process discovery technique was the accessibility of the technique itself. The selected techniques can be found in Tab. 1.

3. Results

Tables 2–5 show benchmark results of BPMN process models depicted in Figs. 3–4. The evaluations were performed using the predefined parameters for particular process discovery techniques recommended by the developers of software packages. No same evaluations with optimised setting parameters of process discovery algorithms were done due to high demands on computing performance. Across all scenarios, discovered process models were sound and structured. According to Tables 2 and 3, all the process discovery algorithms perform well regarding the fitness quality measure with respect to the process model in Fig. 3. The exception is the Fodina discovery technique (FO), which performs relatively poorly in the simulation when the event log contains only 100 cases. However, it performs in the same way as the rest of the discovery algorithms, when there are 8000 cases in the event log. In the case of precision, all the discovery algorithms performed very poorly and thus, all the discovery algorithms also had a poor F-score.

Tables 4 and 5 represent the fitness quality of the process model from Fig. 4 and 8000 cases. sHM6, IM and FO performed well, again achieving the highest possible score. However, when the event log contained only 100 cases, the algorithms had a significantly lower performance regarding the fitness quality in two cases (sHM6 and FO). In the case of precision, all the discovery algorithms performed very poorly again and, thus, all the discovery algorithms also had a poor F-score. The comparison of the performance of particular discovery techniques listed in Tables 2 and 4 and then Tables 3 and 5, respectively, demonstrates that in the case of a simpler process model seen in Fig. 3, discovery algorithms performed better when using a smaller log, and in the case of a more complex model seen in Fig. 4, discovery algorithms performed better when using a bigger log. However, the comparison of the performance of particular discovery techniques listed in Tables 2 and 3 and then Tables 4 and 5, shows that process models with 100 cases have worse overall performance than process models with 8000 cases.

Conclusion and discussion

Based on the evaluation of benchmark results of chosen discovery algorithms, the discovery algorithms perform better overall with more extensive event logs (Tables 2 and 4, 3 and 5, respectively), which makes sense because the more information is contained in the event log, the better process models are produced by discovery techniques in general. However, on the other hand, the discovery algorithms that use less extensive event logs perform better, discovering less complex process models (Tables 2 and 3, 4 and 5, respectively). This also makes sense, because if the discovery algorithm has only limited information available in the log, the less complex models are more reliable to discover respecting the quality dimensions. At some point, Table 4 also shows that the decreasing values of precision have a negative influence on achieved values of fitness. The results above have a practical impact on the management of business processes, as, under the circumstances of Industry 4.0, it makes much more sense to consider adjusting the design of business processes to the available imperfect analytical tools.

It should be considered that one of the essential current problems of automated process discovery techniques is scalability due to a large amount of data that is generated and recorded by information systems and that has to be processed. However, as demonstrated, the process discovery techniques can also have problems of an opposite nature. This is especially true for companies with long delivery cycles, long processing times and parallel production, which are also common within industrial and related sectors. This is also amplified through the vertical and, later, on an even larger scale through horizontal integration of the supply chain within Industry 4.0. The impact of vertical integration in the BPMN model and the chosen case identifier is apparent, as otherwise without the assumption of smart manufacturing, we would not be able to use the single case identifier throughout the entire simulation. The entire process would need to be divided into several subprocesses. The management of business processes is nowadays essential for many companies to be competitive. However, with further progress of the Industry 4.0 concept, the analysis of business processes should be considered as a result of imperfect analytical methods and the emphasis of customers on effectiveness.

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Influence of Modern Process Performance Indicators on Corporate Performance — the Empirical Study

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ABSTRACT
The increasing pressure of globalisation on the worldwide market has forced enterprises to shift their focus from product quality to effectiveness of internal business processes. The object of interest of this paper is a modern management approach based on corporate performance evaluation by measuring the performance of internal processes. The paper aims to prove that the use of modern indicators and the measurement of internal processes belong among factors that have a direct positive impact on corporate performance. To reach the aim, empirical primary research was carried out. The paper focused on research results regarding the use of modern indicators for the measurement of business processes in Slovak industrial enterprises from selected branches. The primary quantitative research was conducted using questionnaires. The research aimed to test the hypothesis stating that enterprises using modern indicators to measure process performance have been reaching more positive ROE values, representing a basic indicator of corporate performance. Dependences among the data selected from the empirical research were analysed using statistical methods, namely, the chi-squared test, T-test and the correlation analysis. Based on the statistically processed data, the authors concluded that business processes are a basic source for the evaluation of corporate performance. Higher ROE values can be reached using modern process indicators, especially in mass production enterprises. The paper contributed to the further development of knowledge in performance management, specifically, process-oriented management.

