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Development and Implementation of the Key Performance Indicator Selection Model for SMEs

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Sergei Kaganski

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Väikese ja keskmise suurusega ettevõtete võtmenäitajate valimimudeli arendus ja juurutus

SERGEI KAGANSKI

TTÜ KIRJASTUS

Contents

List of Publications

The list of author's publications, on the basis of which the thesis has been prepared:

I Kaganski, S.; Paavel, M.; Lavin, J. (2014). SELECTING KEY PERFORMANCE INDICATORS WITH SUPPORT OF ENTERPRISE ANALYZE MODEL. *Proceedings of 9th International Conference of DAAAM Baltic Industrial Engineering,* Tallinn, 97−102.

II Kaganski, S.; Paavel, M.; Karjust, K.; Majak, J.; Snatkin, A. (2015). DIFFICULTIES IN SMES AND KPI SELECTION MODEL AS A SOLVER. *10th International DAAAM Baltic Conference, INDUSTRIAL ENGINEERING,* Tallinn, 33−38.

III Kaganski, S.; Majak, J.; Karjust, K.; Toompalu, S. (2017). Implementation of key performance indicators selection model as part of the Enterprise Analysis Model. *Procedia CIRP, 63: The 50th CIRP Conference on Manufacturing Systems, Taiwan,* Elsevier, 283−288.

IV Kaganski, S.; Toompalu, S. (2017). Development of key performance selection index model. *Journal of Achievements in Materials and Manufacturing Engineering: Achievements in Mechanical and Materials Engineering" AMME`2017, Poland,* Elsevier, 33−40.

V Kaganski, S.; Majak, J.; Karjust, K. (2018). Fuzzy AHP as a tool for prioritization of key performance indicators. *Procedia CIRP: 51st CIRP Conference on Manufacturing Systems, Sweden, 16.05-18.05.* Elsevier, xx-xx.

Copies of the publications are included in the Appendices.

Author’s Contribution to the Publications

The author has contributed to the papers in this thesis as follows:

I Description of the Enterprise analysis model (EAM) concept. Main goals and purposes of usage for the selection of the key performance indicators (KPIs).

II Description of the main issues that small and medium enterprises (SMEs) are facing. Introduction of the concept of the KPI selection model.

III Introduction of the results, from the application of the KPI selection model at a company.

IV Introduction of the refined model (final version) for the KPI selection.

V Introduction of the fuzzy analytical hierarchy process (AHP) and SMARTER criteria goal settings. Combination of two approaches and calculation of the weights for 13 KPIs selected for the thesis research.

Introduction

Recent twenty years have seen a substantial growth in the relationship between the private sector' society. Globalization, deregulation, privatization and a reconsideration of the relationships between state and the market have changed the keystone principles, on which private companies were expected to contribute to the public sector (Raynard & Forstater, 2002; Karjust et al., 2010; Durkacova et al., 2012). Additionally, economic conditions in 2011/2012 and 2014 in the world and the European Union with new challenges today, such as the migrant crisis, political confrontation between EU and Russian Federation, low prices of oil, pushing from bitcoin, have critical impact not only on large corporations but also on SMEs. However, this form of business is still dominating. SMEs are showing higher performance than other companies (Snatkin et al., 2012; Anggadwita et al., 2014; Venckeviciute et al., 2015).

In the metal, paper, chemicals, minerals processing industries, - the performance of the controllers is an important step to make a decision whether the process has been established, optimized correctly and is operating properly (Chioua et al., 2016).

Manufacturing processes are often highly automated with the help of various IT systems, automatized production lines where robots are playing an important role. The production is planned and continuously reviewed by a Production Planning and Scheduling System (P&S). Furthermore, the efficiency and effectiveness of the resources and processes in the production can be calculated by utilizing key performance indicators (KPIs). KPIs can be defined according to the international standard (ISO 22400, 20014) and combined by means of modern analytics solutions and methodologies (Bauer et al., 2016).

Today's, companies need to deal within dynamic environment, where fierce competition, shrinking budgets and heavy price pressures are having a crucial impact on the management and the whole enterprise as well (Sahno et al., 2015). Here it is necessary to have methods and tools that could help companies to improve the situation at production, provide the whole picture and understanding of the situation, and eliminate difficulties in the implementation and measurement of the right KPIs. The high amount of metrics is preventing managers to make right choices in the selection of indicators. Furthermore, the selected metrics at one company may not work on another enterprise. As a result, studies of selection and prioritization of KPIs have been conducted.

The selection of the right metrics is primary and at the same time, one of the most difficult tasks for managers. It is essential to take into account that all that can be measured can be specified as indicators and that the risk of collecting and analyzing wrong data is high. The acquired insubstantial data volume generated from the research will have negative impact on the whole enterprise. The reason is that the waste of the resources: production time, implementation costs etc. will raise dramatically. Under these circumstances, the author's vision is to develop an efficient key performance indicator model.

The main objective of the current study is to analyze KPIs and to develop the KPI selection model combined with the enterprise analysis model (EAM), which would provide valuable information concerning the bottlenecks and is able to help to solve them, focusing on the SMEs goals. To achieve the posed goals, the following activities were performed:

- development of the EAM and the KPI selection model;
- data collection and analysis (sorting, grouping, applying weights);
- ranking of answers;
- KPI selection and implementation of the model.

The fuzzy analytic hierarchy process (fuzzy AHP) with the SMARTER criteria for the evaluation of the KPIs was chosen. One of the ideas was to determine the relative importance of the decision criterion in order to rank the metrics for achieving higher profitability in the company.

Contribution of the thesis and dissemination

The KPI selection model based on the utilization of the fuzzy analytic hierarchy process (fuzzy AHP) and the SMARTER criteria has been proposed and implemented in a SME.

The proposed approach can be recommended specifically for the production and process managers who can implement the KPI selection model developed for the selection of the right metrics in a particular SME.

The main results of the study have been published in peer-reviewed journal papers and presented at a number of conferences.

Abbreviations

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
DUP	Defects Per Unit
EAM	Enterprise Analysis Model
FPY	First Pass Yield
GDP	Gross Domestic Product
HR	Human Resource
IT	Information Technology
KPI	Key Performance Indicators
NEE	Net Equipment Effectiveness
OTD	On Time Delivery
PI	Performance Index
PLM	Product Life Management
PMS	Production Monitoring System
RI	Resource Index
Rel_{index}	Reliability Index
R&D	Research and Development
SI	Significance Index
SME	Small and Medium Sized Enterprises
TTÜ	Tallinn University of Technology

1 Theoretical background and objectives

In recent years, the rate of automation and the significance of the IT systems in modern production have raised dramatically. To be able to stay competitive, it is necessary to know in which direction the enterprise is moving and what the bottlenecks slowing down the productivity rates are. The methodologies of selecting the right metrics have been in focus in many production companies and research institutions.

1.1 Role of the key performance indicators

Today the performance measurement is a main keystone of management in companies (Weber et al., 2012). Measurements are important; they are not only helping to indicate and eliminate the weaknesses but also providing managers with the information that describes the present situation at an enterprise. It is important for companies to define the relevant indicators, their influence on the formulated goals and how they rely on the activities performed (Popova et al., 2012).

The key performance indicators can be defined as "measurements that reflect the health of an organization, and the health of its business development system. They connect the firm's goals and strategies to its activities and outcomes, keeping management informed of overall health: past, current, future."(Enns et al., 2005).

It is not enough just to measure and collect different data, it is obligatory to understand WHAT exactly should be measured and how to deal with the acquired information. "Therefore, carefully selected Key Performance Indicators (KPIs) indicate precisely where to take action to improve performance" (Weber et al., 2005). Furthermore, it is essential to connect KPIs to the reasons, goals and visions of the company where the study was conducted. When there is a transparent and clear link between business goals and maintenance activities, then everyone in the company would be able to see the advantage that maintenance brings to the business (Sondalini, 2014). The metrics can be compared to the road map that helps to drive in right the direction. If the indicators are wrongly chosen and the results are not really reflecting the situation at the company by leading into a wrong path, then management will not be able to cross the finish line. Furthermore, the problems that were not discovered at the right time will start to grow and the consequences will be hard to eliminate.

It is necessary to make the right choice at the beginning. For that reason, the deviation of KPIs, taking into account the high and increasing amount of metrics, as everything that can be measured, can become and indicator. In addition, to achieve a maximum efficiency from applying KPIs, it is important to categorize indicators according to where and by whom they should be monitored (Esposito, 2012). The deviation process of metrics will help to understand how the components of each group/division interact with each other.

Parmenter has identified three main types of performance management (Parmenter, 2010):

1. Key result indicators (KRIs) - providing information how company has done in a perspective;
2. Performance indicators (PIs) - telling to the management what should be done;
3. KPIs - metrics showing what to do in order to increase the performance.

Many companies are using those metrics as a combination where they do not realize it (mixing the three different types and considering them all as KPIs). For that reason, not all enterprises have explored what a KPI actually is.
In addition, Vukomanović et al. have made their own classification (Table 1.2) (Vukomanovi et al., 2010).Parmenter divided the KPIs into 10 main groups (Table 1.1) (Parmenter, 2008).

Table 1.1 KPIs separation proposed by Parmenter

Main Groups of KPIs	**Description**
Leading	financial indicators, measure past performance
Lagging	typically non-financial indicators, measure drivers for future performance
Input	measure assets and resources (labor and capital) invested in or used to generate business results
Process	measure the efficiency or productivity of processes
Output	measure the financial and nonfinancial results of company's activities
Outcome	show overall results of commercial activity from the standpoint of generated profit
Functional	is closely connected to organizational main capability and is valid across multiple groups and companies
Qualitative	a descriptive characteristic or an opinion
Quantitative Industry	measurable characteristics (backbone of most KPIs) specific for line of operations or industry

Table 1.2 Classification of performance management by Vukomanović, et al.

Key Performance Results (KPR)		
KPI-leading performance measures	KPO (key performance objective) -lagging performance measures	PerM-perceptive performance measures

In addition, the KPIs are defined as a quantifiable and operative measurement that reflects the critical success factors of enterprises. The KPIs are needed for understanding and improving production performance from two perspectives: lean manufacturing that is based on eliminating wastes and from the point of achieving strategic sub-goals and goals. The companies who had adopted sustainable practices and had started to follow the KPIs were able to achieve better product quality by improving the first pass yield and quality ratio, higher market share and increased profits (Amrina et al., 2015).

Zhang has divided the industrial KPIs into three groups (Zhang et al., 2017):

1) the engineering KPIs that refer to the technical performance of the plant;
2) the maintenance KPIs that refer to the operating rate and hence to the maintenance time and cost;
3) the economic KPIs that refer to the business profit.

The classification or grouping of the metrics should simplify, first, the understanding of the metrics (Parmenter, 2009; Vukovich, et al., 2010) and second, the choice of right indicators (Parmenter, 2010; Zhang et al., 2017). The classification also helps the management to focus on the specific groups of the KPIs and work in this direction (Zhang et al., 2017).

An industry contains numerous types of equipment, machines and processes that should be controlled and maintained in order to improve the performance and profit for the plant and eliminate the weak spots. The control and maintenance mean that the present situation should be described from every side and compared to the previous period by aiming for the future. The KPIs are a fundamental tool in measuring the performance with company's progress (Lindberg et al., 2015).

It is not only the classification of the KPIs but also different methodologies, technics and methods proposed for the KPIs selection that help to understand the meaning of metrics:

- Eckerson introduced 10 characteristics for creating effective KPIs (Eckerson, 2009):
    - ➢ sparse (the fewer KPIs, the better);
    - ➢ drillable (users can drill into detail);
    - ➢ simple (users understand the KPIs and their meaning);
    - ➢ actionable (users know how to affect outcomes);
    - ➢ owned (KPIs have an owner);
    - ➢ referenced (users can view origins and context);
    - ➢ correlated (KPIs drive desired outcomes);
    - ➢ balanced (KPIs consist of both financial and non-financial metrics);
    - ➢ aligned (KPIs don't undermine each other);
    - ➢ validated (workers can't circumvent the KPIs);
- Doran proposed a five characteristics based approach integrated with SMART criteria: specific, measurable, achievable, relevant, time-bound (Doran 1981);
- Shahin & Mahbood utilized the AHP and SMART criteria for the prioritization KPIs at an organization (Shahin & Mahbod, 2015);
- Kadarsah employed the three components (academic, researching, supporting activities) and AHP technique as a selection methodology (Kadarsah, 2007);
- Parmenter proposed a 12-way model based on the following four foundation stones (Parmenter, 2010):
    - ➢ cooperation with the staff, suppliers and customers;
    - ➢ transfer of power to the front line;
    - ➢ implementation of the measurement with the reports and improvements;
    - ➢ connection of performance measures to the strategy, goals of the company.
- Yuan et al. introduced a questionnaire survey and implementation of the confirmatory factor analysis (CFA) for data evaluation , (Yuang et al., 2012);
- Podgorski implemented the AHP based selection methodology for leading KPIs (Podgorski, 2015);
- Furthermore, the fuzzy multi-criteria group decision-making methodology (FMCGDM) was proposed and developed by Ly (May et al., 2014). The Top-down approach based on the reduction of KPIs is aimed to understand the reason of the negative results, especially inside the process (not only on the control but also on a business level showing the overall plant efficiency).

The indicators help the plant managers to understand better the situation and evaluate the performance of the production at an enterprise, entire plant or process level. A significant achievement in regard to metrics is that they are able to catch the main idea or nature of the process and describe the condition of that process adequately.

However, SMEs are of the opinion that monitoring of the systems/processes is not important from the standpoint of the size of company (since the site management has a wrong view that they are all under control because of small production as compared to large corporations/enterprises). In addition, they suggest that there is no free time for searching for performance indicators.

„Can we identify and use KPIs in our environment and is there any need to do that? “-is the common question rising in SMEs (Parmenter, 2010). If a company really wants to be successful and competitive in the future, then the answer should be “yes”.

The main purpose of measuring is to compare the previous data to new and to make right conclusions for improving and revising the processes in the enterprises. However, to understand which measurements should be done, managers should know not only common problems, questions, situations arising in SME processes in different fields (not only production, there are also logistic, quality etc.) but they should recognize the main problems in THEIR enterprise.

Furthermore, companies often believe that they have identified the right KPIs and are following them; however, like David Parmenter declared: “Show me a company which thinks it has KPIs which are measured monthly and quarterly, and I will show you measures that do not create change, alignment and growth and have never been KPIs.“ (Parmenter, 2006). The described situation is typical: managers are trying to collect all possible data; however, they do not have clear understanding of what and why they are measuring.

Factors involved in the metrics of an enterprise are numerous. They start from employee education and experience not only in the sector the enterprise is operating but in general, involve the financial components (revenue, investments, non-planned costs) and their influence on the present situation. That makes it difficult to standardize the metrics for any company in a way that could show the same effect. Thus, the main goal of this thesis research is to develop the KPI selection model.

1.2 Reasons why small and medium enterprises are selected for implementation

According to the new definition of the European Union, “the small enterprises are defined as enterprises which employ fewer than 50 persons and whose annual turnover or annual balance sheet total does not exceed 10 million euros” (European Commission, 2015, see Fig.1.1). However, if SMEs are defined considering the amount of employees, then some countries have different level of workers, for example, as compared to the EU, in USA this number is below 500 employees (OECD, 2000).

From the economic point of view, the SMEs are playing a dominating role in the economy, development, political stability in every country (Khalique et al., 2011). The SMEs can be regarded as a backbone of the national economy (Peters et al., 1982; Amini, 2004; Radam et al., 2008). They are showing better performance as compared to the large enterprises (Siringoringo et al., 2009).

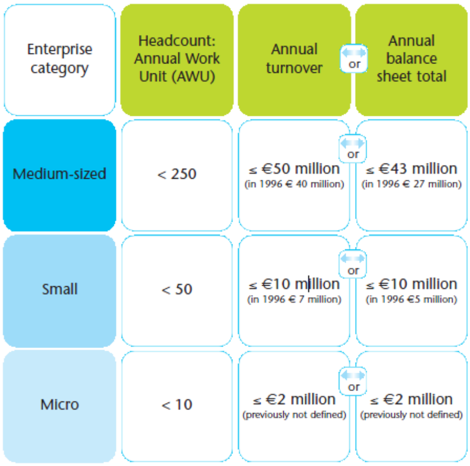

Figure 1.1 Classification of enterprises in EU (European Commission, 2015).

In addition, SMEs have played a crucial role in the recovery from the global crisis since 2008, as documented in Annual Report on EU (Wymenga et al., 2011). On the one hand, SMEs cannot have high investments into research and development (R&D) in amounts comparable with large enterprises. On the other hand, due to the financial and economic aspects, the implementation ratio of the new technologies in SMEs is very high. For example, Lehtimaki (Lehtimaki, 1991) considered the importance of new ideas for product innovations in SMEs in Finland as top priority. However, they are around 5-10% of SMEs that are at the top level of all growing firms, where they are playing a pioneering role in the development and implementation of the new products and markets in sectors like biotechnology, robotics and also they are located at the cutting edge of "new economy" (OECD, 2000).

SMEs account for over 95% of firms and 60-70% of employment and are making a large amount of new jobs in OECD (Organization for Economic Co-operation and Development) economies. In the European Union, SMEs account for 67% of total employment and 58% of gross value added (Wymenga et al., 2011). In Estonia, the SMEs account for 99.7% of the country's non-financial business economy (Table. 1.1). As compared to EU, starting from the year 2009, SMEs' value added growth was strong (Fig. 1.2)

Table 1.1 Key indicators for Estonian enterprises (European Foundation, 2013)

	Total	SMEs 1–249	Micro 1–9	Small 10–49	Medium 50–249	Large >250
Number of enterprises	56,095	55,932	48,692	6,054	1,186	163
Share in total (%)	100.0	99.7	86.8	10.8	2.1	0.3
People employed	417,281	330,345	114,881	111,556	103,908	86,936
Share in total (%)	100.0	79.2	27.5	26.7	24.9	20.8
Value added (EUR millions)	7,264.3	5,315.5	1,531.3	1,769.1	2,015.0	1,948.9
Share in total (%)	100.0	73.2	21.1	24.4	27.7	26.8

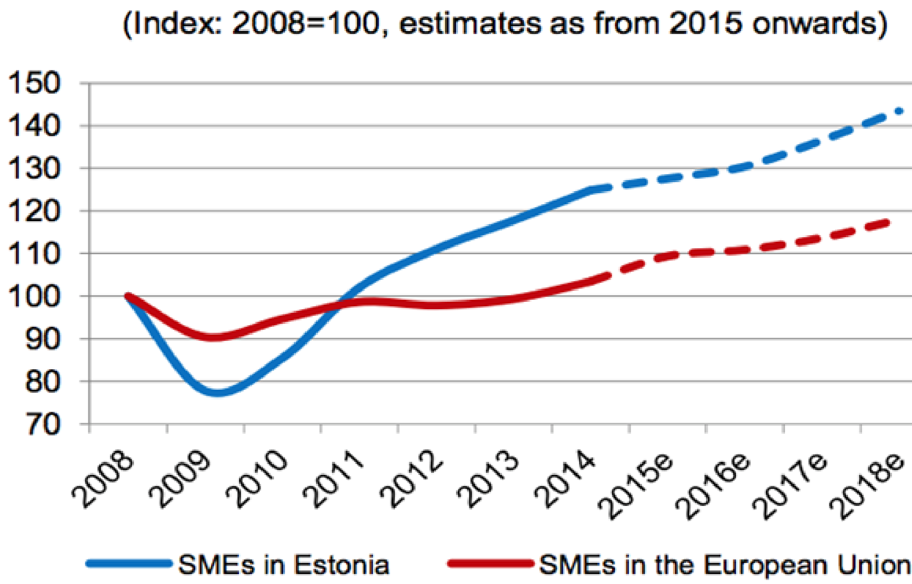

Figure 1.2 Value added of SMEs: Estonia vs EU (European Commission, 2017)

Taking into account the fact that more than 50% of SMEs are collapsing within the first five years, the problems that companies are facing can, first of all, be categorized and secondly, should be solved (Khalique et al., 2011).