KEY WORDS
corporate performance, process performance measurement, process indicator, industrial enterprises

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Introduction

Corporate performance management presents a way of motivation and management by objectives characterised using quantitative performance indicators. Besides the application of traditional methods in business, successful economic development and market environment development also require the application of new modern methods adapted to contemporary market needs. One modern approach is based on corporate performance evaluation by measuring the performance of internal processes (Sujová, 2013). Business processes are objects of the process approach to management based on enterprise search and analysis from the point of view of business activities and activities performed by managing staff. The basic idea of the process approach is that low business performance is caused by ineffective internal processes which should be changed, aiming to increase efficiency and higher added value for the customer. For many authors, process management is the most substantial breakthrough of the 20th century. Process management presents systems, procedures, methods and tools for sustainable maximised performance and continuous improvement of business processes with the aim to fulfil determined strategic goals.

Business process measurement and valuation are based on the identification of parameters and internal structures in each internal business process, including the most important attributes: the customer, inputs, outputs and process boundaries. Process indicators are known as key performance indicators (KPIs). Determining correct KPIs with an informative value is the most important task in effective measurement and management of business processes and also of corporate performance. KPIs of internal processes should be determined in a way that enables to monitor the fulfilment of corporate key result indicators or strategic key success factors. This is the reason why the literature review of the article focused on this part of the business process measurement.

Modern management approaches require using modern methods and indicators for performance evaluation. The interconnection between process performance measurement and corporate performance evaluation has not been addressed in scientific publications. Most of the scientific works deal with corporate performance or process performance separately. Consequently, the decision was made to undertake research focused on the connection between process measurement by modern indicators and the corporate performance result represented by the return on equity (ROE). According to Evans (2018), ROE reflects operational efficiency, and it is more representative than simple profit indicators (profit before or after tax).

The paper aims to prove that one of the factors influencing corporate performance is its management using modern indicators and measuring internal processes. To reach the aim, empirical primary research was carried out.

The second part of the paper presents the research methodology, which was based on primary quantitative research using questionnaires. The third part details the results of the research, and the last part offers the conclusions and explains the contribution to the development of scientific knowledge.

1. Literature review

Theoretical knowledge concerning process performance indicators was compiled from several sources. Publications dealing with the process performance measurement formed the basis for summarising the recent knowledge on the addressed issue.

It is not enough to control product quality at the end of the manufacturing process, and the performance measurement of the entire manufacturing process alone does not consider the hidden factory. In this sense, the hidden factory means many opportunities for non-conformities to occur before a product is delivered to the customer (Sujová et al., 2016). Six Sigma method measures the ability of an organisation to do things right for the first attempt. An opportunity for a non-conformity is defined from all points of view. In the scope of these facts, process management is in the foreground (Soleimannejad, 2004).

When a company wants to implement process management, first, internal processes and their structure must be identified. According to EN ISO 9001, process is a set of activities, by which inputs are transformed into outputs through the utilisation and managing enterprise sources. A process output has a value for both types of customers: internal and external. Clearly defined indicators, target values and rules of process measurement and evaluation are necessary conditions of a functioning process system (Šmída, 2007).

According to Palmberg (2009), the methodology corresponding to process management as a structured and systematic approach to the analysis and continuous improvement of a process can be summarised as process selection, description and mapping, organising for quality, process measurement and quantification, and process improvement.

The identification of performance measures and targets for process management is the contents of process measurement. This issue has been addressed in scientific works by Melan (1989), Jones (1994), Harrington (1995), Sinclair and Zairi (1995), Armistead et al. (1999), Pritchard and Armistead (1999).

Some discussions about process measurement posed a question regarding the process dimension for measurement and relationships between process performance, effectivity, efficiency, productivity, quality, capability and adaptability. According to Sujová, Marcineková and Hittmar (2017), the presumption of effective performance management and sustainable improvement are the measurement, assessment, control, and further optimisation of the internal processes.

According to Rongier (2010), process performance improvement requires to measure two categories of indicators: process efficiency (doing the right things) and process effectiveness (doing things right). According to Oak Ridge Institute for Science and Education (2014), performance measures can be grouped into six categories: process efficiency, effectiveness and:

- Quality as the level of meeting customer needs, requirements and expectations.
- Timeliness, which uses a determined criterion, usually based on customer requirements, to measure whether a work unit was done correctly and on time.
- Productivity as an added value of the process divided by the value of labour and capital consumption.
- Safety, which measures the overall health of the organisation and the working environment of its employees.

One of the most difficult tasks of process measurement is to propose suitable indicators. Process indicators could be divided based on various factors. Differences exist between indicators for production and non-productive processes. According to Parmenter (2007), there are three types of process performance measures:

- Key results indicators (KRIs) measure results of many actions and focus on a long period (customer and employee satisfaction, net profit before tax…).
- Key performance indicators (KPI´s) are the most critical for the current and future success of an enterprise. Parmenter defines seven characteristics of KPI's: not expressed in financial statements, often measured, affecting the CEO and the senior management team, understood by all staff and requiring corrective actions, having a substantial impact on the most of critical success factors, having a positive impact on all other performance measures.
- Performance indicators (PIs) lie between KPIs and KRIs and are shown in the scorecard with KPIs (profit received from the top 10% of the customers, net profit on key product lines…).

Performance requirements for business processes can be specified using process performance indicators (PPIs) with determined target values. A PPI is a kind of key performance indicator (KPI) that focuses exclusively on the indicators defined for business processes. Consequently, it is suitable to integrate the management of PPIs into the whole business process lifecycle from its design to its evaluation (Ortega et al., 2010).

To define PPIs in a way that is unambiguous and highly expressive, understandable by technical and non-technical users and traceable in a business process, PPINOT metamodel can be used as proposed by Ortega et al. (2013), which is independent of the process modelling language.

Gradišar et al. (2008) put forward an approach to measuring and presenting the achieved production objectives in the form of production KPIs and proposed to incorporate KPIs into a closed-loop production control system. To control the production process, it is necessary to measure productivity, product quality and production cost. Productivity is defined as the amount of all products that were manufactured in a certain production period and could be calculated. The mean product quality is the mean value of quality factors of the batches produced in the defined period. To calculate the mean production cost, it is important to sum up variable and fixed costs, and to calculate them for a unit of the final product. Vukomanovič et al. (2010) defined KPIs as indicative performance measures that assess unfinished processes. KPIs are not in direct correlation with, for example, cost but are indirect factors, such as communication and motivation, and lead to the results.

The Activity Based Costing is a method of calculating process costs. First, the activities are identified, and then costs are assigned to activities (based on the use of resources), and finally, costs are allocated to products according to the ratio of activity production (Remeň & Sujová, 2018).

In the scientific paper by Milanović (2011), the most important individual performance measures are divided into four categories: Quality, Time, Flexibility and Costs.

In a case study, Senvar et al. (2014) analysed eight process performance indicators considered to be appropriate for all processes: inventory waiting time, profit/cost of product sale, customer continuity, scrap/sales percentage, change in customer complaints, total performance of suppliers, capacity and research, and development investments per employee.

Agarwal et al. (2007) addressed indicators of process adaptability. Among the most important indicators of process agility belong market sensitiveness, delivery speed, data transfer speed, lead time reduction, service level improvement, cost and uncertainty minimisation, customer satisfaction, quality improvement, trust development, and change resistance minimisation.

One strategic performance management system that uses process principles is a Balanced Scorecard (BSC) developed by Kaplan and Norton (2000). It is a system that divides indicators into four dimensions: the financial perspective, the customer perspective, the perspective of internal processes, and the perspective of learning and growth. The integration of financial performance into the BSC model can be provided through the Creditworthy Model of Performance (Kiselakova et al., 2018). The BSC concept is used mostly in industrial enterprises that use non-financial indicators besides financial in management (Dobrovič et al., 2018).