According to Watt (Watt, 2007), the following steps in the risk management process in SMEs, should be taken into account by managers:

- establishing the SMEs risk strategy;
- determining the SMEs risk appetite;
- identification and assessment of risk;
- prioritizing and managing risk.

All the problems can be divided into two major groups:

- Financial or economic problems (the SMEs success is tied within the local economy: the SME sectors market growth has usually the same ratio as the macro economy as a whole; therefore, if there is an economic downturn, the SMEs will usually also experience difficulty (Berry, 2002));
- Enterprise's general problems (human resource problems, multi-functional management, high employee turnover rate, lack of skills and experience, low productivity and difficulties of finding quality staff (Smit & Watkinks, 2012)).

Considering the financial problems, the SMEs have very limited bank finance, which is only around 10%, while self-finance remains the major source of finance contributing 76.5% of the fixed capital and 51.8 of the working capital (Akterujjaman, 2010). In critical situations, the SMEs have no buffer capital, neither for investments in new technologies not for covering additional costs during prices growth or projects recalculation. For example, according to the World Bank survey (2002), the lack of money for the majority of Bangladesh's SMEs (55%) was the main issue, during their operation. Based on the Shusong Ba study (Ba, 2013), around 41.4% of SMEs have had also trouble in getting bank loans, especially on a long period (Rupeika-Apoga, 2014).

Financial difficulties are one of the main reasons why the SMEs need to choose projects very carefully and see all milestones at an early stage. In contrast to large companies, the SMEs have lack of mortgages with the asymmetric information issues (Han, 2013). Furthermore, if credit is available, the company can still have a lack of freedom and difficulty to choose due to the conditions that may force the purchase of necessary equipment, which can serve as guarantee for the loan (Farsi & Toghraee, 2014).
To reduce the impact of economic/finance issues on SMEs, entrepreneurs should do the following (Barrow, 1997):

- Define market opportunities;
- Pay more attention to team working;
- Choose or develop a suitable marketing entry strategy;
- Operate the profitable ventures.

It is important to know who the clients (to be market oriented) and competitors are by comparing the weaknesses and the strengths.
The management should consider the freight costs, logistics and the prices that should be competitive.

With regard to the measurements of economic aspects today, the majority of the SMEs have not established strict financial accounting systems, including real-check, card-check and account-check. It is difficult to carry out the financial accounting procedure (Wenshuai, 2018). Still, most of the SMEs apply a basic financial accounting system; however, it cannot provide enterprises with complete information (Karadag, 2015). The government should play a key role, providing a better financial environment for SMEs (Han, 2013).

Regarding the basic problems, the employee turnover can be named as one of the main issues that the management should address. The employee turnover is defined as the ratio of the number of workers that had to be replaced in a given time period to the average number of workers and is often used as an indicator that can easily be observed negatively towards the organization's efficiency and effectiveness (Glebbeek & Bax, 2004). Due to limited growth inside of the SME, most of the skilled employees leave SMEs. Furthermore, they see the SMEs as a springboard for their career and for acquisition of knowledge and experience. According to Levy (Levy et al., 2003), the SMEs are knowledge creators but poor at knowledge retention. The education and skills are the main cornerstones to run SMEs successfully.

Employee job satisfaction has direct influence on the employee turnover in organizations. The extent to which an organization is able to hold their workers depends on the level of job satisfaction (Mbah, 2012). Based on the OECD (2009), where eleven countries for job turnover and twenty-two for labor turnover were covered, the following results were achieved: job turnover rates were estimated at 22% (of total employment) over the period 1997-2004, and annual average labor turnover rates at 33% (of total employment) between 2000 and 2005 (European Commission 2010).

The high turnover rate is not only a problem that companies in Europe and in other countries are facing. In their research report, the Boston Consulting Group has mentioned that in the nearest future, companies are going to face the next five critical HR challenges (Cave et al., 2007):

- managing talent;
- managing demographics;

- becoming a learning organization;
- managing work-life balance;
- managing change and cultural transformation.

Taking into account today's situation where qualified workers is becoming scarce, the HRM (human resource management) should be on the same level of importance and monitored similar to the economic issues and aspects (turnover, consumer leverage ratio, retail sales and etc.). The managers should be aware that employees do the main job and the beneficial of the HRM is directly affecting the financial indexes of the company as well. The KPIs that are dealing directly with the HRM would help the management to make the right decisions to change the situation in the enterprise and prevent the outflow of workers.

The productivity issue in SMEs, the measurement and improvement of factory's activities has been and still remains the main research area. While productivity is the amount of output produced relative to the amount of resources (time and money) that go into the production, the efficiency is the value of output considering the cost of inputs (Taucean et al., 2008). Mole (Mole, 2002) has described three main productivity gaps that companies are dealing with:

- gap between nations based on GDP per head;
- gap between company's size (larger firms have higher productivity (Selden, 1999));
- gap connected to the ownership of the companies (internal and foreign-owned).

There are different ways of how to improve the productivity: starting from the automatization of main processes (robotics and production lines that are operating automatically), computerization and ending with the improvement of work conditions for workers. Furthermore, the support of the information resources by government, patents with the technological cooperation and technology acquisition process have an impact on the productivity improvement (Doo et al., 2008). Despite the fact that the global processes like automation and computerization can reduce the amount of errors from labor and raise the productivity, the detection of the constraints (Theory of Constraints) is remaining at general issue. The understanding of purposes "WHY?" processes are going this way should be prioritized.

Because of the abovementioned items and importance of the SMEs not only in EU as a whole but in Estonia, the main focus in this thesis research is to develop and implement the EAM and KPI selection model for the SMEs.

1.3 Objectives of the research

Objective and activities:
The main objective is to study and develop a KPI selection model with predictive functionality that operates in near real time and focuses on SMEs. The main activities (sub-objectives) of the research are:

- development of the EAM;
- development of the KPI selection model;
- implementation of the model in the company.

Scope and limitations of the research:

The development of the key performance indicator selection model with the enterprise analysis model is considered as a first step of the new approach for the SMEs in question from the standpoint of a virtual factory. The developed key performance indicator selection model with the enterprise analysis model were tested in an Estonian company. The package of the metrics acquired during the studies is regarded as the final result. The results achieved in this company cannot be implemented directly in other companies. An approach proposed could be applied, but it needs certain adaption in each enterprise, based on the production field, level of automatization, staff skills, etc.

Main hypothesis of the research:

- The identification of the successful metrics for the analysis and improvement of the production processes can be simplified by implementing the KPI selection model.
- By applying carefully selected metrics, the production process can be improved and the productivity increased.
- EAM provides general information regarding the bottlenecks of the company, where it has been implemented.
- Combining the fuzzy AHP with the SMARTER goal settings will help to rank the metrics and provide better understanding of the impact of metrics on production.

2 Development of the key performance indicator selection model as part of an enterprise analysis model

To understand the nature of the bottlenecks, issues encountered at a company (aspects that affect the production and have negative impact on the productivity) and to develop the relevant methods, a key performance indicators (KPI) selection model is required. The proposed model will improve the situation at production and help to optimize the processes in the whole enterprise.

2.1 Description of the model

The KPI selection model should be seen as an indispensable tool, which is able to help provide support in the identification of the critical spots/weaknesses and resolve them in the future perspective by measuring and analyzing the selected metrics. Furthermore, the model will help to save resources (minimize the required time for making similar analysis in the enterprise, minimize the size of the research group) and also support the management or focus group to make right decisions in selecting suitable indicators for their company taking into account present and future perspectives. The great amount of metrics that is still growing is confusing for the management. As a result, unnecessary quantities of wrong data are being collected and ineffective, unuseful analyses are being performed.

In regard to the structure, the following activities in the KPI selection model can be outlined (Paper IV):

- Analysis of the enterprise (applying the EAM to the company for acquisition of general information where study has been conducted);
- Data analysis (sorting, grouping and applying weights to the answers);
- Weight calculation (weight amendment by multiplication with the reliability index);
- Ranking of answers;
- KPI selection (ranking of KPIs based on SMARTER criteria and by performing fuzzy AHP analysis);
- KPI implementation (starting measuring and following chosen KPIs at the enterprise).

It is reasonable to mention that the whole process of acquiring metrics and studying the company is continuous: after generating and implementing the package of metrics, the management should review the data after a period. The situation at the production is changing rapidly and it is affected by internal and external factors: level of digitalization, change of staff, change of portfolio, where new products are appearing at the production and other factors. For that reason, it is necessary to understand that continuous improvement and monitoring are needed. Fig. 2.1 shows the whole KPI selection model with the data flow and necessary steps.

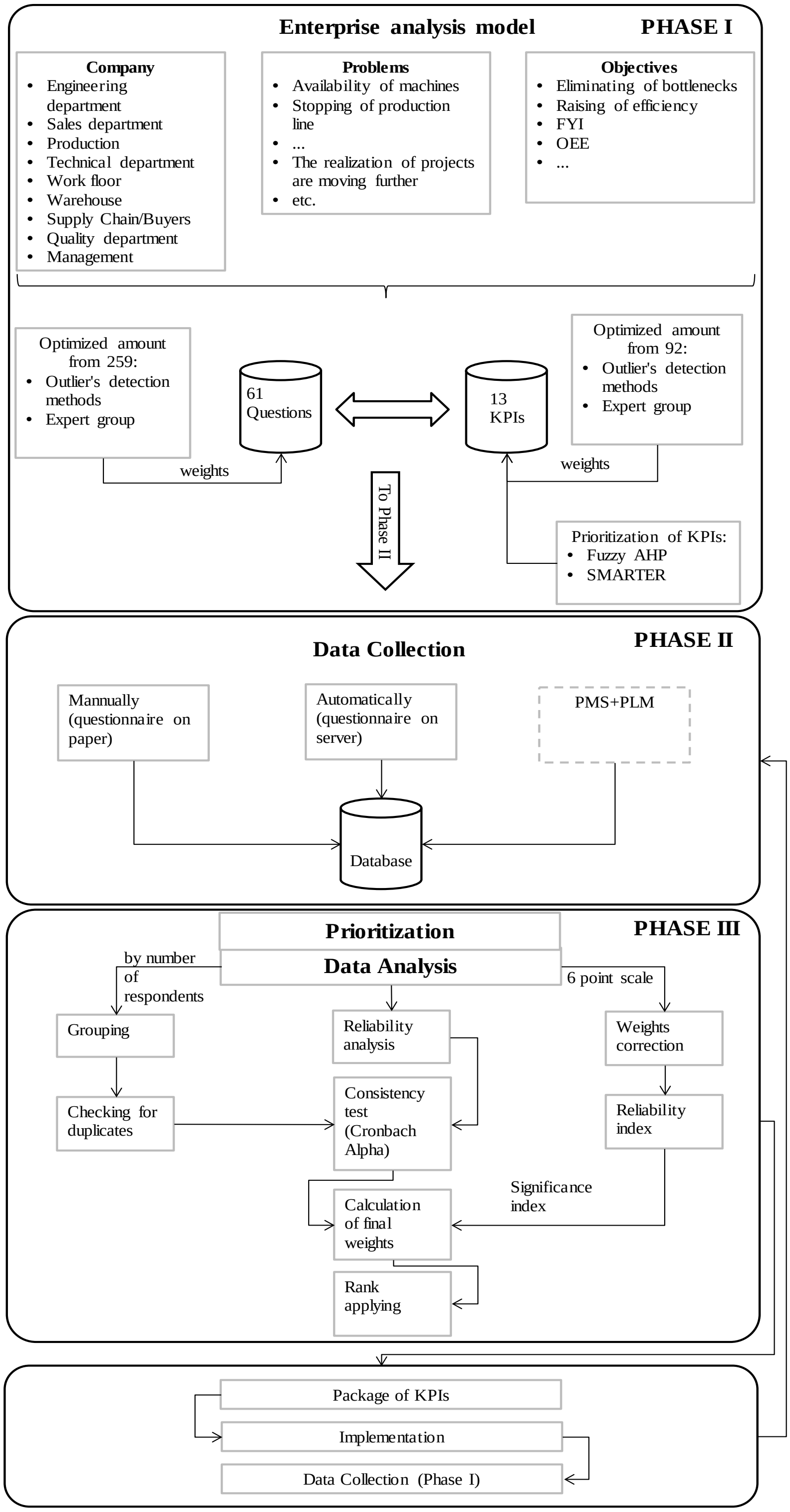

Figure 2.1 KPI selection model (Paper IV)

The first step is the development of the EAM or the investigation of the company where the main study was conducted. The analysis is used to collect the data, understand the main problems at the company and provide this information to the management during reasonable time without remarkable loss in quality (Paper I, Paper IV). The main core of the EAM is the questionnaire that is based on the analysis of over 70 research papers covering production efficiency and effectiveness, optimization of processes and management. The whole amount of questions was divided into 15 categories (Table 2.1), where each category has a different number of constructs (Paavel et al., 2015).

Table 2.1 Construct deviation between questions

Category	Different constructs	Questions
Customer and supplier participation	5	9
Electronic Data Interchange	38	43
Enterprise name	1	1
Financial	1	2
General information	5	5
Human Resource	31	42
Logistics	8	14
Mission and goals	7	12
NPI	21	28
Performance Management	5	11
PLM implementation	13	14
Production	28	52
Quality Management	8	15
Respondent information	6	6
Sales Management	2	5
Summary	179	259

To simplify the work with the EAM, a simple coding classification was used and applied to each question. Figure 2.2 explains the coding. It consists from the letter of the category and four digits. The first two numbers show the serial number in the group and the last number shows if the question has own double or not. "1" means that question is unique; "2" is showing the existence of a clone.

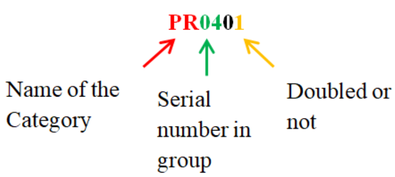

Figure 2.2 Coding used in the EAM

The amount of questions asked from the employees is based on the position that he/she is occupying in the company. In other words, the interviewee is given only his/her package of questions that are covering the field where he/she has experience, knowledge and competence. The 81 job positions taken into account were divided into the following groups:

- Research and Development (R&D);
- Information Technology (IT);
- Business, Sales and Marketing;
- Production;
- Quality;
- Human Resource (HR);
- Purchase and Logistics;
- CEO (high management).

Table 2.1 presents an un-optimized version of the questionnaire. The optimization is covered in section 2.2 of Chapter 2. The questions were composed such that they would describe different situations at a company and the answers would help to find out problems or issues that management is facing. Furthermore, the questionnaire can be divided into two types of questions:

- questions based on the facts;
- questions based on the situations or problems that can appear at the company and where the worker's opinion is requested. The answers on the second type of questions are described by the six-point discrete scale in Table 2.2.

In total, more than 40 different scales for answering were used for data collection (Paavel et al., 2015).

Table 2.2 Point scale

CT001	Strongly agree
CT002	Agree
CT003	Inclined to agree
CT004	Inclined to disagree
CT005	Disagree
CT006	Strongly disagree

The main goals of the EAM can be summarized as (Paper I; Paper IV):

1) to acquire overall information about the enterprise for further study;
2) to identify and understand the weak spots in the production/company;
3) to indicate which data should be collected and the reason for that (from the standpoint of identified critical points).

As the amount of different metrics is more than 17,000 (Baroudi, 2010) (still growing nowadays) and as the major goal was to analyze the production with the processes connected to it, the metrics describing the economic aspect of the enterprise were not taken into account (Paper II).

Furthermore, as questions are connected to the KPIs, the right indicators that rely on the weight of the answer can be chosen in the responses (Paper I; Paper II). To eliminate the misunderstandings and provide better effectiveness of the research, the logical connection between the pairs of constructs and questions, questions and KPIs were tested using a web application (Paper III). The research group (a study group of 10 who has no connection to the study but has enough knowledge and experience in this field) was required to do the matching of constructs with questions to be able to judge if the constructs can be described by questions. The information related to the research group is given in Table 2.3.

Table 2.3 Information related to the research group

Expert n	Experience (years)	Role
Expert 1	43	Professor at TTÜ
Expert 2	18	Associate professor at TTÜ
Expert 3	10	Specialist in the field of production
Expert 4	12	Specialist in the field of production
Expert 5	7	Specialist in the field of production and design
Expert 6	7	Specialist in the field of production and design
Expert 7	8	Specialist in the field of production and process optimization
Expert 8	10	Specialist in the field of process development at production
Expert 9	12	Specialist in the field of production
Expert 10	34	Leading Research at TTÜ

In the same way, the pairs of the KPI and the question were tested. The aim was to understand if the proposed questions can describe the indicators planned to be linked to them. The questions were doubled: the questions were formulated in a different way but the main idea of both of them was the same. Now to be able to accept the answer, both questions should have the same answers or there should be a little turning in scale. For example:

a. wrong machine settings and programs are not reason for production stopping;
b. production never stopped because of wrong machine settings or program.

In addition, the KPIs were divided into following three groups (Paper I; Paper II):

- direct KPIs - are in obvious/direct relation to the responses;
- indirect KPIs - are in connection with more than one question;
- suggested KPIs - are proposed to the management based on the questions/situations.

The direct KPIs are linked to the questions and by answering to them, the metric can be proposed. The indirect KPIs require answers of a group of the questions that the specific indicator is related to. The suggested indicators are additional metrics that the management could start to follow to change the situation described in the question.

The second step is data collection. The main goal here is to acquire data that could be used for further analysis. The data collection process can be achieved in two ways: manual, when the questionnaire is printed out and filled in by respondents individually or automatically, when the whole survey is located on the web server (in cloud) and filled in. As compared to the manual option, the data collection acquired automatically can be easily accessible or be downloaded in a proper way for further study, whereas paper version answers are difficult to group and analyze. In this research, to reduce the time for acquiring questions and to simplify the data processing, the whole survey was established on cloud server. In addition, in the next steps, this database was connected to the product monitoring system (PLM) database to acquire the data of the whole lifecycle, and to PMS, to be able to obtain real time information about the production processes (Paavel et al., 2013; Snatkin et al., 2015). The wireless sensors are fixed to the machines providing the following data: vibrations, temperature, voltage consuming, which in turn could be used to predict the condition of the tool (Aruväli et al., 2014). The main advantage of this procedure is the opportunity to study KPIs, e.g., the OEE (overall equipment efficiency). Online data flow will provide the possibility to make right decisions instantaneously and lead the production in the right way, at the same time saving resources (Aruväli et al., 2014).

The third step of data analysis provides the work with data. First of all, the answers on duplicated questions are checked and filtered. Depending on the amount of the same questions, all answers are grouped to simplify the Cronbach alpha analysis. In addition, to define the impact of the answer on the situation described by the question, the index of significance was applied; the 6-point scale was used (Paper III). The questions with the lowest average value should be taken into account first.

Next, the calculation of weights by multiplication with the reliability index was performed. Also, the consistency test by calculating the Cronbach alpha was made. When the “right” answers are separated (sorting of the answers on the duplicate questions), then the final weights are applied to the answers to be able to judge the importance of the problem covered by the question.

Before entering the final step, the KPIs were selected for the study. First of all, the approach used was the same as that for the optimization of the EAM (the filtering process was done based on the expert group decisions and on the outlier’s methods: modified Z-score, Turkey’s method and adjusted boxplot) (Paper IV). Secondly, the fuzzy AHP hierarchy was implemented based on the SMARTER goal settings with the combination of the main task of this thesis research (Paper V).

As the KPI selection model is a cyclic process, after implementing metrics into the production, the whole procedure should be repeated to understand how the situation has changed and what the impact on the effectiveness achieved is. There is also a possibility that during the time, the situation has changed again and the problems that have appeared in the previous period are currently not urgent. This means that the model provides an opportunity for the management to be quite flexible and adaptive in different situations.

2.2 Optimization of the enterprise analysis model

The aim of this chapter is to develop an effective enterprise analysis model that helps to perform analysis in a reasonable time frame without remarkable loss in quality. For this reason, first, a thoroughgoing set of questions and KPIs was composed and next, this set was limited to bounds allowing resource effective analysis. Thus, the optimization problem considered can be formulated as:

Min R_i
subjected to
$KPI \leq KPI^*,$ (2.1)
questions ≤ questions*,
$PI > PI^*.$

In quotation 2.1, R_i stands for resources (total time for analysis, working hours for completing the questionnaire, etc.), KPI^* and $\mathrm{questions}^*$ are estimated upper limits for the number of KPIs and questions, respectively. In order to keep the model adequate, the information related to performance PI should be retained upper critical limit PI^*.

2.2.1 Optimization procedure

The basic steps of the KPI selection/optimization procedure can be outlined as follows:
Step1. Forming initial questionnaire, KPIs
Step1.1. Composing initial questionnaire based on literature, experts
Step1.2. Composing initial KPIs
Step1.3. Identifying links between constructs and questions
Step1.4. Identifying links between questions and KPIs
Step1.5. Classification of KPIs (direct, indirect, suggested)
Step2. Applying an expert group for reducing questions, KPIs
Step2.1. Omitting questions unrelated or weakly related to KPIs
Step2.2. Omitting questions/KPIs, with no or weak impact on production
Step2.3. Ranking questions
Step3. Applying outlier's method for reducing questions, KPIs
Step3.1. Selection of outlier's methods
Step3.2. Employing the standard deviation method,
Step3.3. Employing the modified Z score method
Step3.4. Employing Tukey's method
Step3.5. Employing the adjusted boxplot method
Step3.6. Selection of outliers based on the results of applying outlier's methods
Step4. Estimating the final set of KPI-s and questions
Return to Step2 in case the number of questions and KPIs are still too sizeable to perform effectively in SME (KPI≤KPI*, Questions ≤ Questions*).

Note that contrary to the standard approach, in the case of the posed optimization problem, the initial solution is selected consciously infeasible. The first two constraints of (2.1) are not satisfied due to the thoroughgoing set of questions and KPI-s considered as candidates for the final set.

To reduce the time for completing the survey by investigated companies and concentrate more on the production and its efficiency, optimization of the EAM was required. The full optimization process is illustrated in Fig 2.3.

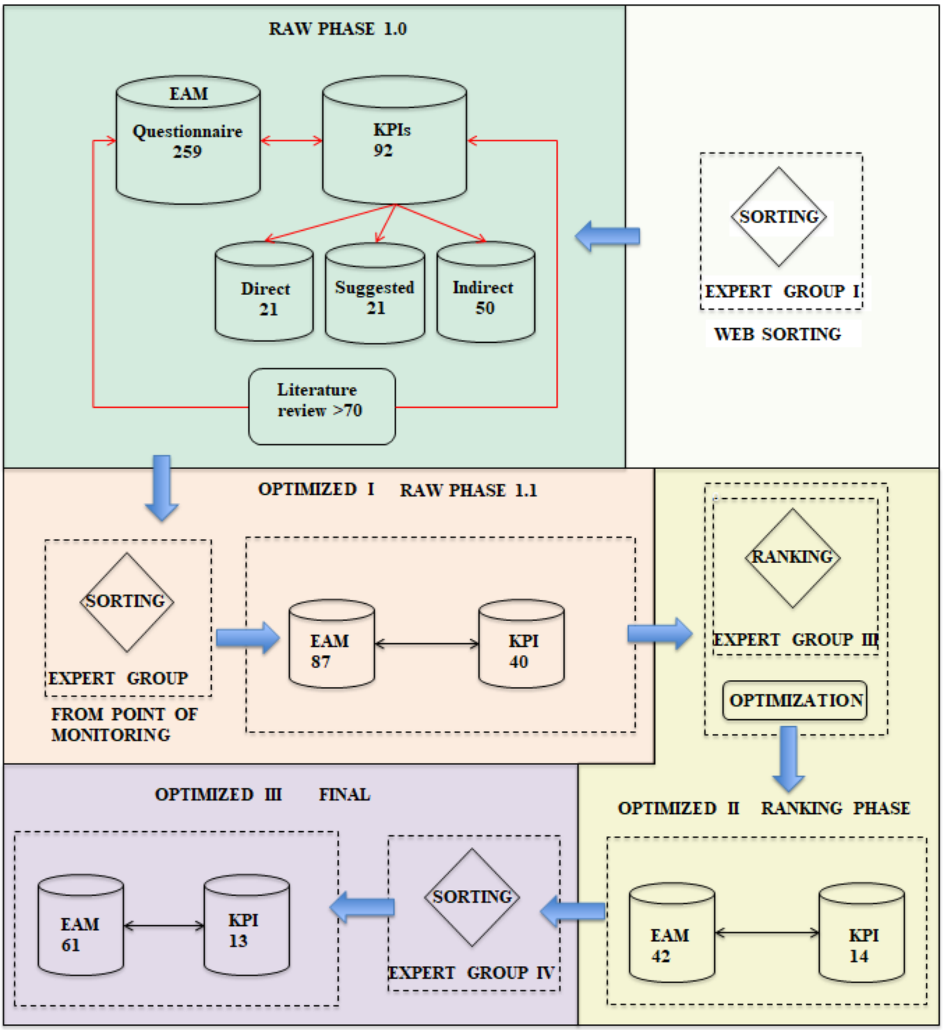

Figure 2.3 The optimization process

The first stage is the raw phase and initial data were taken from the previous study. The next step, raw phase 1.1, was established. A new expert group was formed and only questions with KPI connected to the production were selected. As a result, 87 questions and 40 KPIs were selected. In the ranking stage, a new expert group of 10 persons was employed (at least 5-year experience in this research field or in enterprise) and the importance of the questions in the 1 to 10 point scale was evaluated. Here 10 points - the question is very important from the standpoint of production and 1 – the question cannot provide necessary information for productivity and efficiency evaluation.

The average rank was calculated for each question and the results are presented in Table 2.4.

Table 2.4 Average rank of question

Amount of questions	**Average Rank**
15	>8
27	>6…<8 (6 and 8 bounds included)
44	≤5

The same process was applied to the group of 40 KPIs; the results are given in Table 2.5.

Table 2.5 Average rank for KPIs

Amount of questions	**Average Rank**
5	>8
9	>6…<8 (6 and 8 bounds included)
26	≤5

The optimized phase II and III are described in section "Application Outlier's detection methods". The results of optimized I phase are shown in Table 2.6.

Table 2.6 Result of the Optimization after phase I

	Raw Phase 1.0	**Optimized Raw phase 1.1**
Questions	259	87
KPIs	92	40

2.2.2 Application outlier's detection methods

During ranking phase, the ranked questions, received from the experts may contain outliers that have different impact on the data set when compared with others. The outliers may have critical impact on the data analysis. The goal was to optimize the questions by eliminating "faulty" answers from the total range set (Aggarwal, 2013).

Four different and simple outlier's detection methods were chosen:

- standard deviation method;
- modified Z score method;
- Tukey's method;
- adjusted boxplot.

One of the simplest methods used to find out outliers is the standard deviation method. According to the Chebyshev inequality, if a random X with mean μ and variance σ^2 exists, then for any k>0,

$$P(|X-\mu| \geq k\sigma) \leq 1/k^2, \qquad (2.2)$$

$$P(|X-\mu| \leq k\sigma) \geq 1-1/k^2 \ . \qquad (2.3)$$

The expression $1-1/k^2$ helps to define exactly what the amount of data would be within k standard deviation of the mean (Kvanli et al., 2006; Dol & Verhood, 2010). If data is following a normal distribution, then:
$2SD\ Method: \bar{X} \pm 2\ SD,$
$3SD\ Method: \bar{X} \pm 3\ SD,$
where $\bar{X}$ and SD stand for the sample mean and standard deviation, respectively.

The method can be helpful in tracking and eliminating extreme values from the dataset. The data outside those intervals can be regarded as outliers (Kvanli et al., 2006; Dol & Verhood, 2010).

As the second method, the modified Z-score, instead of the Z-score, was utilized in this study. Shiffler (Shiffler, 1988) has shown, that outliers cannot exist for small data sets, which is computed as $(n-1)/\sqrt{n}$. Furthermore, to avoid extreme values the median and the absolute deviation of the median (MAD) were inserted in the modified Z-score method (Shiffler, 1988; High, 2000). The modified Z-score can be calculated as:

$$M_i = \frac{0.6745(x_i - \tilde{X})}{MAD}, where\ E(MAD) = 0.675\sigma\ for\ large\ normal\ data,$$
$$MAD = median\{[x_i -]\}, where\ \tilde{x}\ is\ the\ sample\ median. \quad (2.4)$$

According to the modified Z-score method, the data can be considered as outlier, if $|M_i|>3.5$ (Inglewicz & Banerjee, 2001).

Tukey has introduced a graphical tool for displaying univariate data (Tukey, 1977). The Tukey's method has been selected because usage of quartiles in this method guarantees lower sensitivity of it to extreme values. The Tukey's boxplot is described by the following formulas:

$$IQR\ (Inner\ Quartile\ Range) = Q1(lower\ quartile) - Q3(upper\ quartile), \quad (2.5)$$

$$Inner\ fence = [Q1 - 1.5IQR, Q3 + 1.5IQR], \quad (2.6)$$

$$Outer\ fence = [Q1 - 3IQR, Q3 + 3IQR]\ . \quad (2.7)$$

All the data located between the inner fence and its nearby outer fence are possible outliers. Values located above the outer fence are outliers (Inglewicz & Banerjee, 2001; Songwon, 2002; Tukey, 1977).

With regard to the skewed distribution, Tukey's boxplot is not reliable. The adjusted boxplot should be used to measure skewness of the data. Instead of quartiles, the med couples (MC) are used in this method.

When $X_n=\{x_1, x_2,...,x_n\}$ is a data set sampled independent of a continuous univariate distribution and it is sorted in a way as $x_1 \le x_2 \le ... \le x_n$, MC is defined as:

$$MC(x_1, \dots, x_n) = med \frac{(x_j - med_k) - (med_k - x_i)}{x_j - x_i}, \quad (2.8)$$

where med_k is the median of x_n, *i* and *j* have to satisfy $x_j \le med_k \le x_j$ and $x_i \ne x_j$.
The method marks the observations that lie outside the intervals:

$$[c_1, c_2] = [Q_1 - 1.5e^{-3.5MC}IQR, Q_3 + 1.5e^{4MC}IQR]\ if\ MC \ge 0, \quad (2.9)$$
$$[c_1, c_2] = [Q_1 - 1.5e^{-4MC}IQR, Q_3 + 1.5e^{3.5MC}IQR]\ if\ MC \le 0\ . \quad (2.10)$$

In the case of MC=0, we are dealing with a standard boxplot (Brys et al., 2005; Vanderviere & Huber, 2004).

The described methodologies for outliers' detection were applied to the questions, ranked by the experts. The next step was the correlation of weight average. After the ranking phase and optimization, the total amount of the questions was reduced from 87 to 40 and KPIs from 40 to 14.

An example of the implementation of outlier detection methods for one particular case is shown in Fig. 2.4.

The date for finishing project is always moving further.										
Expert N	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
Importance	7	7	2	8	9	8	7	9	8	7

Results											
Methods and conditions	Standard deviation				Z score	Modified Z score	Tukey's method		Adjusted Boxplot		
	-3SD	3SD	-2SD	2SD	AbsZ >3	AbsMi >3.5	Fences		MC	Fences	
							Inner	Outer		Inner	Outer
Expert 1					0.1006	0.3373					
Expert 2					0.1006	0.3373					
Expert 3					2.6146	3.7098					
Expert 4					0.4022	0.3373					
Expert 5	1.2334	13.1666	3.2223	11.1778	0.9050	1.0118	8.5/ 6.5	10/ 5	0	8.5/ 6.5	10/ 5
Expert 6					0.4022	0.3373					
Expert 7					0.1006	0.3373					
Expert 8					0.9050	1.0118					
Expert 9					0.4022	0.3373					
Expert 10					0.1006	0.3373					

Figure 2.4 Example of applying outlier detection methods.

The standard deviation shows that the answer from Expert 3 cannot be taken into account based on the condition set in equations (4.1) and (4.2). The modified Z-score also shows that based on the equation, the result of the Expert 3 cannot be taken into account. Similarly, the Tukey's method and the Adjusted Boxplot show the Expert 3 is an outlier.

In the final phase of data optimization, the questions selected as outliers in the ranking phase were introduced to the expert group to make sure that the questions eliminated are unnecessary. The weights were applied to the questions and the average values of each were calculated. The questions that received more than 6 points from 10 were considered as final data. According to these results, final amounts of 61 questions and 13 KPIs were established (Table 2.7).

Table 2.7 Results after phase 2 and 3

	Optimized II ranking phase	**Optimized III Final**
Questions	40	61
KPIs	14	13

The optimized questionnaire was used in the case study. As compared to the non-optimized EAM, the results achieved will save time and use of resources.

2.3 Conclusion of Chapter 2

Considering the high amount of metrics, difficulty to evaluate right indicators and also eliminate all issues encountered in the company, measurements with further improvements and optimization remain a basic task for the management.

In this section the first phase of the KPI selection model was described in details. The general procedure for the EAM optimization was proposed and implemented. As a result of employing the outlier's methods and expert's decisions the total number of KPI-s was reduced from 40 to 13 and the number of questions from 259 to 61.

3 Prioritization of the key performance indicators

The chapter is focused on the subtask of the KPI selection model: the prioritization of the KPIs based on SMARTER criteria and fuzzy AHP.

3.1 SMARTER criteria and fuzzy analytical hierarchy process approach

The goals are not only to lead enterprise's efforts but also to support the management in moving straight ahead to company's visions. The goal setting is one of the key processes that should be done by the management in the first place (Oracle, 2012S). However, by setting objectives that are complicated a risk arises that they could be too difficult or unrealistic to achieve. Furthermore, KPIs that reflect enterprise's goals, should be based on the criteria which make them suitable for further studies (Shahin & Mahbood, 2007). G.T. Doran has proposed a SMART way of setting objectives (Doran, 1981). Although, many organizations have applied a SMARTER model considering the fact that two additional criteria are a good reminder to the managers that they are staying on top of the process (Graham, 2012; Ross, 2014).

3.1.1 SMARTER criteria

SMARTER model consists of seven steps (Graham, 2012; Ross, 2014; Shahin & Mahbod, 2007):

Specific – The goals should be detailed, clear and as specific as possible. Loose, not clear or uncertain goals are not desirable. When goals are specified, then it is easier to take necessary steps to achieve targets.

Measurable - Each target, process or KPI should be measurable. The measurement itself could be quantitative or qualitative, but it should be according to standards and requirements.

Achievable – The objectives should be set at the right level. They need to be ambitious and realistic however, making them too simple will not be motivating; on the other hand, each KPI should have the standard value that should be achieved.

Relevant (if sometimes it is linked with agreed then it is similar to achievable) – every colleague in a team or as individual, needs to understand and compare how the objective is relevant to their role and the main course of the team. Furthermore, KPIs should provide insight in the performance of the company in obtaining its strategy. In case the KPI is not measuring a team's or enterprise's goal or does not affect the organization's performance, it is useless.

Time-specific (or time-sensitive) – the work or tasks should have time frames. The deadlines for completing the objectives would provide possibilities to monitor and analyze the progress. In addition, it is better to understand the metric when everyone knows the time frames in which it should be measured and realized.

Explainable or *Evaluated* – the KPIs have been measured without understanding the reason of measuring. Managers need to ensure, that everyone, who is involved in the process, is aware of goals and tasks. It is worth mentioning that KPIs should evaluate performance and progress of what is measured (if it is the performance of a team or of a process)

Relative or *Reviewed* – the KPIs should be relative and they still could be implemented even if the company and volumes are growing.

3.1.2 Fuzzy analytical hierarchy process

Analytical hierarchy process (AHP) is a powerful decision-making methodology developed by Saaty in the 1980s to simplify the decision making process (Saaty, 1980). It includes qualitative and quantitative techniques and makes it possible to decompose complex problems into simpler sub-problems where each level shows a set of objectives or criteria relative to each sub-group (Shahin & Mahbod, 2007; Saaty, 1980; Kong & Liu, 2005). The nine-point scale simplifies the choice of criteria and provides information regarding to dominance of each element over others with respect to the importance of each criterion of the higher levels of the hierarchy. Individual points of view are made in groups, taking into account the pertinent decision maker and are handled as a foundation for the analysis of the reasons for specific judgements; there is the one week spot that occurs during the setup of comparisons matrixes (Sun, 2010; Saaty, 1987). When the number of characteristics is rising in hierarchy, more matchings between attributes need to be applied. Furthermore, by rising of criteria and sub/criteria, the experts are dealing with physical and mental fatigue. As a result, the judgements are becoming unreliable, subjective and imprecise. Therefore, the triangular fuzzy numbers (TFN) is a valuable solution for handling the subjective and imprecise judgements. The fuzzy set theory was developed by Zadeh and has become an important methodology in pair-wise comparisons. The fuzzy number can be defined as triple M=(l, m, u) where its membership function is defined as (Chang, 1996):

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, x \in [l,m], \\ \frac{x}{m-u} - \frac{u}{m-u}, x \in [m,u], \\ 0, \qquad otherwise, \end{cases} \tag{3.1}$$

where $l \leq m \leq u$, l and u are lower and upper values, m is middle value of M. When all three numbers are equal ($l = m = u$), then we are dealing with non-fuzzy numbers. Main operations for two triangular numbers were described by Kaufmann (Kaufmann, 1991) as:

$$M_1 (+) M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2), \tag{3.2}$$

$$M_1 (x) M_2 \approx (l_1 l_2, m_1 m_2, u_1 u_2), \tag{3.3}$$

$$M^{-1} \approx (1/l_1, 1/m_1, 1/u_1). \tag{3.4}$$

The triangular fuzzy scale for pair-wise comparison is presented in Table 3.1.

Table 3.1 Scale for Fuzzy AHP pair-wise comparison (Paper V)

The relative importance of the two sub-elements	**Fuzzy triangular**	**Reciprocal fuzzy**
Equally important	1 1 1	1, 1, 1
intermediate value between 1 and 3	1 2 3	1/3, 1/2, 1
Slightly important	2 3 4	1/4, 1/3, 1/2
intermediate value between 3 and 5	3 4 5	1/5, 1/4, 1/3

Table 3.1 Continued

Important	4 5 6	1/6, 1/5, 1/4
intermediate value between 5 and 7	5 6 7	1/7, 1/6, 1/5
Strongly important	6 7 8	1/8, 1/7, 1/6
intermediate value between 7and	7 8 9	1/9, 1/8, 1/7
Extremely important	9 9 9	1/9, 1/9, 1/9

The aim of the case study is to assign priority/rank indexes to metrics, which in its own turn should help managers to simplify the choice of metrics that should be followed in the first place in the company. Furthermore, it is not only the simplification of the process but also the prioritization of the tasks. It is worth mentioning that the success of the proposed steps for acquiring ranks for KPIs is in direct relation with the selection of the expert group: the competence, experience and sense of responsibility.

3.1.3 Procedure for acquiring priority indexes for key performance indicators

The procedure proposed for acquiring priority indexes for KPIs can be divided into the following subtasks (Paper V):

1. Development of the hierarchy tree, based on the goal, criteria (SMARTER goal settings) & sub-criteria (13 KPIs);
2. Preparation of the matrixes for data collection (pair-wise comparison);
3. Data collection from the expert group;
4. Consistency check of the matrix (fuzzification of data);
5. Evaluation of the weights of criteria (SMARTER goal settings) and sub-criteria (KPIs);
6. Prioritization of sub-criteria (KPIs).