The Holistic Process Performance Measurement System requires the relevant data of performance from various operational information systems, such as workflow systems or ERP systems. It is the approach of extracting data from different operational IT systems (Kueng, 2001): personal data from human resources, sale data from customer orders, clickstream data from the web server and market research data from the external database. According to this idea, the performance measurement system (PMS) is designed based on the business process at the scale of an enterprise. The SCOR model, developed by the Supply Chain Council and seventy world's leading companies, provides a unified representation of supply chains with five general processes: Plan, Source, Make, Deliver and Return (Hudson, 2001).

The corporate performance can be evaluated by a systematic decision-making procedure that combines selected multiple-attribute decision-making (MADM) methods combined with the analytic hierarchy process (AHP). AHP is applied to facilitate group decision making among managers and to set their priorities for further performance evaluation (Franek & Kashi, 2017).

The theoretical knowledge study led to the following typology of process indicators:

- Universal process indicators have a universal character and can be used by different measurements. They are usually connected with such categories as time, flexibility, environmental impact and costs.
- Indicators for the measurement of production processes are indicators needed for operative production management, such as labour productivity, capital productivity, total effectivity of equipment, fulfilling the standards of machines and workers, material turnaround, the rate of working hours to performance.
- Indicators for the measurement of non-production processes. Non-production processes are all processes running before the production (product development and innovation, marketing process), during the production (machine maintenance and repair) and after the production (service, sale).

The enterprises use many indicators, so it is necessary to create a system for preserving functionality and clarity. It is essential to connect corporate performance management and process performance. It can be achieved by the integration of process performance indicators into corporate KPIs.

What process indicators are suitable? What indicators are used in companies achieving the highest performance results? Has a modern approach to performance measurement impacts on performance results? As these research questions were deemed important, an empirical research was undertaken to test the following hypothesis: Enterprises that use modern indicators for process performance measurement have been reaching more positive ROE values.

2. Research methods

A questionnaire was used for primary quantitative research to analyse the current performance management situation in Slovak enterprises. The research objective was to analyse the use of traditional and modern methods and tools for process performance management and measurement in Slovak enterprises from selected industrial branches. In the first step, the database of enterprises was created. The information sources mostly came from the Internet databases and the Slovak Statistical Bureau. The database comprised 2235 enterprises from branches of engineering, construction, automotive and wood-processing industries. Internet applications were used to develop the online questionnaire and distribute it to the enterprises. Data collection and the creation of the on-line database were undertaken in the first quarter of 2018. In total, 164 filled questionnaires were returned, which comprised a representative research sample.

Questionnaire questions were divided into three areas: common characteristics (branch, region, ownership, number of employees, activity orientation, type of production organization), financial results (turnover, indicator ROE) and the area of internal processes. Questions concerning indicators for process measurement were as follow:

- What indicators for the measurement of production process performance are used in your company?
- What indicators for the evaluation of employee performance in processes are used in your company?
- What internal processes and their indicators are regularly measured and evaluated in your company?

An integral part of the research objective was testing the main hypothesis, stating that enterprises that use modern indicators for process performance measurement have been reaching more positive ROE values.

In addition, two more hypotheses were tested:

- The use of modern employee performance indicators does not depend on the reached ROE value.
- Regular measurement of internal processes does not depend on the reached higher ROE value.

The acquired data was statistically evaluated. The acceptable margin of error (the confidence interval) was set to ±10%. The proportion of characteristic is unknown, so the probability of characteristic occurrence was 50%. The confidence level was 95%. Statistical formulas were used for counting the sample size using an Internet application "Sample Size Calculation", and the result was 97.

Dependences among the selected data were analysed using chosen statistical methods: the chi-squared test, T-test and the correlation analysis. First, pivot tables were created. The next step was to count the expected frequencies and compare them with observed frequencies.

Chi-squared test or χ2 test is a statistical test commonly used to compare observed data with data expected to obtain according to a specific hypothesis. The Pearson's chi-squared test as a test of independence assesses whether paired observations of two variables are independent of each other. The chi-squared statistic can then be used to calculate a p-value by comparing the value of the statistic to a chi-squared distribution.