Fig.3.1 shows the hierarchy tree for pair-wise comparison:

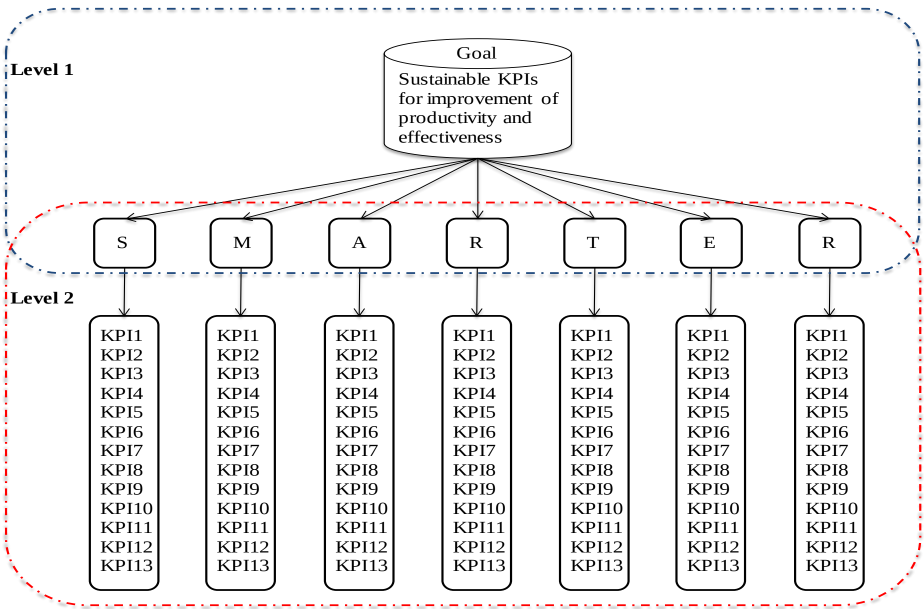

Figure 3.1 The hierarchy tree for pair-wise comparison (modified, Paper III)

During the first step, the comparison on the first level between SMARTER criteria and the main goal of “Sustainable KPIs for improvement of productivity and effectiveness” was established. On the second level, the pair-wise comparison between sub-criteria (KPIs), taking into account each SMARTER goal setting, was performed. The pair-wise comparison was done by the expert group of 10 members who have over 5-year experience in the field of production and process optimization.
Table 3.2 shows the optimized KPIs used in pair-wise comparison:

Table 3.2 KPIs selected for the study (Paper V)

KPI abbreviation in comparison matrix	Definition
KPI1	Inventory turnover
KPI2	% of additional freight costs
KPI3	Product quality/quality ratio
KPI4	FPY (firs pass yield)/Throughput yield
KPI5	DPU (defects per unit)
KPI6	Employee’s efficiency
KPI7	Changes implementation time
KPI8	Actual production Time
KPI9	OEE (Overall Equipment effectiveness)
KPI10	NEE (Net Equipment effectiveness)
KPI11	OTD (On time delivery)
KPI12	Tact time
KPI13	Unit/Line Reliability

The hierarchy tree establishes pair-wise comparison between the following pairs: goal-criteria; criteria-sub-criteria. After pair-wise comparison, a matrix was composed to ensure the quality and trustworthiness of the collected data; the consistency check should be regarded as the next step. In this thesis study, the defuzzification method for converting triangular fuzzy numbers to crisp numbers, was used. The defuzzification (Table 3.3) was performed according to the following equation (Kwong & Bai, 2003):

$$M_{crisp} = (4m + l + u)/6, \tag{3.5}$$

where M_{crisp} is the crisp number, m is medium bound, l and u lower and upper bounds of triangular fuzzy number, respectively.

Table 3.3 Example of defuzzified numbers vs fuzzy triangular numbers (Paper V)

	Specific	
Criteria	**Fuzzy triangular numbers**	**Defuzzified numbers**
Specific	1, 1, 1	1
Measurable	2, 3, 4	3
Achievable	1/4, 1/3, 1/5	0.3472
Relevant	2, 3, 4	3
Timely	1, 1, 1	1
Explainable	1, 1, 1	1
Relative	1/6, 1/5, 1/4	0.202778

After deffuzification, the consistency check methodology proposed by Wind & Saaty in 1980 was applied. Furthermore, for each matrix, the consistency check was performed.

The consistency ratio (CR), according to Wind & Saaty, was calculated by the use of the following equations:

$$CI = (\lambda_{max} - n)/(n-1), \tag{3.6}$$

$$CR = \frac{CI}{RI}, \tag{3.7}$$

where, λ_{max} is the largest eigenvalue of a matrix, n is the dimension of the matrix and RI is a random index, that depends on n (Table 3.4).

Table 3.4 RI according to Golden and Wang 1990

n	3	4	5	6	7	8	9	10	11	12	13
RI	0.58	0.89	1.12	1.24	1.33	1.40	1.45	1.49	1.51	1.54	1.56

The acceptable value of the CR should be <0.1; otherwise, the experts should redo the whole process. If a negative ratio is obtained, the data should be reviewed once more. In case the crisp matrix is consistent, the resulting fuzzy matrix is also consistent (Buckley & Csutora, 2001).

Fig. 3.2 shows the comparison between SMARTER criteria and the goal of the study from one of the experts.

	Goal																				
	Specific			Measureable			Available			Realistic			Timely			Explainable			Relative		
S	1	1	1	0.17	0.2	0.3	0.17	0.2	0.3	0.17	0.2	0.25	0.17	0.2	0.3	1	1	1	1	1	1
M	4	5	6	1	1	1	0.17	0.2	0.3	2	3	4	1	1	1	4	5	6	4	5	6
A	4	5	6	4	5	6	1	1	1	1	1	1	1	1	1	1	1	1	2	3	4
R	4	5	6	0.3	0.33	0.5	1	1	1	1	1	1	1	1	1	2	3	4	2	3	4
T	4	5	6	1	1	1	1	1	1	0.33	0.5	1	1	1	1	0.33	0.5	1	1	1	1
E	1	1	1	0.17	0.2	0.3	1	1	1	0.3	0.33	0.5	1	2	3	1	1	1	1	1	1
R	1	1	1	0.17	0.2	0.3	0.3	0.33	0.5	0.3	0.33	0.5	1	1	1	1	1	1	1	1	1

Figure 3.2 Example of a fuzzy comparison matrix at the first level by one of the experts (Paper V)

Table 3.5 gives the average consistency ratio for comparison at first level. The average value CR = 0.133 is higher than permissible value of CR<0.1. However, considering, that we are dealing with an average mean and the calculated ratio is allocated near to 0.1, we can talk about consistency of the matrices.

Table 3.5 Average CR of matrixes on level 1 (Paper V)

Goal: Sustainable KPIs for improvement of productivity and effectiveness							
Criteria	Specific	Measurable	Achievable	Relevant	Timely	Explainable	Relative
CR	0.133						

Table 3.6 shows the average consistency ratio for comparison at second level (comparison between sub-criteria and criteria). Average value for “Measurable vs KPIs”

was calculated as CR =0.154>0.1. However, it is around 85% which can be considered as acceptable result. The "Timely vs KPIs" CR =0.104>0.1 has also been accepted.

Table 3.6 Average CR of matrixes on level 2 (Paper V)

	Criteria						
	Specific	Measurable	Achievable	Relevant	Timely	Explainable	Relative
CR sub-criteria vs criteria	0.857	0.154	0.067	0.095	0.104	0.064	0.044

The weights are required for the prioritization of metrics. In conformity with the weights the ranks have been assigned to criteria and sub-criteria. According to Buckle, the geometric mean $\tilde{r}$ of fuzzy comparison values for each criterion can be calculated as:

$$\tilde{r} = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{\frac{1}{n}}, i = 1, 2, \dots, n, \tag{3.8}$$

where $\tilde{d}_{ij}$ is an average fuzzy triangular number, n is the dimension of the matrix.

The fuzzy weight $\widetilde{w}_i$ of criteria or sub-criteria can be found by the multiplication of each $\tilde{r}$ with the reverse vector:

$$\widetilde{w}_i = \widetilde{r}_i \times (\widetilde{r}_1 + \widetilde{r}_2 + \dots + \widetilde{r}_n)^{-1} = \left(lw_i, mw_{i,}, uw_i\right). \tag{3.9}$$

In addition, two more steps are required before starting the calculation of fuzzy weights: the sum of each $\tilde{r}$ should be calculated and the reverse sum of the vector with placing values in an increasing sequence should be performed.

It is worth mentioning that $\widetilde{w}_i$ is still triangular fuzzy number and it needs to be defuzzified. According to Chou and Chang (Chou and Chang, 2008), the centre of area method is applied:

$$M_i = \frac{lw_i + mw_{i,} + uw_i}{3}. \tag{3.10}$$

M_i can be normalized by the use of the following equation:

$$M_i = \frac{M_i}{\sum_{i=1}^{n} M_i}. \tag{3.11}$$

Tables 3.7 and 3.8 give the normalized weights of the criteria and sub-criteria levels with assigned ranks. To acquire the final weights for KPIs, they were summarized by the SMARTER criteria weights.

Table 3.7 SMARTER criteria weights and ranks (Paper V)

Criteria	**Normalized weight**	**Rank**
Specific	0.117933191	5

Table 3.7 Continued

Measurable	0.189824875	2
Achievable	0.137347325	4
Relevant	0.226618511	1
Timely	0.102053705	6
Explainable	0.169461049	3
Relative	0.056761343	7

Table 3.8 Weights and ranks for KPIs (Paper V)

KPI n	Specific	Measureable	Achievable	Relevant	Timely	Explainable	Relative	Total	Rank
KPI1	0.0080	0.0130	0.0215	0.0160	0.0116	0.0288	0.0065	0.1054	4
KPI2	0.0029	0.0079	0.0106	0.0039	0.0038	0.0065	0.0025	0.0381	13
KPI3	0.0197	0.0245	0.0102	0.0174	0.0072	0.0249	0.0057	0.1096	2
KPI4	0.0119	0.0112	0.0079	0.0128	0.0080	0.0073	0.0029	0.0619	10
KPI5	0.0115	0.0216	0.0124	0.0127	0.0060	0.0195	0.0039	0.0876	5
KPI6	0.0066	0.0099	0.0057	0.0154	0.0056	0.0159	0.0043	0.0634	8
KPI7	0.0134	0.0167	0.0069	0.0066	0.0064	0.0108	0.0029	0.0637	7
KPI8	0.0140	0.0258	0.0147	0.0313	0.0145	0.0181	0.0079	0.1265	1
KPI9	0.0085	0.0115	0.0067	0.0177	0.0058	0.0093	0.0031	0.0625	9
KPI10	0.0052	0.0071	0.0054	0.0158	0.0043	0.0064	0.0032	0.0475	12
KPI11	0.0097	0.0198	0.0167	0.0293	0.0128	0.0124	0.0064	0.1073	3
KPI12	0.0030	0.0144	0.0093	0.0261	0.0110	0.0046	0.0033	0.0719	6
KPI13	0.0033	0.0064	0.0092	0.0216	0.0051	0.0051	0.0042	0.0548	11

According to the results obtained, the metrics should meet the following goal setting criteria: indicators should be relevant, measurable and explainable. Considering the ranks, assigned to metrics, managers should pay major attention to the following KPIs: actual production time, product quality/quality ratio, OTD (on time delivery). However, it does not mean, that OEE, FPY and other metrics should be considered as "non-necessary" metrics.

3.2 Conclusion of Chapter 3

The procedure for the prioritization of the KPIs based on SMARTER criteria and fuzzy AHP has been proposed. The approach introduced helps to understand better the nature of metrics and also simplify the selection process. During the study, TOP3 metrics (actual production time, product quality/quality ratio, on time delivery) from the package of 13 KPIs were highlighted. However, it does not mean that other metrics have no impact on a company. The proposed package should be taken into account as a useful tool.

4 Results of implementation

To ensure better handling of the EAM and reduction of the time of data analysis, the questionnaire was established in the cloud server environment. The total amount of questions was 61, according to Table 2.7 in Chapter 2.

4.1 An algorithm for the analysis of answers

The following algorithm has been proposed for the analysis of the answers (Paper III):
Step 1. Data acquisition from the cloud server;
Step 2 Application of the weight to the answers depending on their significance;
Step 2.1 Weights amendment by multiplication with reliability index;
Step 2.2. Sorting the duplicate questions by finding differences in the weights for the same problems;
Step 2.3 Creating new groups for the reliability test;
Step 3. Testing the consistency by calculating the Cronbach Alpha;
Step 4. Calculating the mean weight for each answer taking into account the results of the consistence test;
Step 4.1. Application of ranks based on the calculated weights;
Step 5. Generation of the KPI package.

The algorithm was implemented in a private company and the corresponding description is given below. The primary field of the company where the case study was conducted is the production of equipment for power distribution networks, industrial control and automation systems for different sectors, including energy, industrial and public utilities. The main business of the company is the manufacturing of sheet metal components/products for the data communication networks and telecom. The company is located in three countries: Lithuania, Finland, and Estonia. The company employs around 460 workers. The main production units are located in Estonia. The enterprise analysis model and the KPI selection model were tested to evaluate the performance of the company and to detect the bottlenecks in the production (Paper I; Paper II; Paper III).

In order to determine the impact of each answer on the situation described by the question, the index of significance was applied to each response. In the six- point scale used, 6 - is the most favorable answer and 1 is the opposite (Lemmik et al., 2014). In other words, the questions (situations that they are describing) with the lowest average value should be analyzed first. For the "yes" and "no" questions, depending on the question's context, 6 points or 1 point were applied. Depending on the problem description (taking into account the question's context), the two variant of scales should be distinguished. The scales are shown in Table 4.1.

Table 4.1 Scale used for answers evaluation

Consent	Scale	Opposite Scale
Strongly agree	6	1
Agree	5	2
Inclined to agree	4	3
Inclined to disagree	3	4
Disagree	2	5

Table 4.1 Continued

Strongly disagree	1	6

To improve the evaluation of the answers depending on the position of the employee in the company and his/her influence on the decision-making based on the experience, the reliability index was introduced.

The reliability index describes the trustworthiness of the answer and can be calculated as:

$$Rel_{index} = \frac{ExpCurPos \times YearsCurComp \times TotalExpInArea \times PosCoef}{100}, \quad (4.1)$$

In equation (4.1) ExpCurPos,YearsCurComp, TotExpInArea and PosCoef stand for the experience on the current position, years in the current company, total experience in the considered area and the position coefficient, respectively.

The value of the position coefficient characterizes the impact of the worker's position on the answer: the higher the coefficient, the more trustworthy information will be and the higher influence it will have on the final answer. To evaluate the coefficients values, we took into account the judgment of an expert group of 10 members who have over 5-year experience in the field of production and process as their main research/activity area (7 from industry, 2 from university and 1 from competence center). The values of the coefficients are given in Table 4.2 (Paper III):

Table 4.2 The scale of the significance index (SI)

Position at work	**Coefficient**
Manager	1
Engineer	0.9
Specialist	0.8
CEO	0.7

The corrected weight obtained by multiplying the reliability index with the answer's weight was calculated and used in the further study as the final value of the importance of the question. The obtained results are shown in Fig. 4.1.

The employees of the company conducted a structured survey. A total of 54 people participated and 37 respondents returned their completed questionnaires. The rest were incomplete and not taken into account.

ID	64	62	15	19	20	21	23	59	58	88	31	54	53	37	38	39	40	41	52	51	46	50	48	49	67	69	70	71	86	79	89	83	85	90	92	93	94	
Trustability	0.7	1	1	1	1	1	1	1	1	1	1	0.7	1	1	1	1	1	0.7	1	1	1	1	1	1	1	1	0.7	1	1	1	0.7	0.7	1	1	1	0.7	1	
Questions	Weights																																					
RE0201	5	5	5	6	5	6	6	6	6	5	6	3	5	5	6	6	6	4	5	6	6	6	4	6	6	5	4	6	6	6	5	4	5	6	6	5	6	37
RE0301	5	6	6	6	5	6	6	6	6	5	6	3	5	6	6	6	6	4	6	6	6	6	6	6	6	6	4	6	6	6	5	5	6	6	6	5	6	37
RE0401	6	6	6	6	6	6	6	6	6	5	6	6	6	5	6	6	5	5	6	6	6	6	6	6	6	6	4	6	6	6	5	5	5	6	6	5	6	37
HU2101[0]					5											5																						2
HU2102[0]					5											5																						2
HU2301[0]			4		4	4						4				3				5																		6
HU2302[0]			4		4	3						3				3				3																		6
LO0201[o]	5							3	1	1									2	1			3		1								5	2	2	5	3	13
LO0301[o]																				1					1													2
LO0401[o]	4							3	1	1									2				3										5	2	5	3	3	11
LO0601[o]			6			6						6								6					5													5
LO0202[o]	5							3	1	1									2	1			3		1								5	2	2	3	3	13
LO0302[o]																				1					1													2
LO0402[o]	5							3	1	3									2				3										5	2	2	2	3	11
LO0701[o]	4							3	1	1									2				3										5	2	2	4	3	11
LO0602[o]			6			6						6								6					5													5
LO0702[o]	5							4	2	4									5				4										5	2	5	4	3	11
NP1201[0]			3			4						2								3																		4
NP1202[0]			3			3						3								5																		4
NP1203			4			4						7								6																		4
PE0101[0]			4			4						5								5																		4
PE0303			2			2						2								3																		4
PE0102[0]			4			4						5								5																		4
PE0302[0]			4			2						1								5																		4
PE0301[0]			4			1						1								3																		4
PR0201	6							1	6	1									6				1															6
PR0401[0]	5							3	1	1		2							2				3								1		5	2	4	3	3	13
PR0501[0]	4							3	1	4		4							4				3								2		2	4	3	5	4	13
PR0601[0]	4							3	3	4		4							3				4								2		2	2	3	3	1	13
PR0701[0]	5							3	2	4		4							2				4								2		2	4	3	5	5	13
PR0801[0]	5							3	3	2		3							2				3								4		2	4	3	4	1	13
PR0402[0]	5							3	2	2		2							3				3								1		2	2	3	5	1	13
PR0502[0]	4							3	3	4		3							4				3								4		2	4	3	5	5	13
PR0602[0]	2							3	3	4		4							3				4								2		2	4	3	3	1	13
PR0702[0]	5							3	3	3		3							3				4								5		2	4	3	5	1	13
PR0802[0]	4							3	2	2		3							3				4								2		2	2	3	4	1	13
PR1701[0]	2							3	3	2									4				5										2	3	3	5	6	11
PR1801[0]	4		4			6		5	4	4		4							4	5			5															10
PR1702[0]	5							3	5	2									5				4										5	4	3	5	6	11
PR1802[0]	4		4			4		5	4	5		4							4	4			5															10
PR2002[0]	5		4			4		4	5	4		4							3	4			4										5	4	3	4	6	15
PR2101	6		6			6		6		6		1							1	6																		8
PR2003[0]	5		4			3		4	3	5		3							1	3			4										5	4	3	5	6	15
PR2001	6		6			6		6		6		1							1	1			6											1		1		11
PR2102[0]	5		4			4		4	4	5		4							6	4			5															10
PR2103[0]	5		4			6		4	5	6		4							6	5			5															10
PR2301	6		6			1		6	1	6		1							1	1			1															10
PR2601	6		1			1		1	1	6		1							6	6			6															10
QU0501[0]	4							5	4	5		4							5				5								6		2	4	5	3	5	13
QU0701[0]			3			2						3								2											5							5
QU0502[0]	4							4	3	5		4							4				4								4		2	5	5	2	1	13
QU0702[0]			3			2						4								2											4							5
	34	3	27	3	7	27	3	34	32	34	3	39	3	3	3	7	3	3	34	31	3	3	33	3	9	3	3	3	3	3	17	3	25	26	25	26	25	

Figure 4.1 The final matrix used for further analysis

To simplify the analysis of the received data, the answers were grouped by the number of respondents from whom they were received (in Fig. 4.1, the groups are colored with specific color). For example, the questions: "Production never stopped because of the lack of material" (PR0401) and "Lack of material did not affect the production last year" (PR0402), were asked from 13 respondents and were added into one group; however the question: "Do you have line production?" (PR0201) from 8 respondents was added to another group.

A reliability analysis was performed to check the consistency of the survey data. The Cronbach's Alpha was calculated. According to the theory, the data is reliable if the Cronbach's coefficient alpha is above 0.700 and the acceptable minimum is 0.600 (Hair et al., 2006; Yuan et al., 2012). The alpha coefficients for each group of answers are given in Table 4.3. Groups with only one member were not included into this analysis.

Table 4.3 The alpha coefficients for each group of answers (Paper III)

Group No	Amount of questions	Number of respondents	Cronbach Alpha
Group 1	12	13	0.75644
Group 2	2	13	0.96342

Table 4.3 Continued

Group 3	6	10	0.44492
Group 4	6	11	0.68942
Group 5	8	4	0.62338
Group 6	2	5	1
Group 7	4	5	0.78539
Group 8	2	20	0.14924
Group 9	4	6	0.37037
Group 10	2	15	0.85010

Table 4.3 shows that the results of groups 3, 8, 9 are not consistent. The "yes and no" questions could be the reason of the low consistency, as the data set was filled with 6 or 1, depending on the answer.

The answers on duplicated questions, which differ from each other by more than 1 point, were not taken into account and were eliminated from the analysis. The main idea of the duplicated questions was to check, if the described problem was fully understood by the respondents or not.

The average value of weight was calculated and the rank was applied for each question (Paper III). By the average value equal or more than 4, the investigated situation, described by the question was recognized as acceptable. Arguments with average weight between 3.5 and 4 were placed into the second group. The situations with average weight less than 3.5 were placed in a group, which should be taken into account at first sight. In the Table 4.4, results of 3 groups (after taking into account the results of consistency from Table 4.3) are given. For the study, only the results of group 3 (weights less than 3.5) were investigated in the current study. In Table 4.5, the importance of the problems is characterized by the values of the rank and average weight of the questions.

Table 4.4 Dividing into groups from the standpoint of weights

Group No	Criteria	Amount of questions
Group 1	≥ 4.0	13
Group 2	3.5<4.0 or equal to 3.5	19
Group 3	<3.5	17

Table 4.5 Importance of group 3 questions and their ranks (Paper III)

ID	Questions	Average	Comment	Rank
HU2302	We can shuffle our staff between different projects without losing efficiency and productivity.	3.183	Higher->Better	15
LO0201	Last year you had no problem with lack of material.	2.331	Higher->Better	4
LO0301	Last year you did not need to use special transport.	1	Higher->Better	1
LO0401	Last year you did not need to postpone transport due to delay of production or outsourcing.	2.673	Higher->Better	10

Table 4.5 Continued

LO0701	During last year we had no issues with deliveries to clients.	2.509	Higher->Better	6
PE0303	How often do you review performance measures for accuracy/appropriateness to current needs?	2.1	Higher->Better	2
PE0302	Company routinely measures the Overall Equipment Effectiveness (OEE).	2.925	Higher->Better	12
PE0301	Overall Equipment Effectiveness is one of your general indicators.	2.175	Higher->Better	3
PR0401	Production never stopped because of lack of material.	2.377	Higher->Better	5
PR0501	Production never stopped because of the unit/line breaking.	3.104	Higher->Better	14
PR0601	Production never stopped because of human resources.	2.646	Higher->Better	9
PR0701	Production never stopped because of the wrong machine settings or programs.	3.031	Higher->Better	13
PR0801	Production never stopped because of the old version of the detail.	2.511	Higher->Better	7
PR1701	During last year we had no breakdowns of our equipment.	3.264	Higher->Better	16
PR2301	Do you analyze workplace effectiveness?	2.791	Higher->Better	11
PR2601	Do you measure production unit/line reliability?	3.291	Higher->Better	17
QU0701	Total productive maintenance (TPM) is practiced and supported by all levels within the plant.	2.521	Higher->Better	8

Based on the Table 4.5, the most important issues that need to be investigated by managers are:

1. problems with deliveries to client as additional unplanned transport was used;
2. the performance is reviewed less than required, due to this fact, the management can have a wrong idea about the factory productivity and it's condition;
3. OEE is not measured and followed properly; due to this fact, the state of equipment park can be in critical condition and not perform properly.

4.2 Key performance indicator ranking

According to the main concept of the analysis model (Paper I; Paper II; Paper III), each argument/question was connected to KPIs at the beginning of the survey and the main KPIs group with their ranking rating was selected (Table 4.6) in the previous studies (Paper V). Based on this knowledge, the metrics that the company should follow in the future to change the situation were selected.

Table 4.6 The ranks of KPIs

KPI	KPI Rank	Average of question rank	Final
Employee efficiency	8	12	10
OTD (On time delivery)	3	5.25	4.125
OEE (Overall Equipment Effectiveness)	9	7.67	8.33
Actual production time	1	9.83	5.42
NEE (Net Equipment Effectiveness)	12	14.33	13.16
FPY (First Pass Yield)	10	18	14
Product quality/quality ratio	2	18	10
Unit/Line reliability	11	17	14
Changes implementation time	7	7	7
Tact time	6	9	7.5
Inventory turnover	4	4.5	4.25
%of additional freight costs	13	5.5	9.25
DPU (Defects Per Unit)	5	7	6

Based on the KPIs ranking and the issues ranks, Table 4.7 shows the final ranks. According to the results, TOP3 critical issues at the tested company were:

- Late deliveries to client (not proper planning of production, lack of employees);
- Material issues (late deliveries from supplier, not proper planning of the material);
- Wrong production time calculation, downtimes, lack of material etc.

Table 4.7 Recommended package of metrics based on ranking (Paper III)

KPI	Rank	Importance
OTD (On time delivery)	1	↑
Inventory turnover	2	High
Actual production time	3	
DPU (Defects Per Unit)	4	
Changes implementation time	5	
Tact time	6	
OEE (Overall Equipment Effectiveness)	7	
% of additional freight costs	8	
Product quality/quality ratio	9	
Employee efficiency	10	
NEE (Net Equipment Effectiveness)	11	
FPY (First Pass Yield)	12	
Unit/Line Reliability	13	Low

The quality issues according to the analysis also need to be followed by the management. Taking into account the material problems (condition of the material, wrong replacement due to the late delivery), the elimination of them could also strongly affect the final productivity.

The production time in a coupe with technical issues of the machines should also be taken into account. The provided metrics are just stones for building a strong foundation. However, the proposed analysis should be performed not only once but iteratively, since the management of the company is a dynamic process.

Main differences of the proposed approach from widely used ‘classical’ models (Eckerson, 2009; Doran, 1981; Shahin & Mahbod, 2015; Kadarsah, 2007; Yuan et al., 2012; Podgorski, 2015; May et al., 2014) can be outlined as:

- The methodology is combining different methods in one KPI selection model (FAHP and SMARTER criteria).
- KPI selection model enables identification of the items to be measured and which metrics should be followed.
- The majority of approaches are just offering metrics without taking into account the specifics of the company.

5 Conclusion

Based on the objectives and results obtained, the general conclusions of the thesis research are as follows:

1) Key performance indicator selection model with the enterprise analysis model have been introduced. The synergy of the two models was used to acquire better results in the selection of the metrics.
   Based on the model, the whole process of selection, analysis, weight implementation, ranking and generation of suitable key performance indicators has been implemented as a case study at a company. The acquired results were presented. (Hypothesis 1 confirmed).
2) By applying the package of metrics based on the EAM results, the management can concentrate their attention on the weak spots and increase the production, as the critical issues were discovered and covered by the model. (Hypothesis 2 confirmed).
3) The proposed concept allows generation of the right metrics based on the results of the enterprise analysis model that in its turn provides information regarding weak spots in the enterprise. (Hypothesis 3 confirmed)
4) The fuzzy AHP in combination with SMARTER criteria was used for judging the chosen Key performance indicators and applying the weights to understand better the impact of the metrics on production. (Hypothesis 4 confirmed)

Novelty of the study:
A new theoretical approach was proposed and implemented as a case study.

- The combination of different methods and methodologies were synced into one to acquire the synergy. The key performance indicator selection model was combined with the enterprise analysis model.
- The new KPI selection model was proposed and tested.
- The proposed models help to select suitable metrics and discover the weak spots in the investigated company.

Further research:
Development of an advanced KPI selection model is a continuous process (cycle process). With regard to a continuously growing competition, undoubtedly, more tests of models and different developments are required.
The results, which were obtained in the current study, can be used, extended in future works as follows:

- Application of the proposed model for a number of SMEs. Determination of features arising for particular types of SMEs;
- The web interface could be developed to provide availability of data acquisition instantly. The clear key performance indicators should be chosen rapidly without loss in time and involvement of additional resources for research;
- The synchronization of the proposed model with the PMS and PLM at different levels.

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Lühikokkuvõte
Väikese ja keskmise suurusega ettevõtete võtmenäitajate valimimudeli arendus ja juurutus

Tänu ettevõtete omavahelisele konkurentsile erinevates valdkondades tuleb tootmisprotsesse pidevalt arendada, optimeerida ja efektiivistada, kuid samas ka nende toimimist jälgida ja monitoorida, kõrvaldamaks kitsaskohti. Tootmise jälgimissüsteemide rakendamisel on vaja teada milliseid võtmenäitajaid on ettevõtte ja valdkonna spetsiifikas oluline monitoorida ja analüüsida, selle saavutamiseks on esmalt vaja kasutada ettevõtte võtmenäitajate valimimudelit.

Ettevõtte võtmenäitajate valimismudel võimaldab parandada juhtimistegevust vähendades aega ning ressursse, mis omakorda on vajalikud analüüsi tegemiseks ettevõttes ning mõõdikute selekteerimiseks. Paljud uurimisasutused ja -ettevõtted tegelevad erinevate süsteemide arendamiste ja juurutamistega, mis võimaldavad andmeid koguda ning protsessile ja tehnoloogiale olulisi mõõdikuid selekteerida ja mõõta. Arvestades eelnevalt tehtud töid antud valdkonnas, arendati ja esitati konsolideeritud mudel.

Käesoleva uurimistöö põhieesmärk seisnes mõõdikute valimimudeli arendamises, mis omakorda võimaldab genereerida vajalikke mõõdikuid, kasutades sisendina ettevõtte analüüsi mudeli tulemusi. Käesolev töö põhineb avaldatud artiklitel.

Uurimistöö käigus optimeeriti ettevõtte analüüsimudelit eesmärgiga leida väikese ja keskmise suurusega ettevõtte kitsaskohad. Kasutades Fuzzy AHP-d ja SMARTER kriteeriume töötati välja mõõdikute valimimudel. Optimeerimise- ja andmeanalüüsi protsesside hindamiseks kaasati 10-ne liikmeline ekspertide rühm. Andmete optimeerimisel rakendati valiku tuvastamise meetodeid, näiteks modifitseeritud Z-skoor, Turkey meetod ja kohandatud boksplot meetod.

Kogu arendusprotsess on kirjeldatud ja saadud tulemusi on valideeritud konkreetse ettevõtte andmete baasil. Kuna ettevõtte olukord muutub dünaamiliselt ja vajab eri lähenemist, peab kogu analüüsi protsess olema pidev ja arenev.
Tootlikkuse mõõdikute valimimudeli väljatöötamise põhjal teostati järgmised etapid:

• ettevõtte analüüs (ettevõtte uurimine, kus on läbi viidud uuring);
• uuringu andmete kogumine;
• andmete analüüs (sorteerimine, rühmitamine, kaalude rakendamine);
• kaaluteguri määramine;
• vastuste järjestamine;
•tootlikkuse mõõdikute valimine (mõõdikute järjestamine SMARTERi kriteeriumide alusel ja Fuzzy AHP analüüsi teostamisel);
• mõõdikute rakendamine (saavutatud mõõdikute juurutamine ning jälgimine).

Märksõnad: tootlikkuse mõõdikud, SMARTER kriteeriumid, Fuzzy AHP, ettevõtte analüüsi mudel, olulisuse indeks, järjepidevuse test, väljundite avastamise meetodid, väikese- ja keskmise suurusega ettevõtted.

Abstract

Development and Implementation of the Key Performance Indicator Selection Model for Small and Medium Enterprises

Due to the high competition between enterprises in different fields the production should be monitored and controlled by eliminating bottlenecks and by raising the efficiency. This can be achieved by the implementation of the KPI selection model.

The model will be able to improve the management's work by decreasing the resources required to perform analysis in the company and to select metrics. Nowadays, many research institutions and companies have studied different systems in data collection and in the selection of metrics. Taking this into account, a consolidated model has been proposed.

The main objective of the current study was to develop a KPI selection model that enables us to generate a package of metrics as an output by using the input from the enterprise analysis model. The current work is based on the published articles.

First, the enterprise analysis models, the main idea of which is based on the data collection for understanding and studying the weak spots in the company (main focus on the small and medium sized enterprises), were developed and optimized. Next, the KPI selection model was developed by utilizing the fuzzy AHP and SMARTER criteria approach. In addition, a group of 10 experts who have excellent knowledge and experience in the field of production was involved in the optimization and data analysis processes. The outlier detection methods like: modified Z-score, Turkey's method and adjusted boxplot were applied in data optimization.

The whole development process has been described and validated as a case study in a company. As the situation at the company is changed dynamically and with own specifics, the whole process should be repeatable/continuous.

Based on the development of the KPI selection model, the main activities/steps were outlined:

- Analysis of the enterprise (investigation of the company, where study has been conducted);
- Data collection for the study;
- Data analysis (sorting, grouping, applying weights);
- Weight calculation (weight amendment by multiplication with reliability index);
- Ranking of answers;
- KPIs selection (ranking of KPIs based on SMARTER criteria and by performing Fuzzy AHP analysis);
- KPIs implementation (starting measuring and following chosen KPIs at the enterprise).

Keywords: key performance indicators, SMARTER criteria, Fuzzy AHP, Enterprise analysis model, significance index, consistency test, outliers detection methods, SME.

Appendix 1

PUBLICATION I

Kaganski, S.; Paavel, M.; Lavin, J. (2014). SELECTING KEY PERFORMANCE INDICATORS WITH SUPPORT OF ENTERPRISE ANALYZE MODEL. *Proceedings of 9th International Conference of DAAAM Baltic Industrial Engineering,* Tallinn, 97−102.

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SELECTING KEY PERFORMANCE INDICATORS WITH SUPPORT OF ENTERPRISE ANALYZE MODEL

Kaganski, S.; Paavel, M. & Lavin, J.

Abstract: *Key performance indicators (KPI) are instruments, which can help companies to get necessary information about enterprise's conditions at current moment and also provide management with further plan of action. In addition, continuous study of metrics supports enterprises with regular development and innovation aspects. However, the main problem that acquires by dealing with metrics is their amount. Number of different indicators is so large, that the possibility of putting them together in one package, which would be used for specific company, is low. The main objective of this study is to analyze the influence of KPIs for product life management (PLM) and production monitoring systems (PMS) on production efficiency and on profit of small and medium enterprises (SME)[1]. One of the subtasks is to create an analyze model for enterprises that will help to understand, what types of KPIs should be studied and focused by management.*
Key words: Key performance indicators (KPI), weight factor analyze, PLM, PMS, SME

1. INTRODUCTION

The objective of this paper is to give an overview of enterprise analyze model (EAM) and its' main concepts and thoughts. The general idea of development the EAM is to simplify the choice of key performance indicators (KPIs) for different and specific small and medium size enterprises (SMEs). The model would help managers to make clear, what data should be collected for further studying and what improvements should be done in the future. During the enormous amount of KPIs (for example, there are databases/libraries, which include 17000 different metrics [2]), it's very difficult to choose, what kind of indicators should be implemented for different enterprises. Despite the fact, that data collection and analyze is one of the main activities of management, the meaning of what to measure, should be the main priority. Managers should know not only what common problems, questions and situations are appearing in SME processes in different fields (not only production, but also logistic, quality etc.), but exactly the main problems in THEIR enterprises.

Through the main KPI's for the certain company the manager can monitor the production line or unit [3], analyze different processes and techniques [4,5] depending on the availability and weight of the specified KPI's.

2. KEY PERFORMANCE INDICATORS

2.1 Definition and meaning

Measurements are important; they are showing for managers the problematic points and are helping to solve different issues for getting benefits. It is essential for companies to determine the pertinent indicators, how they relate to the formulated goals and how they depend on the performed activities [6]. Additionally, indicators can provide managers with action plan and exactly declare, what should be done in the first place.

Company can be compared with living form/organism. When we are talking about health monitoring, then the pressure is measured, also all the results from blood test and other, that can show to the doctors exactly, in what stage the patient is, are analyzed. The same should be done in every commercial organization. Considering the thoughts written above, KPIs are measurements that show the health of company and of its business development system. They combine companies' goals and strategies to its incomes, outcomes and provide management with information of common condition: past, current, future [7].

2.2 The distribution of KPIs by types

To better understand, to simplifier searching and to make right solutions, KPIs need to be categorized or divided into groups or types.

According to Corbin (2009) the type of key performance indicator affects how the measure is used. Additionally, the type of performance measure determines its impact on other performance measures [8].

From the chronological aspect, KPIs can be divided into two types: **leading indicators and lagging indicators** [7].

Leading indicators are activity or task-based metrics that are measured early and can be influenced to affect future outcomes. They are measured today to determine if goals will be met tomorrow, and they are measured early and often enough to allow for changes that can impact the predicted outcomes.

Lagging KPIs are historical measurements that look back to determine if success was achieved. Additionally they are affected by another indicator. Financial measures are lagging: they prove how well the firm has performed. Agency Gross Income (AGI) from new clients is a lagging indicator of business development success [7,8].

Vukomanović, Radujković, Nahod (2010) [9] have named the set of KPIs as Key Performance Results (KPR) and have made own classification:

- KPI-leading performance measures;
- KPO-lagging performance measures;
- PerM-perceptive performance measures.

PerMs are measures that report stakeholders' perception in projects and can be lagging or leading. Usually they are generated through interviews and questionnaires.

Furthermore they have found, that many authors, who are trying to classify indicators, are confused KPIs for KPOs and only few of them, have acknowledged, that there should be additional group PerM (Vukomanovic, 2007) [10].

There is another opportunity for classification KPIs. They can be divided into types/groups depending upon how they should be used and what exactly should they show [11]:

- Strategic/Operational;
  Longer term facilities (strategic) versus shorter term activity (operational)
- Result/driver;
  Depending of the enterprise's implemented changes and activities, metrics can show the result of those actions. The influence on understanding performance is crucial.
- Leading/Lagging (see above);
- Qualitative/quantitative;
  The satisfaction questionnaires of customers or employees can be an example of qualitative metrics. During different surveys, the data would be stored and analyzed. Calculated values will show and describe to managers exactly, what situation is at this moment. In other words, qualitative/quantitative indicators are the real-time measurements, which help to value the situation at the certain period of time. Quantitative KPIs can be used for process optimization. Additional examples of quantitative metrics are: "Employee turnover",

“Units per man-hour” or Maintenance backlog [12].

Effectiveness/efficiency;

In order to measure how much of your targets were reached effectiveness indicators can/should be used. They compare actual to expected values e.g. actual to expected sales, saving on budget etc. Efficiency indicators can measure how "well" your resources (people, machines, money) were performed. [13].

The distribution should simplify the choice of indicators. However, the groups, by which indicators are divided, are wide spreaded and include enormous amount of different KPIs. The question: „Why this or that metrics should be selected? “ is still open.

3. ENTERPRISE ANALYSE MODEL (EAM)

The enterprise analyze module is a preparatory phase in KPI selection. It should help to create necessary points for further studying and should show to managers and owners the weakest spots of an enterprise. Concluding from the above written thoughts, the main goals of EAM are:

1) getting common information about enterprise;
2) making clear weak spots;
3) letting know what data should be collected and for what purpose (taking into account weak points).

EAM is module that consists of enterprise mapping and of questionnaire. When we talk about enterprise map (EM) approach, then it was created in 1998 by John Wu and has been used to support different US government agencies and private industries. EM can be compared to geographical map and gives information about location, size, field of actions, missions, visions and etc. of company [14, 15]. Received from mapping, data could be used in getting know what fields are important for company. In addition, with this we can get general information of firm and also make conclusions about necessary actions and points, which should be analyzed during the process. In figure 1 is presented map, which would be used during research for getting data for analyzing. It’s a template and during research can be adapted to various SMEs and additional fields can be added.