The T-test is a statistical hypothesis test in which the test statistic follows a Student´s distribution if the null hypothesis is supported. It can be used to determine if two sets of data are significantly different from each other (Shuttleworth, 2008).

The strength of the mutual dependence between selected relations was analysed using the correlation analysis. The statistical correlation is a statistical technique which shows whether two variables are related. It is measured by the coefficient of correlation (r). Its numerical value ranges from +1.0 to -1.0. It indicates the strength of a relationship. The closer the coefficients are to +1.0 and -1.0, the greater is the strength of the relationship between the variables (Rubin, 2010, s. 136-137). The formula for calculating the correlation coefficient (r) is:

$$Correl(X,Y) = r = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \qquad (1)$$

3. Discussion of research results

Once the theoretical knowledge was studied to test the research hypothesis, process indicators were divided into two groups:

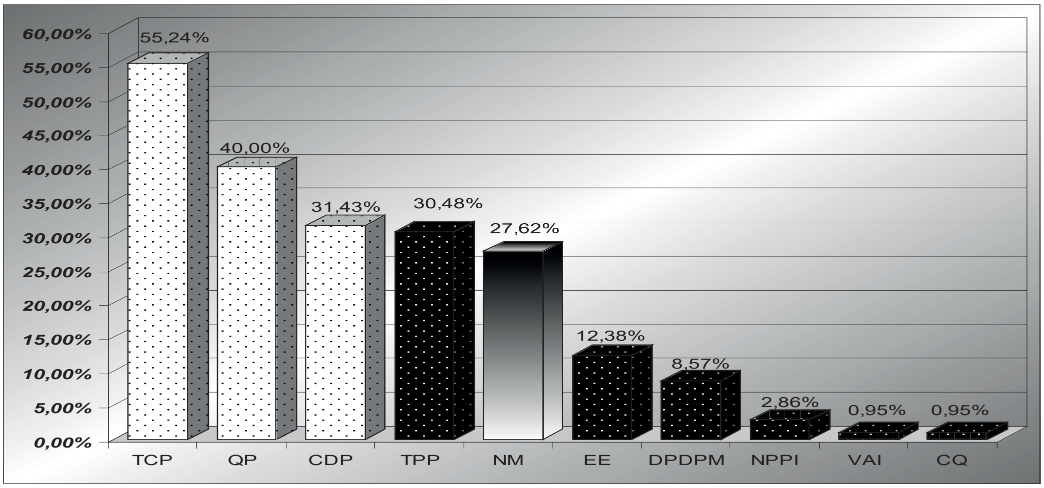
- traditional process indicators based on process costs, quality and time measurement,
- modern process indicators based mostly on process productivity, efficiency and value-added measurement.

This part of the paper shows the selected research results that present the impact made by the use of modern process indicators on corporate performance of Slovak enterprises and enable the verification of the stated hypothesis by showing the existence of connections between effective process performance measurement and the reached ROE value as a representative indicator of corporate performance.

The paper presents the results of the statistical CHI-square test, T-tests and the correlation analysis between used process indicators, the number of regularly measured processes and the reached ROE value. Results of the descriptive statistic concerning ROE are presented in Tab. 1. Kurtosis of the set data was

Tab. 1. Descriptive statistics ROE

Mean	3.385714286	Kurtosis	-0.26829549
Standard Error	0.391195286	Skewness	0.832625377
Median	3	Range	13
Mode	1	Minimum	-1.5
Standard Deviation	4,008558838	Maximum	11.5
Sample Variance	16.06854396	Sum	355.5



Legend:

	Traditional indicators	*Total cost of the process (TPC),*
		Quality of the process (QP)
		Continual duration of the process (CDP)
	Modern indicators	*Total productivity of the process (TPP),*
		Efficiency of the equipment (EE)
		Duration of product development and placement on the market (DPDPM
		Number of product and process innovation in a defined period (NPPI)
		Process value-added index (VAI), Customer quality (CQ)
	Not measured	*Not used any process performance indicator (NM)*

Fig. 1. Used process indicators

negative; it means that the distribution of the data was relatively flat in comparison with the normal distribution. The positive skewness means that the distribution was asymmetric, and most of the data were smaller than the mean value.