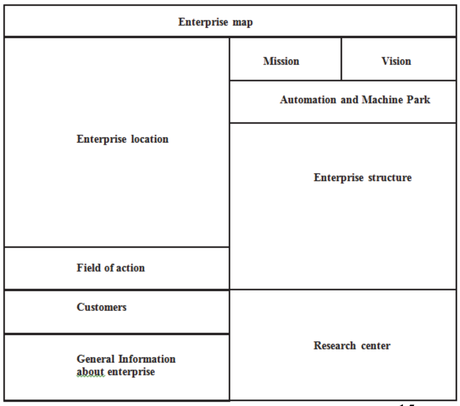

Fig 1. Enterprise map (adapted from [15])

Questionnaire is one of the oldest and mostly spread tools for data collection. The advantages of this research instrument are availability (cheap), quality and standardized answers what makes it really comfortable to use and do not need much effort. Opportunity to choice is guarantying to receive necessary data for further research.

In this study, questions are constructed in this way, that by responding on them, the potential critical fields would be brought out. In addition, to the each query would be added weights to determine significance of the issue. Every answer would have own scale to judge the impact on selecting KPIs. This would provide management with information about state of company on concrete moment and simplify the choice of metrics.

Figure 2 shows the example of questions, which would be used. The questions are form HR block and KPI „turnover rate“ is linked to them.

The high turnover rate is not only problem, that companies in Europe and in other countries should face. The Boston Consulting Group in their research is mentioning that in the nearest future, companies will face five critical HR challenges: managing talent, managing demographics, becoming a learning organization, managing work-life balance and managing change and cultural transformation [16].

How many employees (white-collar workers) have left your company during last year?	
a) 0-10	(1)
b) 10-50	(2)
c) 50-100	(3)
d) >100	(4)

What is the average training time for new employee (white-collar workers)?	
a) <1 week	(1)
b) 1-2 weeks	(2)
c) <1 month	(3)
d) >1 month	(4)

	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12
4	4	8	12	16

Fig 2. Example of questions and matrix

According weights in right column the matrix can be constructed. This way the impact on indicator „turnover rate“ can be evaluated. Furthermore, the classification of KPIs, which were suggested in previous study [1], would be used for questions' formation.

4. CASE STUDY

The EAM would be tested on real enterprise and data would be collected for further studying. On Figure 3 is illustrated all process/model of selecting KPIs for company. EAM is first phase and during it, the KPI, according collected information, should be selected.

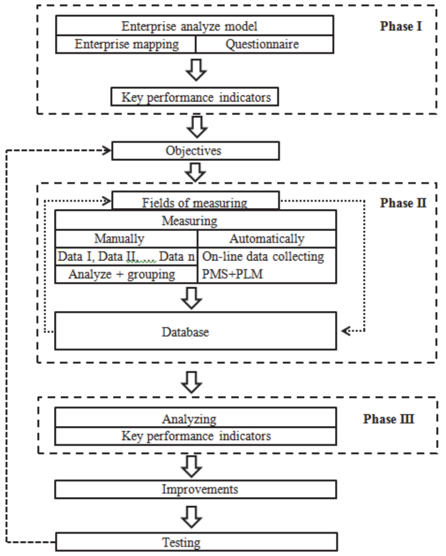

Fig 3. KPI selecting model

The second phase is measurement. First of all the fields of measuring should be selected. Knowledge of critical points from the first phase will reduce the searching sphere and configured metrics will focus attention of management on themselves.

There are two ways of collecting information: the manually and automatically.

However, there are 3 general issues that appear during data collection: untimeliness, inaccuracy and bias. Taking into account that this raw information forms the basis for production reports - and according to them, decisions are made - any problems with the primary data collection can start a chain reaction, which will have crucial impact on enterprise [17]. Taking into account disadvantages of manually information gathering, the automation should be first priority. During manual collection, different questionnaires, surveys will be filled: for example employees before leaving could evaluate employer and fill forms about pluses and minuses of work place. After that data should be sorted and transferred to main database. If forms were on paper, then step by step all should be migrated into electronic format.

In automatic data collection, support of PMS and PLM would be used. During the monitoring process, data in real time from different machines would be received. Wireless sensors will be preferred. PMS, based on wireless sensor nodes, are relatively inexpensive and it can be installed on old and modern manufacturing equipment [[18]]. Those sensors can eliminate the cost of cables and simplify the installation. Wireless monitoring is used rarely in the shop floors [[19]].

During PLM the data about products, pre-production processes will be collected. It's a huge complex of IT tools and applications, which support digital design and manufacturing practices in several ways [[20]].

In addition, all the information about incoming materials, outgoing goods are fixed by scanners (barcodes) and stored in enterprise resource planning (ERP) system. Modern ERP system, if it already has KPI module, can provide management with necessary data, otherwise, it could be directly connected to the database.

Third phase is analyzing. In process of it, KPI will get numerical values, which will used by management for evaluating of enterprises' condition.

Improvements and testing should be done. The process is cycle, so it should be continuing even if goals were achieved.

5. FURTHER RESEARCH

The EAM would be used for collecting data of real company. Taking into account, that the amount of various companies (different field of actions, different structures and etc.), next points/steps should be analyzed:

- optimization of EAM (mapping + questionnaire) for possibility of using by various SMEs;
- optimization and automation of data collection (e-module via Internet for surveys);
- support of PMS and PLM for additional data.

6. CONCLUSION

Considering the productivity, HR and other issues in SME, the measuring, process of collecting data and comparing them with previous (continuous improving), still remains main priority and is real challenge to the management. The EAM and selecting KPIs process in total (figure 2 and 3), were described in this paper. Further steps were defined for next research.

Described methodology and model/module, first of all, would be a good assistance for managers to simplify and automate metrics' selection and secondly, can be used for further studies in this field (process and model development).

Testing and correcting of the model in addition with data flow optimization, have been foreseen as next tasks.

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Appendix 2

PUBLICATION II

Kaganski, S.; Paavel, M.; Karjust, K.; Majak, J.; Snatkin, A. (2015). DIFFICULTIES IN SMES AND KPI SELECTION MODEL AS A SOLVER. *10th International DAAAM Baltic Conference, INDUSTRIAL ENGINEERING,* Tallinn, 33−38.

10th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING
12-13 May 2015, Tallinn, Estonia

DIFFICULTIES IN SMES AND KPI SELECTION MODEL AS A SOLVER

Kaganski, S.; Paavel, M.; Karjust, K.; Majak, J.; Snatkin, A.

Abstract: *Small and medium enterprises are seen as „backbone of the European economy"[1] Nowadays, in „harsh environment" and difficult economic situation, to be able to survive, SMEs should not only optimize production, find new investors, rise effectiveness and productivity, but also change the way of thinking and try to understand all processes in production and company itself instead of just „driving forward with closed eyes". The measurement of processes and company's condition at present moment should be one of the keys to success. Continuous development and analyse would provide management team with plan of actions. The main objective of this paper is to introduce difficulties and problems, with which enterprises are faced in their life. Furthermore, to show concept of KPI selection model for enterprises, which would help to understand, what KPIs should be taking into account and studied by management and how those metrics can change the situation and solve all difficulties. In addition, during the applying of model, the amount of data and data flow in enterprise would be optimized.*
Key words: *Key performance indicators (KPI), Small and medium enterprises (SME), KPI selection model.*

1. INTRODUCTION

The last twenty years have seen profound change in the private sector's relationship with society. Globalization, deregulation, privatization and a reconsideration of the links between state and market have changed the basic principles on which private companies are expected to contribute to the public sector [2, 3]. Additionally, the economic conditions in 2011/2012 in the World and in the European Union with new difficulties nowadays, due political issues and food embargo as a counter from Russian Federation, have crucial impacts on SMEs but still, this form of business is remaining the most important and widely spread. They are showing a better performance in compering to big enterprises and corporations [4,5], additionally, the dynamic role of SMEs-as a chine of the European economy-seems to have been played important role in the recovery from the global crisis since 2008 [1]. On the one hand, SME cannot effort high cost researches and developments (R&D) like large enterprises, due the financial and economic aspects, on the other hand, the speed of implementation of new technologies and methods (Lehtimaki considered the importance of new ideas for product innovations in SMEs of Finland to top of management [6]), comparing with large enterprises, are high and not so much time and money consuming. Additionally, SME can be innovative in other ways-modernization of products and processes to win new markets (LE are not interested in small markets, they are trying to get a really wide spreading markets and big clients).

2. DIFFICULTIES THAT ARE APPEARING IN SME

Watt has distinguished following steps in the risk management process, which should be taken into account by managers [7]:
• Establishing the SMEs risk strategy;

• Determining the SMEs risk appetite;
• Identification and assessment of risk;
• Prioritizing and managing risk.

Also, if we try to divide problems, with which enterprises are facing, then there will be two main groups:

• Financial or economic problems (SMEs success is tied in with the local economy as the SME sectors market growth is usually at the same rate as the macro economy as a whole, therefore, if there is an economic downturn, SMEs will usually also experience difficulty [[8]].

• Enterprise based problems (human resource problems, multi-functional management, high employee turnover rate [one of the common problems nowadays], lack of skills and experience, low productivity and difficulties of finding quality staff [[9]].

Considering financial problems, SMEs have very limited bank finance, which is only around 10 per cent, while self-finance remains the major source of finance contributing 76.5 per cent of fixed capital and 51.8 of working capital [[10]]. In critical situations SMEs don't have the buffer for not only investments in new technologies but also for covering additional costs during prices growth or projects recalculation. For example, according World Bank survey (2002) the lack of money for the majority of Bangladesh's SMEs (55%) was the main issue, during their operation.

To reduce the impact of economic/finance issues on SMEs entrepreneurs should to [[11]]:

• Definite market opportunities;
• Pay more attention to team working;
• Choose or develop suitable marketing entry strategy;
• Operate the profitable ventures.

It is important to know, who the clients are and of course do not forget about competitors and comparing to them, what would be the main strengths and weaknesses. Additionally, entrepreneurs should think about the logistics and the prices should be also competitive. To open new firm and to start business is quite easy, but to stay afloat and continue to grow is very difficult.

When we are talking about measurements of economic aspects, then nowadays, the majority of SMEs has not established strict financial accounting system, including real-check, card-check and account-check. It's is difficult to carry out the financial accounting procedure [[12]]. Although most SMEs apply basic financial accounting system but it does not match smoothly with the logistics, manufacturing, sales and cannot provide enterprises with complete information [[13]].

Considering the enterprise based problems, Employee Turnover is one of the common problems. "It is the ratio of the number of workers that had to be replaced in a given time period to the average number of workers" (Agnes, 1999) [[14]]. It is often utilized as an indicator of company performance and can easily be observed negatively towards the organization's efficiency and effectiveness (Glebbeek & Bax, 2004) [[15]]. Due to limited growth of SME most of the skilled employees leave SMEs. According Levy, SMEs are knowledge creators but poor at knowledge retention [[16]]. Employee job satisfaction has influence on employee turnover in organizations. The extent to which an organization is able to retain its employees' depends on the level of job satisfaction that is made available to these workers. [[17]]. However, taken into account nowadays situation, the main reasons of high turnover is salary. Young specialists are searching the best place, which could include a good salary, an interesting job and good additional opportunities for further rise. According to the European Statistic 2010, In a recent OECD (Organisation for Economic Co-operation and Development study (2009)) covering eleven countries for job turnover and twenty-two for labour turnover and using harmonized data, job turnover rates were estimated at 22% (of total employment) over the period 1997-2004, and annual average labour turnover rates at 33% (of total employment) between 2000 and 2005 [18].

The high turnover rate is not only problem, that companies in Europe and in other countries should face. The Boston Consulting Group in their research is mentioning that in the nearest future, companies will face five critical HR challenges [19]:

• Managing talent;
• Managing demographics;
• Becoming a learning organization;
• Managing work-life balance;
• Managing change and cultural transformation.

Considering the nowadays situation, the lack of qualified workers is becoming more problematic with every year. HRM should be on the same level of importance, like the economic issues (turnover, consumer leverage ratio, retail sales and etc.). Managers should not forget that the main job is done by workers and the beneficial HRM is directly influencing the financial indexes of company. KPI of HR for management can help to make right decisions to changes the situation in enterprise.

3. KPI SELECTION MODEL

To understand the main purpose of bottlenecks and difficulties at company, the necessary measurements should be performed by management to be able to evaluate the impact of each factor. KPI selection model [20] should be seen as tool, which is able to identify the critical spots in enterprise and solve them in nearest future perspective. The idea is to use traditional methodical questionnaires to make management understandable and to bring out the main bottlenecks and weaknesses in the production and general enterprise processes.

On Fig 1 the main first phase of KPI selection model is been illustrated. The draft version was described in article Kaganski 2014 [20], however, during practical study, it would get final review and optimized. The first phase is questionnaire, which could be called also as a preparation phase. Survey for KPI has been built concerning the productivity KPIs. In this study, questions are constructed in this way, that by responding on them, the critical spots and problems would be identified. The questions are linked with KPIs that would be investigated after data collection. In turn, KPIs are divided by 3 groups:

• Direct KPI – indicators, which are in explicit relation to the responses;
• Indirect KPI – indicators, which are in connection to more than one question;
• Suggested KPI – indicators, which are proposed to the management for further studying.

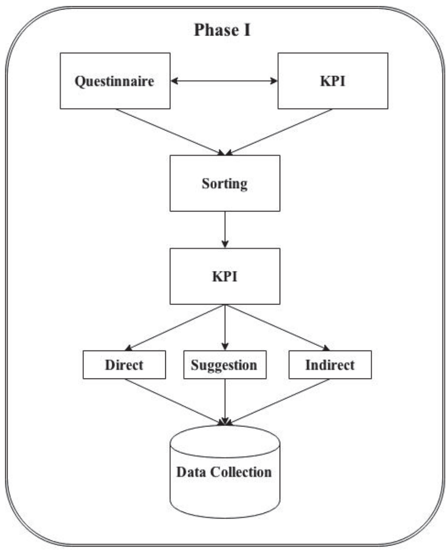

Fig. 1. The first phase of KPI selection model

In table 1, the example of distribution for KPIs from first phase has been shown. This kind of approach provides possibility to show management, if right KPIs have been followed (direct KPIs). Furthermore, depending of the problems, which would appear after analyse of the answers, suggestions can be provided to company, what could be measured.

Question	KPI		
	Direct	Indirect	Suggestion
What's the average age of white collars (Admin person) in your company?	% of employee over age 55		
Your age range	Average age range of employee		
What's the average age of Blue collars (factory floor persons) in your company?			
How long have you been employed in the current enterprise?	staff turnover ratio		
How many white collar employees have left your company during last year?	staff turnover ratio	Satisfaction	
How many Blue collar employees have left your company during last year?	staff turnover ratio		
Company is offering appropriate training for the job, as well as specific Occupational Health's Safety & Welfare training?			Employee Training Index

Table 1. Example of question vs KPI

Indirect KPIs can be specified only by answering at least on two questions, which are connected to it. As for example, KPI-satisfaction can be followed in company only by knowing the situation with staff turnover, trainings and benefits availability and etc.

To eliminate misunderstanding and check the relationship between pairs "question-KPI" the sorting was performed in WEB resource "Optimal workshop" [21] by case study group. The case study group is group of researches, who has no connection to the study, but in spite of that has necessary knowledge and experience in the field.

Survey should be filled by workers from all areas, including "blue collars", "white collars" and CEO. The independent point of view of each employee would help to construct the right representation.

4. CASE STUDY

The selection model would be tested on different manufacturing companies, which are dealing within divergent fields to evaluate the compatibility of it. Taking into account, that prevailing language at companies in Estonia can be divided to 3 main groups: Estonian, English, Russian, -

the survey should be providing the opportunity to be used in any condition. After acquiring mandatory amount of data, analyse should be done. Each studied company would receive the methodology of improvement steps for the future and also, the whole picture of all enterprises by detection standard bottlenecks, would be analysed. Furthermore, the questionnaire is only one step of data collection and can be considered as manual way. The other opportunity is to use advantage of PMS (product monitoring system) and get data directly from machines, production lines to the database for further study. Wireless sensors would be attached to machine park and provide data of parameters: vibration, temperature, voltage consuming, which in turn could be used to prognoses the condition of tool. [22] The usage of wireless sensors would reduce costs (not need for cables and wires) and simplify the assembly and installation. [23] The advantage of this approach is the possibility to study KPI: OEE (overall equipment efficiency) and all related with it metrics. Online data flow gives the opportunity to make right decisions in instance and drive the production in right direction, which would save time, resources and nervous.

5. FURTHER RESEARCH

The KPI selection model would be tested in practice and acquired data analysed. Taking into account, that testing model on one enterprise isn't enough for optimization, next points should be done/analysed:

• Optimization of KPI selection model (questionnaire & linked KPIs);
• Data from PMS as first step for further study;
• Different SMEs for collecting right amount of data.

6. CONCLUSION

Considering the efficiency of production in SMEs, HR issues, material flow and other critical subjects at companies, the measurement with further improvements and optimization remains general task for management. The difficulties, which were described in article, cannot be eliminated in an instant; however, the necessary measures could be done in order to avoid further difficulties. The KPI model structure and difficulties, which are occurring at companies, were described in this paper. Later steps were defined for next researches.

The KPI selection model could become the main fundament on which decisions and improvements would relay. Furthermore, it should simplify the work of management and make production more transparent. Optimization, data collection and analysing are foreseen as next tasks.

7. ACKNOWLEDGEMENTS

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Appendix 3

PUBLICATION III

Kaganski, S.; Majak, J.; Karjust, K.; Toompalu, S. (2017). Implementation of key performance indicators selection model as part of the Enterprise Analysis Model. *Procedia CIRP, 63: The 50th CIRP Conference on Manufacturing Systems, Taiwan,* Elsevier, 283−288.

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The 50th CIRP Conference on Manufacturing Systems

Implementation of key performance indicators selection model as part of the Enterprise Analysis Model

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Abstract

Nowadays, to be able to stay in competitive environment, organizations have come to the understanding, that monitoring of enterprise processes and factory floor is one of the ways to achieve better efficiency, performance and overview. As consequence of several frameworks, the methodologies has been proposed during last years. The companies are dealing with different key performance indicators (KPI), which help to focus on the parameters at that particular enterprise and are powerful tools in management processes. The real time monitoring systems for monitoring the KPIs will help companies to identify progress toward sales, marketing and customer service goals. However, the amount of different available metrics provides difficulties to make right decisions.
In the current study the Enterprise Analysis Model (EAM) with the results, obtained by applying KPI selection model as part of the EAM, were introduced. The model was tested in private company. The package of KPIs, which should be followed by management, was generated. The proposed method enables to save time and resources during analysis and selection of metrics.

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Keywords: key performance indicators (KPI); enterprise analysis model (EAM); production monitoring.

1. Introduction

Critical situation in the World economy (globalization, urbanization, fall of oil prices, restrictions from EU and Russian Federation on economic level) made companies to understand, that in order to be successful in dynamic environment with competitors, shorter product lifecycle and heavy price pressures, when costs are driving down by third party countries, they need to be agile, flexible and concentrate on their business strategy, which has moved from production or cost oriented ideology to more strategic orientation [1-6].

Within couple of last years, the enterprises were not only lack of the capital, but also trying to retain consumers as well. In order to achieve those goals, the company's performance should be at the high level: products or services should be made/provided at the right place, time, quantity and for right customer [7, 8].

The Key Performance indicators are the modern tools that help to keep the performance in the production on the high level [9, 10]. The possibility to discover and understand the bottlenecks, opportunity to evaluate the efficiency of workers and machines, setting higher goals and achieving them by moving straight forward is possible, when you are following and monitoring in real time the right metrics in your enterprise. Measurement of performance allows to make clear performance issues, compare current situation to the goals and to provide exact steps towards elimination of the problems [11, 12].
Kelvin has defined KPIs as "When you can measure what are speaking about and measure it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of meager and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely, in your thoughts advanced to the stage of science" [13]. It is not exception that companies are measuring wrong metrics,

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collecting the unnecessary information into databases and getting confidence that there is nothing to worry [14].

The successful metrics in one company could not always work on another, in spite of that that they are in the similar area. It's obvious, that the success of KPIs are depending on their continuous measurability [15]. Metrics should be adjusted to company's structures, production processes and internal/external data flows. That's why each management should follow their own KPIs and compare them with the competitors, on the right time and place [16]. Each indicator describes only a concrete sector and field of the company's activity. As a result, the packages of the successful indicators are required to be built by the management. Considering the number of different metrics and their impact on the enterprise's condition in total, management had been faced with the difficulties in selection of the right metrics on the right time [17].

In the current paper an attempt is made create a package of necessary metrics and implement the KPI selection model in particular private company based on this package of metrics [18, 19].

2. Enterprise Analysis Model (EAM) description

The Enterprise Analysis Model (EAM) is a tool, which allows performing analysis of the enterprise during reasonable time without remarkable lose in quality. The model helps to identify the weak spots of the company and provides the information regarding data, which should be collected for changing the situation in near future [18].

The EAM include questionnaire, based on analysis over 70 research papers covering production efficiency, design optimization of manufacturing processes, decision making, management and control etc. problems. Composing questions there is kept in mind that the answers should help to understand the situation in company and identify the bottlenecks. The questions are linked to KPIs, which means that by answering to questions, the right metric depending on the weight of the answer, will be selected. To eliminate the wrong answers each question has its own double (different formulation but the same meaning). The answer would be counted as "right" only when both answers are identical (to main question and its double) or there would be a little swing in scales (like strongly agree versus agree). The questions are grouped based on the position of the employee or in other words the specific package of questions was composed for particular job position in the company shop floor [17-20].

In order to use resources more effectively, design optimization of the EAM has been performed. As result of employing expert decisions and the outlier's methods the total number of KPIs was reduced. Three different outlier's detection methods have been employed: modified Z-score, Turkey's method and adjusted boxplot methods. These methods help to eliminate extreme values in the data. The data outside intervals determined by these methods are considered as outliers [21].

The start and final amount of questions and KPIs for study has been shown in Table 1 [20]:

Table 1. The amount of questions and KPIs for study

EAM	Raw	Optimized
Questions	259	61
KPIs	92	13

In addition, the EAM is a part of the KPI selection model and can be divided into next main phases:

- Data collection (getting answers on the questions);
- Data analysing;
- Weight calculation (based on answers);
- Ranking of the answers;
- KPIs selection;
- KPIs implementation;
- Data collection.

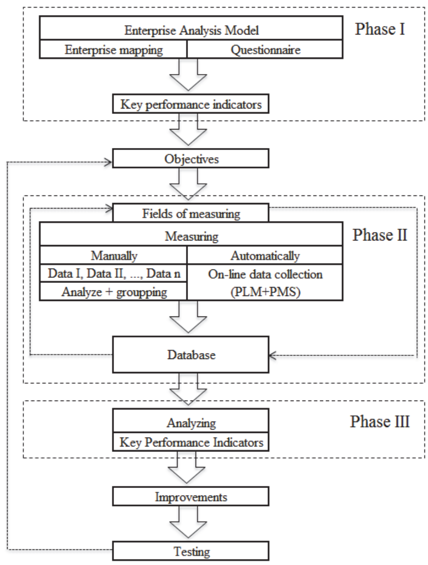

Fig.1. Main concept of the KPI model

In the Figure 1, the main concept of the model has been shown. The EAM model is located in phase and is been used for collecting information about company by applying mapping and questionnaire, which can be merged into one survey.

The whole process, shown in Fig.1 should be repeated continuously, as the situation is changing rapidly and requires monitoring of the whole manufacturing processes in the company.

3. Algorithm for analysis of answers

The questionnaire was established in cloud server environment. The total amount of questions was 61 and the package of questions for each person depend on his/her position in enterprise [20].

An algorithm proposed for the analysis of the answers can be outlined as follows:

Step 1. Acquiring data from the cloud server;
Step 2 Applying weight to the answers depending on their significance;
Step 2.1 Weights amendment by multiplication with reliability index;
Step 2.2. Sorting the duplicate questions by finding differences in the weights for the same problems;
Step 2.3 Creating new groups for liability test;
Step 3. Testing the consistency by calculating the Cronbach Alpha;
Step 4. Calculating mean weight for each answer taking into account the results of consistence test;
Step 4.1. Applying ranks based on the calculated weights;
Step 5. Generating the KPI package.

The algorithm has been implemented in private company. Corresponding description is given in next section.

4. Case study

4.1 Description of the company

Company's primary field, where the case study was conducted, is the production of equipment for power distribution networks, industrial control and automation systems for different sectors, including energy, industrial and public utilities. The main business of the company is the manufacturing of sheet metal components/products for the data communication networks and telecom. The company is located in 3 countries: Lithuania, Finland, and Estonia. Company is providing work to around 460 workers. The main production units are located in Estonia. The Enterprise analysis model [18, 19] and the KPI selection model [18-20], were tested to evaluate the performance of the company and to detect the bottlenecks in production.

4.2 Data analysis

In order to determine the impact of each answer on the situation described by the question, the index of significance has been applied to the each response. The 6 point scale has been used, where 6 - is the most favourable answer and 1 is the opposite [22]. In the other words, the questions (situations that they are describing) with the lowest average value should be analysed first. For the "yes" and "no" questions, depending on the question's context, the 6 or 1 point have been applied. Depending on the problems description (taking into account the questions' context), the two variant of scales should be distinguished. The scales have been shown in table 2.

Table 2. The 6 point scale

Consent	Scale	Opposite Scale
Strongly agree	6	1
Agree	5	2
Inclined to agree	4	3
Inclined to disagree	3	4
Disagree	2	5
Strongly disagree	1	6

For the better evaluation of the answers, depending on the position of employee in the company and his/her influence on the decision making, based on the experience, the reliability index has been introduced.

In this study the reliability index describe trustworthiness of the answer and can be calculated as:

$$Rel_{index} = \frac{ExpCurPos \times YearsCurComp \times TotalExpInArea \times PosCoef}{100}, (1)$$

In equation (1) ExpCurPos,YearsCurComp, TotExpInArea and PosCoef stand for the experience on the current position, years in current company, total experience in considered area and position coefficient, respectively.

The value of the position coefficient characterizes the impact of the worker's position on the answer: the higher the coefficient, the more trustworthy information will be and higher influence it will have on the final answer. For evaluation of the coefficients values, the judgement of expert group of 10 members, who have experience in the field of production and process optimization more than 5 years and for whom this is the main research/activity area, was taking into account (7 from industry, 2 from university and 1 from competence centre). The coefficients values and the results are introduced in table 3:

Table 3. The scale of significance index

Position at work	Coefficient
Manager	1
Engineer	0,9
Specialist	0,8
CEO	0,7

The corrected weight, obtained by multiplying reliability index on the answer's weight, has been calculated and used in further study as the final value of importance of the question.

The employees of the company conducted a structured survey. A total of 54 people have participated and 37 respondents returned to the completed questionnaires. The rest of the ones were incomplete and were not taken into account.

To simplify the analysis of the received data, the answers were grouped by the number of respondents from whom they were received. For example the questions: "Production never stopped because of the lack of material" and „Lack of material did not affect production in last year", were asked from 13 respondents and were added into one group, however the question: "Do you have line production?" from the 8 respondents was added to one of another group.

A reliability analysis was performed to check the consistency of the survey data. The Cronbach's Alpha was calculated. According to the theory, the data is reliable, if Cronbach's coefficient alpha is above 0.700 and the acceptable minimum is 0.600 [23, 24]. The alpha coefficients for each group of answers are given in table 4. Groups with only one member were not included into this analysis.

Table 4. The alpha coefficients for each group of answers

Group No	Amount of Questions	Number of respondents	Cronbach Alpha
Group 1	12	13	0.75644
Group 2	2	13	0,963415
Group 3	6	10	0,444922
Group 4	6	11	0,689423
Group 5	8	4	0,623377
Group 6	2	5	1
Group 7	4	5	0,785388
Group 8	2	20	0,149239
Group 9	4	6	0,37037
Group 10	2	15	0,850098

From the table 4 we can see that the results of the groups 3, 8, 9 are not consistent. The "yes and no" questions could be the reason of the low consistency, as the data set was filled with 6 or 1, depending on the answer.

The answers on duplicated questions, which have differed from each other more than 1 point, were not taken into account and were eliminated from the analysis. The main idea of the duplicated questions was to check, if the described problem was fully understood by respondents or not.

The average value of weight was calculated and the rank was applied for each question. By the average value equal or more than 4, the investigated situation, described by the question, was recognized as acceptable. Arguments with average weight between 3.5 and 4 were placed into a second group. The situations, with average weight was less than 3.5 were placed in a group, which should be taken into account at first sight. In the table 5 the importance of the problems has been characterized by the values of the rank and average weight of the questions.

Table 5. Questions ranking

ID	Questions	Average	Comment	Rank
HU2302	We can shuffle our staff between different projects without losing efficiency and productivity.	3.183	Higher->Better	15
LO0201	Last year You had no problem with lack of material.	2.331	Higher->Better	4
LO0301	Last year You did not needed to use special transport.	1	Higher->Better	1
LO0401	Last year You did not needed to postpone transport due to delay of production or outsourcing.	2.673	Higher->Better	10
LO0701	During last year we haven't had issues with deliveries to clients.	2.509	Higher->Better	6
PE0303	How often do You review performance measures for accuracy/appropriateness to current needs?	2.1	Higher->Better	2
PE0303	Company routinely measures the Overall Equipment Effectiveness (OEE).	2.925	Higher->Better	12
PE0301	Overall Equipment Effectiveness is one of Your general indicators.	2.175	Higher->Better	3
PR0401	Production never stopped because of lack of material.	2.377	Higher->Better	5
PR0501	Production never stopped because of the unit/line breaking.	3.104	Higher->Better	14
PR0601	Production never stopped because of human resources.	2.646	Higher->Better	9
PR0701	Production never stopped because of the wrong machine settings or programs.	3.031	Higher->Better	13
PR0801	Production never stopped because of the old version of the detail.	2.511	Higher->Better	7
PR1701	During last year we haven't had breakdowns of our equipment.	3.264	Higher->Better	16
PR2301	Do You analyse workplace effectiveness?	2.791	Higher->Better	11
PR2601	Do You measure production unit/line reliability?	3.291	Higher->Better	17
QU0701	Total productive maintenance (TPM) is practiced and supported by all levels within the plant.	2.521	Higher->Better	8

It is worth to mention that according to the main concept of the analysis model [18-20], each argument/question was connected to KPIs at the beginning of the survey and the main KPIs group with their ranking rating was selected (see table 6) in the previous studies [17]. Based on this knowledge, the metrics, which company should follow in the future to change the situation were selected.

Based on the KPIs ranking and the issues ranking, the final table with rankings is introduced in the table 7. According to the results, TOP3 critical issues at the tested company were:

- Late deliveries to client (not proper planning of production, lack of employees);
- Material issues (late deliveries from supplier, not proper planning of the material);
- Wrong production time calculation, downtimes, lack of material and etc.

Table 6. Ranking of the main KPIs

KPI No	KPI Name	Rank
KPI1	Inventory turnover	4
KPI2	% of additional freight costs	13
KPI3	Product quality/quality ratio	2
KPI4	FPY (first pass yield)	10
KPI5	DPU (defects per unit)	5
KPI6	Employee efficiency	8
KPI7	Changes implementation time	7
KPI8	Actual production time	1
KPI9	OEE (Overall Equipment effectiveness)	9
KPI10	NEE (Net Equipment effectiveness)	12
KPI11	OTD (On Time delivery)	3
KPI12	Takt time	6
KPI13	Unit/Line reliability	11

The quality issues according to the analysis, also need to be followed by management. Taking into account the material problems (condition of the material, wrong replacement due to the late delivery), the elimination of them could also strongly affect the final productivity.

The production time in coupe with technical issues of the machines should also be taken into account. The provided metrics are just stones for building strong foundation. However, the proposed analysis should be performed not only once but iteratively, since the management of the company is dynamic process.

Table 7. The package of recommended metrics in company examined

KPI	Rank	Importance
Actual production time	1	
Product quality/quality ratio	2	High
OTD (On Time Delivery)	3	
Inventory turnover	4	
DPU (Defects Per Unit)	5	
Tact time	6	
Changes implementation time	7	
Employee efficiency	8	
OEE (Overall Equipment Effectiveness)	9	
FPY (First Pass Yield)	10	
Unit/Line reliability	11	
NEE (Net Equipment Effectiveness)	12	
% of additional freight costs	13	Low

Obviously, such an KPI ranking depend on particular company examined, but certain match for companies working in the same area can be expected.

Conclusion and future study

Taking into account the high amount of different metrics, the management of the company is facing difficulties with selection of the right key performance indicators, that should be followed and monitored. The common picture, which has appeared in the last years is the wrongly chosen metrics that does not provide necessary information regarding the actual production situation.

In the current study an algorithm is proposed for analysis of the answers of questionnaire. In order to perform analysis in reasonable time without remarkable lose in quality first the optimization of the model has been conducted. By applying expert decisions and the outlier's methods the total number of KPIs was reduced to 13 (from 92). Next, the data analysis has been performed based on answers analysis algorithm. As result the package of metrics, acquired by the KPI selection model has been selected for particular company.

The future study of the research group is related with optimization of EAM by developing/adaption multi-criteria optimization tools and methods [25-28], also implementation of the model in different companies.

Acknowledgements

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Appendix 4

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Development of key performance selection index model

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ABSTRACT

Purpose: The main idea of this paper is to introduce the refined model for selection of the Key performance indicators (KPI). The KPI selection model can be considered as a tool for analysis of the enterprise, which should be able to simplify the choice of the right metrics for the company, where study has been conducted. The Enterprise analysis model (EAM) will provide the information regarding weak spots on the production and provide further steps to the management. Those actions will save time and reduce resources that are necessary to implement metrics in company.

Design/methodology/approach: Main activities performed include: optimization of EAM; Fuzzy AHP and SMARTER criteria's for ranking the KPIs; reliability analysis and weights appointment to questions and KPIs. In addition, the expert group has participated in the analysis of this work and has made a high impact on the results.

Findings: The main result of this work is the final version of the KPI selection model.

Research limitations/implications: The future research should be focused on optimization of the model and in adding additional module for automatic data collection. The Production Monitoring System (PMS) that should help to collect data about the status of the machine park, taking into account the downtime, overall equipment efficiency (OEE) and etc.

Practical implications: The proposed model can be used in SME (small and medium enterprises) in order to improve the productivity. The concept was tested in particular company.

Originality/value: The KPI selection model combine different methodologies into one general approach. Due to this fact, the process of finding right metrics can be reduced significantly. The proposed approach allows saving resources for the research of metrics.

Keywords: Key performance indicators (KPI); Enterprise analysis model (EAM); Performance; Optimization; SMARTER criteria

Reference to this paper should be given in the following way:

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

Manufacturers are trying to improve production by applying the monitoring systems and use of Key Performance Indicators (KPIs). KPIs are showing the level of performance what system can achieve through measurable attributes, such as the amount of material, energy, or time consumed in a process. With the high amount of the Internet of Things (IoT) and the increasing availability of data in real time, manufacturers have availability to calculate a broad range of KPIs [1].

When an assembly line experiences downtime, it incurs both financial and productivity costs, in addition to environmental costs resulting from inefficient or ineffective use of resources. The material is wasted in the form of scrapped components and Work In Progress (WIP) and the energy with the effort is wasted in powering idle machines and factory itself while the production lines are restored to an operational state [2].

The KPIs allow gathering knowledge with experience and exploring the best way to achieve organization sub goals and main goals by taking under control the processes and data flows in company.

Kelvin defined KPIs as "When you can measure what are speaking about and measure it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of meager and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely, in your thoughts advanced to the stage of science" [3]. It happens often that the companies are measuring the wrong metrics and spending a lot of time and resources by collecting data without any visible profit. According to Parmenter, there are 3 main types of performance measures [4]:

1. Key result indicators (KRIs) tell you how you have done in perspective;
2. Performance indicators (Pis) tell you what to do;
3. KPIs tell you what to do to increase performance dramatically.

Many performance measures, which are chosen and used by management, are the combination of these three types. Talking about KPIs, they measure the performance of an enterprise relative to its goal hereby enabling improvements where there are errors [5].

In the industries such as metal and paper, chemicals, minerals processing-the performance of the controllers is an important step to make a decision whether the process has been established correctly and is operating properly [6].

The production in the process manufacturing is often highly automated by the various IT/software systems and production lines with combination of robots. The production is planned and scheduled by a Production Planning and scheduling System (P&S). The efficiency and effectiveness of the resources in the production plant can be estimated through KPIs. They can be defined according to the international standard (ISO 22400:2014), and composed together by means of modern analytics solutions and methodologies [7].

In addition, KPIs are defined as quantifiable and operative measurements that reflect an enterprise's critical success factors. KPIs are very important for understanding and improving manufacturing performance, both from point of the lean manufacturing perspective of excluding wastes and from the general perspective of obtaining strategic sub-goals and goals. It has been reported that those companies who have adopted sustainable practices were able to achieve better product quality by improving the first pass yield and quality ratio, higher marker share and increased profits [8].

Zhang et al. [9] showed that industrial KPIs can be classified into three groups:

1. Engineering KPIs that refer to the technical performance of the plant;
2. Maintenance KPIs that refer to the operating rate and hence maintenance time and cost;
3. Economic KPIs that refer to business profit.

An industry contains numerous types of equipment and processes that are a challenge to control and maintain in order to achieve highest performance and profit for the plant. KPIs are fundamental in measuring the performance and its progress and can provide information about the performance in different areas such as energy, raw material, control & operation, maintenance, planning & scheduling, product quality, inventory, safety. The reason for low performance is waste in different forms. By identifying the waste and implementing actions that reduces waste improves performance. Waste exists in different forms, for example energy, raw materials and downtime. Based on identifying process signals or combinations of process signals that are strongly correlated with the KPI of interest. The KPI is then improved by changing the correlated process signals in the direction that improves the KPI [10].

In addition, different selection methodologies of KPIs have been proposed: starting from Eckerson and his 10 characters [11], Doran [12] with SMART criteria and continuing with new approaches as the usage of AHP and SMART criteria for prioritization KPIs at organization by Shahin & Mahbood [13]; the KPI tree and AHP technic as selection methodology by Kadarsah [14], 12-way model, proposed by Parmenter [4] questionnaire survey and applying of Confirmatory factor analysis (CFA) for data evaluation by Yuan, Wang, Skibnewski and Qi [15], AHP based selection methodology for leading KPIs by Podgorski [16].

Furthermore, Fuzzy multi-criteria group decision-making methodology (FMCGDM) developed in a useful practitioner manual by Ly [17]. Methodology-top-down approach which focuses on KPI exhibiting degradation and the drills down to the root cause of the degradation, eventually a process, not only the control level but also on a business level reflecting the overall plant efficiency. Indicators help plant managers to assess the performance of the production at enterprise, plant or process level. Important thing about metrics is that they capture the essence of the production process and are therefore specific to the application.

High amount of different factors, starting from employee's education, skills and experience not only in the field, in which enterprise is operating but in general, to the financial components (budget, revenue, investments, not planned costs) and their influence on present situation, are making difficulties to standardize metrics in such way, that they could work with the same effect in different companies. Taking this into account, the objective of this paper is to introduce the KPI selection model (the whole process).

2. KPI selection model

For better understanding the nature of the bottlenecks and issues at company and to develop the necessary steps that would not only improve the situation at production and the whole enterprise itself but also would eliminate them at all the Key performance indicators selection model is required. The KPI selection model should be seen as a cure, which is helping to understand and identify the critical spots and resolve them in future perspective. The basic concept of the model was introduced in [18-22] and the final version is depicted in Fig. 1.