Results of primary quantitative research that are partly related to the use of process indicators are shown in Fig. 1. According to the figure, 28% of monitored enterprises do not use any modern process indicator. An enterprise uses 1.83 indicators on average (modern or traditional). Approximately 41% of the sample use one or more than one modern indicators. 46.5% of those enterprises have only domestic capital, and 9.3% have mainly domestic capital.

The dependence between the use of modern process indicators and the reached ROE value was confirmed by the CHI-square test, T-test and the correlation coefficient:

- $\chi 2 = 0.05$, which means that the statistically significant dependence exists between variables. Additionally, the researched sample was divided into two parts: enterprises with small-lot production or job-work and enterprises with mass production. CHI-Square Tests were made for these parts. The P-value for the first group was calculated = 0.59, so no statistically significant dependence exists between the variables. On the other hand, in the second part, the P-value was 0.04, so statistically significant dependence exists between variables.
- The T-test showed that T Stat is higher than t Critical for one tail test. It means that enterprises using modern process indicators reach a higher ROE level. Results are shown in Tab. 2.
- The correlation coefficient: $r = 0.586$ means strong positive dependence between the variables.

Fig. 2 presents a bar chart showing the percentage of the use of employee performance indicators in the researched sample. The research results given in Fig. 2 indicate that 10.48% of the sample use no employee performance indicators. An enterprise used 2.18 indicators on average. The most widely used modern indicator was VAE (employee value added). A third of the sample used one or more modern indicators. This part of the sample used 44 modern indicators and 64 traditional indicators.

Tab. 2. T-test: two-sample assuming equal variances

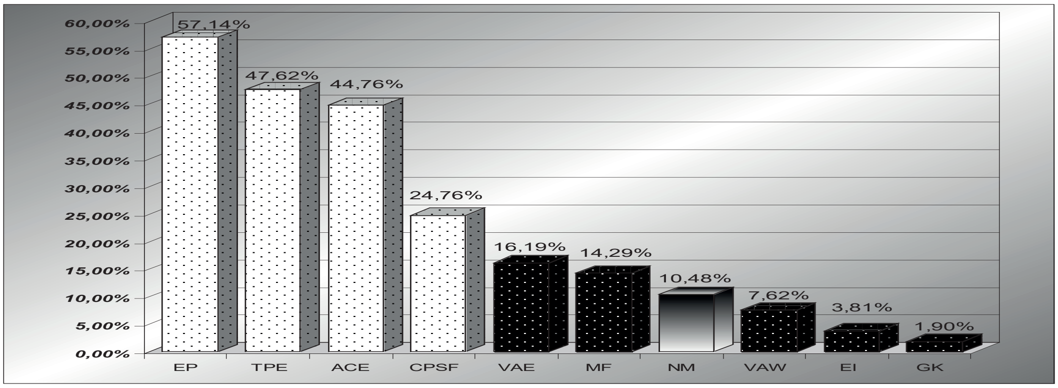
ROE	Modern indicators using	
	Yes	No
Mean	3.885714286	2.385714286
Variance	17.51573499	12.06008403
Observations	70	35
Pooled Variance	15.7148405	
Hypothesized Mean Difference	0	
df	103	
t Stat	1.827783123	
P(T<=t) one-tail	0.035238462	
t Critical one-tail	1.659782274	

To verify the main research hypothesis, a CHI-square test was used. Both hypotheses were defined. H0: The use of modern employee performance indicators does not depend on the reached ROE value; and Ha: The use of modern employee performance indicators depends on the reached ROE value. The calculated p-value was under the 0.05 (actually, 0.01787), so the null hypothesis was rejected. In other words, there was a statistically significant relevance between the use of modern employee performance indicators and the reached ROE value.

The strength of dependence between monitored variables was found using the correlation coefficient. The strongest relationship was found between the reached ROE value and the number of used indicators for employee performance measurement. The reached correlation coefficient of 0.579 means a strong dependence, only 33.49% of the ROE value variability depended on the number of used indicators.

The following bar chart (Fig. 3) shows internal processes that were mostly measured by Slovak enterprises. Research results presented in Fig. 3 showed that enterprises mostly measured the production process. 9.52% of the sample did not measure any process, 85.7% measured the main processes, 62.9% measured the support processes and 30.5% measured the managerial processes. An enterprise measured 3.25 processes on average.

In the next step, the CHI-square tests have been used. The research sample was divided into two groups according to the reached level of return on equity (ROE < 4% and ROE > 4%). The null hypothesis stated that Regular measurement of internal processes does not depend on the reached higher ROE value. According to Tab. 3, the null hypotheses were rejected in two cases. A statistically significant

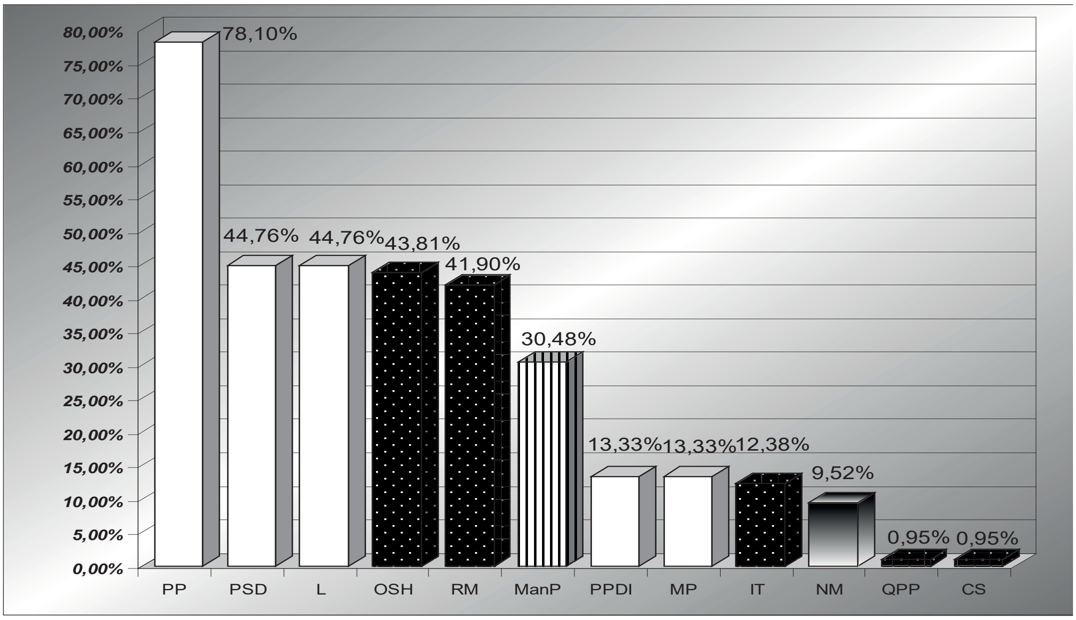


Legend: *Traditional indicators*: *Employee productivity (EP)*, *Total performance per employee (TPE)*, *Averaged costs per employee (ACE)*, *Coefficient of performance standards fulfilment (CPSF)*

Modern indicators: *Employee value added (VAE)*, *Motivational factors (MF)*, *Wages value added (VAW)*, *Number of employee innovation (EI)*, *Amount of given knowledge per defined period (GK)*

Not measured: *Not used any employee performance indicator (NM)*

Fig. 2. Used employee performance indicators



Legend:

	☐ *Main processes*	*Production process (PP)*
		Process of sale and delivery (PSD)
		Logistics (L)
		Process of new product development and innovation (PPDI)
		Marketing processes (MP)
	Support processes	*OSH and fire protection (OSH)*
		Repair and maintenance (RP)
		Information systems and IT support (IT)
		The quality of production process for manufacturing workers (QPP)
		Customer satisfaction (CS)
	Managerial processes	*(ManP)*
	Not measured	*Not measured any process (NM)*

Fig. 3. Regularly measured processes

Tab. 3. ROE and regularly measured processes

	Main processes	Managerial processes	Support processes
p-value	0.02151	0.01063	0.78615
H_0	Rejected	Rejected	Fail to reject

dependence was found between the degree of return on equity and the measurement of the main processes and managerial processes.

Furthermore, the influence of the qualitative level of process implementation on ROE was tested. The data was used for the CHI-square test and the P- value was = 0.002. Statistically significant dependence was found between the level of process management and the level of ROE.

As for the correlation analysis, a strong relationship was found between the qualitative level of process implementation and the reached ROE value. The correlation coefficient of this relationship was high (r = 0.626).

In addition, the T-test for two samples was used (Tab. 4). Data in Tab. 4 showed that T Stat was higher than t Critical for one tail test (p-value = 0.02), and also for two tail test (p-value = 0.03). It means that the influence of the level of process implementation on the reached ROE was statistically significant with the

Tab. 4. T-test: two-sample assuming equal variances

ROE	Process implementation	
	High level	Low level
Mean	4.185185185	2.539215686
Variance	18.39902166	12.49843137
Observations	54	51
Pooled Variance	15.53465744	
Hypothesized Mean Difference	0	
df	103	
t Stat	2.138741325	
P(T<=t) one-tail	0.017410201	
t Critical one-tail	1.659782274	
P(T<=t) two-tail	0.034820403	
t Critical two-tail	1.98326409	

probability of 95%. Enterprises with higher levels of process implementation had 4.19% of ROE on average, and enterprises with lower levels of process implementation had 2.54% of ROE on average. The difference was statistically significant.

4. Discussion

The research findings have shown that enterprises with higher corporate performance results used modern indicators for process measurement, such as the total process productivity, the efficiency of equipment and process innovations. These indicators correspond with Rongier (2010), who pointed to the necessity to measure process efficiency by process improvement. Most of the researched enterprises used indicators for costs, quality and the duration of the process, which was also defined by the Oak Ridge Institute for Science and Education Performance (2014) and by Milanović (2011).

As for employee performance indicators, the research showed that productivity, cost and the total performance of employees were monitored the most. However, enterprises with higher performance results used indicators based on added value and innovations or knowledge transfer. The study by Ortega et al. (2010) confirmed that the mentioned indicators were suitable for the integration into the whole corporate lifecycle and corporate KPIs, according to Parmenter (2007).

According to the research findings, the mostly measured processes were the main processes, namely, production and supply and sale, but not marketing and innovation processes. In the group of supported processes, the satisfaction of customers and employees with the quality was monitored the least. However, according to Rongier (2010) and Senvar et al. (2014), it is very important when an enterprise wants to improve its performance.

The research also confirmed that enterprises with a higher level of process management reach higher performance. This result supports the findings of previous research carried out by different authors (Marcineková & Sujová, 2015). The results presented in the paper also extended the findings by Sujová and Marcineková (2015), which proved that modern methods of process management have a positive impact on corporate performance.

Conclusions

The results of primary quantitative research in Slovak industrial enterprises confirmed the hypothesis stating that enterprises using modern indicators for business process measurement reached the best corporate performance results represented by return on equity (ROE). The most used process indicators in Slovak manufacturing companies were traditional: process costs, quality and duration. The used modern indicators were the total process productivity and equipment efficiency. On the other hand, more than 27% of enterprises did not measure internal processes.

Higher ROE values can be reached using modern process indicators, especially in mass production enterprises. Modern process and employee performance indicators are based on traditional indicators but mostly differ by future orientation. Using this type of indicators, firms become more competitive. In particular, the results of the CHI-square test and the correlation analysis showed the existence of a high dependence between return on equity (business performance indicator) and process (main and managerial) monitoring. Moreover, the relevance between the level of process management implementation and the reached ROE level was statistically confirmed. Enterprises, having implemented internal processes at a higher qualitative level, had higher ROE values.

Therefore, it can be stated that aiming to achieve higher corporate performance Slovak enterprises should pay attention to the measurement of internal processes using modern indicators. Slovak enterprises should increasingly focus on regular evaluation and improvement of innovation processes and marketing process.

The mentioned findings allow concluding that business processes are a basic source of corporate performance evaluation. It is important to know which process improvement has the greatest impact on the total performance so that manager could focus on critical (key) areas.

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