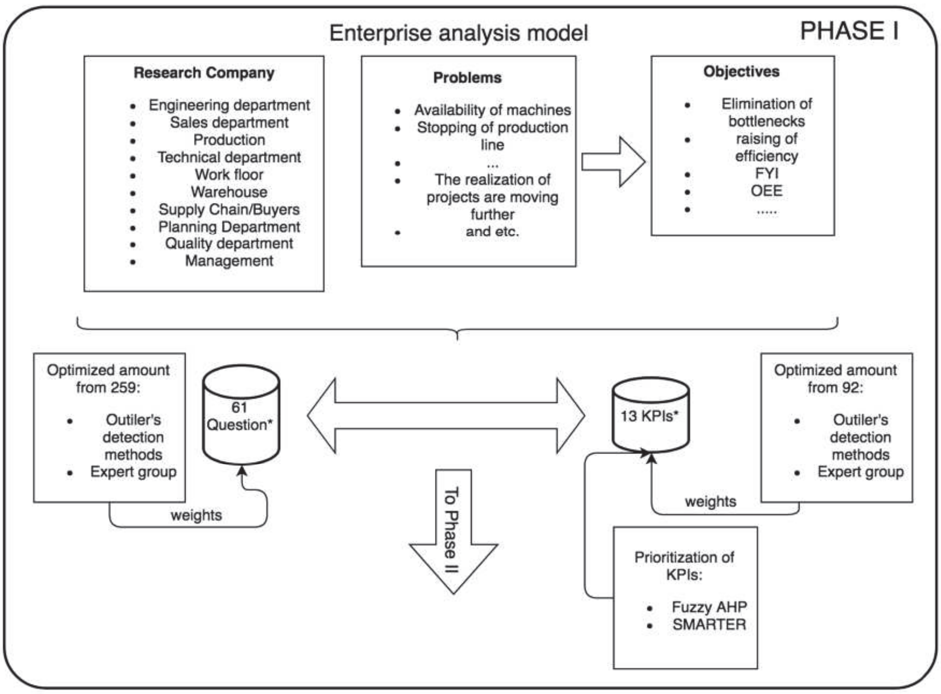

Fig. 1. KPI selection model

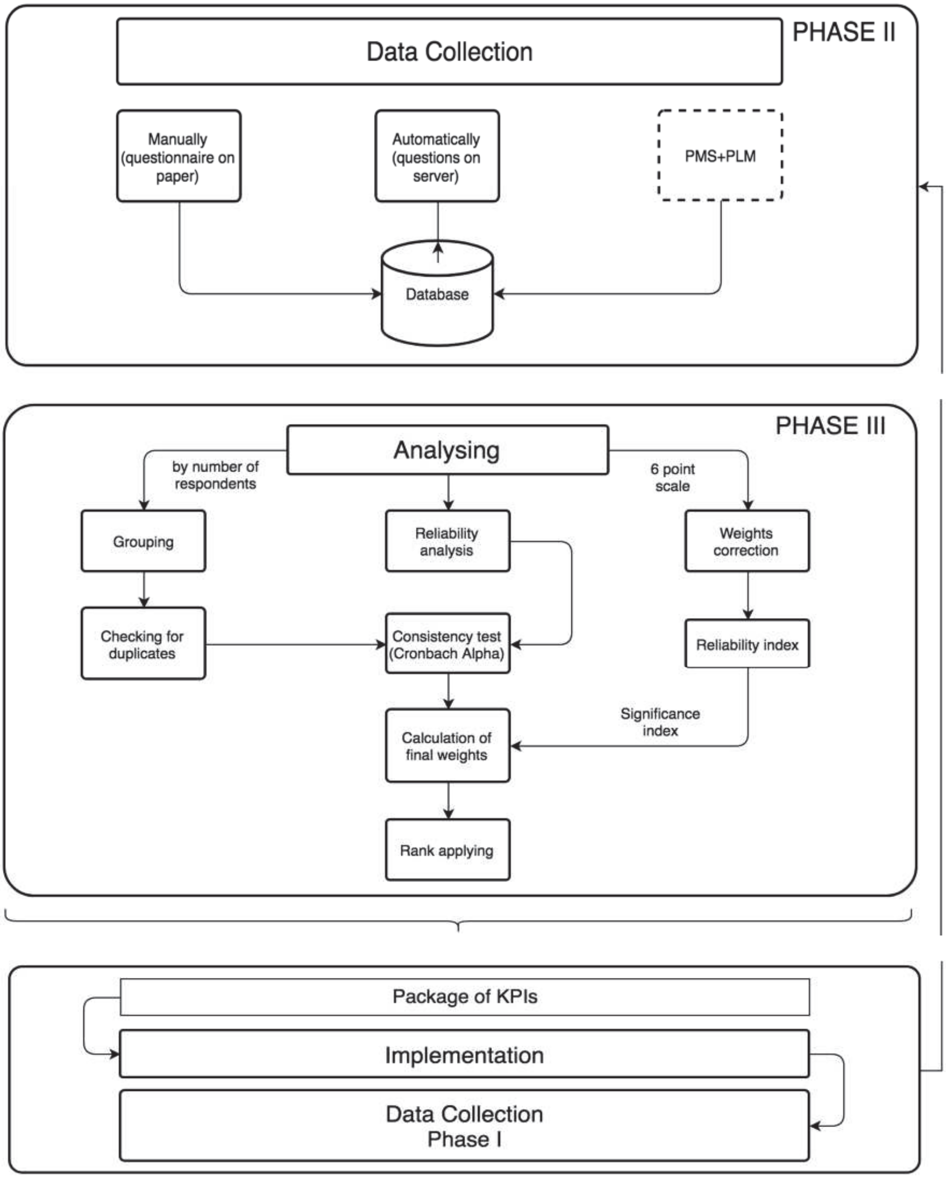

Fig. 1. KPI selection model (continue)

The proposed model can be divided into next basic activities:

- An analysis of the enterprise (investigation of the company, where study has been conducted);
- Data collection for the study;
- Data analysis (sorting, grouping, applying weights);
- Weight calculation (weight amendment by multiplication with reliability index);

- Ranking of answers;
- KPIs selection (ranking of KPIs based on SMARTER criteria and by performing Fuzzy AHP analysis);
- KPIs implementation (starting measuring and following chosen KPIs at enterprise).

It's wise to mention, that the whole process is never-ending: after acquiring the package of metrics, it should be implemented in production and followed in the future. As the situation at production and at the whole enterprise is changing by internal and external factors during time, the metrics, which were needed to follow during one period aren't critical at present. The continuous improvement is required.

The first step "An analysis of the enterprise" is the investigation of the company, where the main study has been conducted. The analysis of the enterprise is used to understand the main issues at company and provide this information to management during reasonable time without remarkable lose in quality [20]. The main core of the EAM is the questionnaire that is based on analysis over 70 research papers covering production efficiency and effectiveness, optimization of processes at production and management. Questions were composed in a way, where they would describe different situations at company and the answers on them would help to find out where the enterprise is standing at present time and with what problems the management has been faced. To summarize, the main goals of the EAM are:

1. Acquiring overall information about enterprise;
2. Understand the weak spots;
3. Point out what data should be collected and for what purpose (taking into account the identified critical points).

As the amount of different metrics is over than 17.000 [23] and as the major goal was to analyse the production and the processes, the metrics, connected to economic aspect of the enterprise wasn't taking into account (for example, sales department wasn't involved in the study).

Furthermore, questions are connected to KPIs, therefore by answering to questions, the right indicators relying on the weight of the answer, will be chosen. Moreover, the logical connection between next pairs: constructs and questions, questions and KPIs were tested in WEB resource „Optimal workshop" to eliminate the misunderstandings and provide better effectiveness of the research [21]. In addition, the questions are doubled, that means, that the answer will be accepted only then, when the pair of questions will have the same answers or there will be a little turning in scales.

To reduce time on completing the EAM and to use resources more effectively, the optimization was performed by using the expert decisions (group of 10 members: 7 from industry, 2 from university and 1 from competence centre, who have enough knowledge and experience in the field of production, process optimization and monitoring more than 5 years). In addition, the questions are divided between jobs and positions of workers in enterprise and employee, for example, who are experts in field of engineering, won't receive question about logistics. The final amount of questions and metrics that was selected for the study is introduced in Table 1 [21].

Table 1.
Final amount of questions and KPIs for study

EAM	Raw	Optimized
Questions	259	61
KPIs	92	13

The second step is "Data collection". The whole process can be achieved in two ways: manual, when questionnaire is printed out and filled in by respondents or automatically, when questionnaire is located on cloud server and the data can be easy accessible or can be downloaded in proper way for further study. In this research, to reduce the time for acquiring questions and also to simplify the data processing, the whole survey was established on cloud server. In addition, what can be seen as next steps of research is connecting of this server to the Product Lifecycle Management (PLM), for acquiring the data of the whole lifecycle of the product, and to Production Monitoring System (PMS), to be able to get real time information about production processes [24,25]. The wireless sensors would be fixed to machines providing the following data: vibrations, temperature, voltage consuming, which in turn could be used to predict the condition of the tool [26]. The main advantage of this procedure is the opportunity to study: for example the OEE (overall equipment efficiency). Online data flow will provide the possibility to make right decisions in instance and lead the production in right way with saving resources [27].

The third step "Data analysis" is covering the work with data. First of all, the answers on duplicated questions are checked and filtered. Depending on the amount of the same questions, all answers are grouped to simplify the Cronbach alpha analysis. In addition, to define the impact of the answer on the situation, described by the question, the index of significance was applied; the 6-point scale was used [20]. The questions, with lowest average value should be taking into account at first.

Next the calculation of weights by multiplication with the reliability index has been performed (implementation of Key Performance Indicators selection model as part of the Enterprise Analysis Model). Also the consistency test by calculating the Cronbach alpha was performed. When the "right" answers are separated (sorting of the answers on the duplicate questions), then final weights are applied to answers to be able to judge the importance of the problem covered by the question. The proposed algorithm for analysis of the answers was introduced in Kaganski [20].

Before entering to the final step, the KPIs were selected for the study. First of all, the same approach as was used for optimization of EAM has been applied (the filtering process was done based on the expert group decisions and on the outlier's methods: modified Z-score, Turkey's method and adjusted boxplot) [20]. Secondly, the Fuzzy AHP hierarchy has been constructed based on the SMATER goal settings with the combination of the main task of the research [28]. In Table 2 the weights from point of SMARTER criteria and the ranks of the KPIs are given.

The TOP3 KPIs that should be taking into account and should have the higher impact on the production are the following:

- Actual production time,
- Product quality/quality ratio,
- OTD (On Time Delivery).

The weights of answers and KPIs are taking into account and calculating the average composes final package of metrics.

As the KPI selection model is a cyclic process, after implementing metrics into production, the whole procedure should be repeated to understand how the situation has changed and what impact on the effectiveness has been achieved. There is also possibility, that from amount of time, the situation has changed once more and the problems that have appeared at previous period are currently not actual. This means that the model provides the opportunity for management to be a quite flexible and adaptive in different situations. The future study planned cover application of multi-criteria optimization tools and methods developed by workgroup for optimization of EAM model [29-33].

Table 2.
Weights and ranks of the KPIs selected for study

No.	Key performance indicators	Specific	Measurable	Achievable	Relevant	Timely	Explainable	Relative	Total	Rank
KPI1	Inventory turnover	0.00803	0.01303	0.02151	0.01604	0.01157	0.02875	0.00647	0.10540	4
KPI2	% of additional freight costs	0.00285	0.00789	0.01061	0.00395	0.00377	0.00650	0.00249	0.03805	13
KPI3	Product quality/quality ratio	0.01969	0.02452	0.01021	0.01742	0.00715	0.02496	0.00568	0.10963	2
KPI4	FPY (First Pass Yield)/ Throughput yield	0.01185	0.01122	0.00787	0.01279	0.00803	0.00730	0.00287	0.06194	10
KPI5	DPU (Defects Per Unit)	0.01150	0.02160	0.01243	0.01264	0.00597	0.01953	0.00393	0.08760	5
KPI6	Employee efficiency	0.00664	0.00996	0.00565	0.01537	0.00561	0.01585	0.00433	0.06340	8
KPI7	Changes implementation time	0.01343	0.01669	0.00685	0.00658	0.00640	0.01084	0.00288	0.06368	7
KPI8	Actual production time	0.01403	0.02582	0.01474	0.03128	0.01454	0.01811	0.00787	0.12639	1
KPI9	OEE (Overall Equipment Effectiveness)	0.00852	0.01148	0.00674	0.01768	0.00580	0.00915	0.00309	0.06247	9
KPI10	NEE (Net Equipment Effectiveness)	0.00520	0.00707	0.00544	0.01584	0.00434	0.00640	0.00322	0.04750	12
KPI11	OTD (On Time Delivery)	0.00971	0.01983	0.01674	0.02932	0.01278	0.01242	0.00636	0.10716	3
KPI12	Takt time	0.00318	0.01436	0.00934	0.02612	0.01103	0.00461	0.00334	0.07197	6
KPI13	Unit/Line Reliability	0.00332	0.00635	0.00920	0.02160	0.00507	0.00506	0.00422	0.05482	11

3. Conclusions

The KPI selection model was proposed in order to avoid situations where wrong data will be collected and incorrect indicators selected.

In order to explain better the proposed approach, each step was described separately. By applying experts' decisions and different outlier's methods, the EAM and the amount of KPIs used for the study were optimized. The final questionnaire was reduced to 61 questions and KPIs to

13. Such a reduction simplifies significantly implementation of KPIs, save time and resources. The proposed model will help to generate the metrics, that should be followed in company and which will have the impact on the whole production process.

However, it should be kept in mind that the KPIs selection model proposed is based on repetitive application of selection procedure since the situation in company is changing in real time.

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Appendix 5

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Fuzzy AHP as a tool for prioritization of key performance indicators

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Abstract

Performance measurement, as a new procedure for monitoring enterprise life and actions, was introduced first in the manufacturing industries. Recently, due to the growing competition between companies, different frameworks, systems, and methods were proposed for small and medium enterprises. The key performance indicators (KPI) are known as a powerful tool, which would provide valuable information regarding bottlenecks and weak spots in companies.

In the current study, the fuzzy analytical hierarchy process (AHP) based on SMARTER criteria and 13 KPIs, has been developed and weights for the SMARTER criteria were calculated. The priority ranks of KPIs were obtained.

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Keywords: key performance indicators; fuzzy analytical hierarchy process (fuzzy AHP); SMARTER criteria.

1. Introduction

Changes in global economy (globalization, fall of oil prices, restrictions from EU and Russian Federation on economic level with implementation of new technologies in manufacture field) made companies to realize that in order to stay alive in harsh dynamic environment with fierce competition and heavy price pressures, they need to focus on their business strategy, which has made a shift from production or cost-oriented approach to more strategic [1-4]. As a result, the organizations deal with a number of key performance indicators (KPIs) covering different areas [5]. Each indicator describes a particular activity/characteristic of the company only. That's why the package of successful indicators is required by managers. However, due to the number of different metrics and their impact on enterprise's health in total, the management has been faced with difficulties in selection of the right metrics. Another restriction of usage of the package of KPIs is that it cannot be utilized in a simple way to improve targets due to the fact, that each independent indicator needs to be faced to some benchmark value without concerning the remaining aspects of the company's activities, which are not related to that metric [6]. It is worth to mention, that KPIs, which have changed the situation and are followed in one company, couldn't work and turn the situation in another, due to the different fields of action, production capabilities, availability of implementing new technologies, different IT solutions and etc. It's necessary to recognize, that reviewing and analysing of wrongly chosen metrics can have a crucial impact on company-the uncovered problems would still continue to damage processes despite the fact that "rightly chosen" indicators are in "green" fields.

On the one hand, the KPIs can have a negative impact on the creativity by establishing restrictions and constraints when dealing with different issues. On the other hand, they can drive management in the right direction by decreasing the unnecessary information and reducing the time.

The objective of this paper is to introduce the Fuzzy AHP (an approach for evaluation the relative importance between attributes by means of pairwise comparison) and the opportunity to rank metrics based on SMARTER criteria (a method for setting objectives, similar to SMART but uses additional two criteria). Traditional form of AHP that uses 9 point scale does not provide good results by dealing with the uncertainty, which can reduce the reliability of the evaluation. The Fuzzy AHP needs to be implemented to eliminate this limitation [7, 8, 9]. In addition, a group of 10 experts was

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invited to participate in the evaluation of criteria vs goal and criteria vs sub-criteria by using triangular fuzzy numbers. The final ranks and weights for each research subject were introduced and evaluated.

2. SMARTER goal settings

In any company, goals are leading enterprise's effort, supporting and optimizing resources, helping in moving straight ahead to their visions. In other words, the goal setting is one of the main processes that should be addressed by management [10]. However, by setting objectives, which are complicated, there is a risk that they could be too difficult to achieve. Furthermore, KPIs, which reflect enterprises goals, should be based on criteria which make them suitable for further studies [5]. In [11] G.T.Doran has proposed SMART way of setting objectives. Although, many organizations have applied SMARTER model considering the fact, that two additional criteria are good reminder to managers that they are staying on top of the process [11].

Specific - Goals should be detailed and as specific as possible. Loose, not clear or uncertain goals are not desirable. When goals are specific, it is easier to take necessary steps to achieve targets.

Measurable - Each target, process or KPI should be measurable. The measure itself could be quantitative or qualitative, but measurement should meet standards and requirements.

Achievable – Objectives should be set at right level. They need to be ambitious and realistic, however, making them too simple won't be motivating and on the other hand, each KPI should have the standard value that should be achieved.

Relevant (if sometimes it's linked with agreed then it's similar to achievable) – every colleague in a team or as individual, need to understand and compare how the objective is relevant to their role and main course of the team. Furthermore, KPIs should provide insight into the performance of the company in obtaining its strategy. In case, when KPI is not measuring a team's or enterprise's goal or doesn't affect the organizations' performance, it's useless.

Time-specific (or time-sensitive) – Work or tasks should have time frames. The deadlines for completing the objectives would provide possibilities to monitor and analyse the progress. In addition, its better understand metric, when everyone knows the time frames in which it should be measured and realized.

Explainable or *Evaluated* – Very often, KPIs have been measured without understanding the reason of measuring. Managers need to ensure, that everyone, who is involved in process, is aware of goals and tasks. Worth to mention that KPIs should evaluate performance and progress of what is measured (is it performance of a team or of a process)

Relative or *Reviewed* – KPIs should be relative and they still could be implemented even company and volumes are growing [5, 11, 13].

3. AHP and fuzzy AHP approach

The analytical hierarchy process (AHP) is a powerful decision-making methodology, which was developed by Saaty in 1980s to simplify the decision making process [13]. It includes qualitative and quantitative techniques and provides the possibility to decompose complicated problems into sub-problems, which simplify the comparison of alternatives [5, 14, 17]. It can also be used to evaluate the environmental performance of each life cycle phase [12]. Although, the nine-point scale simplifies the choice of criteria and provides information regarding dominance of each element over others [18, 19], there is the one weak spot, which occurs during the setup of comparisons matrixes-the information unpredictability cannot be simply explicit by a discrete scale [15]. When the number of characteristics is rising in a hierarchy, more matchings between attributes need to be applied. Furthermore, the experts are not able to represent properly their background knowledge regarding the actual problems [16]. As result, the judgements are becoming unreliable and subjective. However, to deal with the impreciseness of experts' judgements the fuzzy set theory has been selected. The theory was developed by Zadeh and has become widely used in pair-wise comparison [20]. The Fuzzy AHP approach is represented by triangular fuzzy numbers (TFN). The numbers can be identified as triple M = (l, m, u), where its membership function is defined in [21] as

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, x \in [l,m], \\ \frac{x}{m-u} - \frac{u}{m-u}, x \in [m,u], \\ 0, \quad otherwise. \end{cases} \tag{1}$$

In (1) l, m and u stand for the lower, medium and upper values of M, respectively ($l \le m \le u$). In special case where all three numbers are equal ($l = m = u$), then we are dealing with no-fuzzy numbers. The main operations for two triangular numbers were described by Kaufmann in [22] as

$$M_1 (+) M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

$$M_1 (x) M_2 \approx (l_1 l_2, m_1 m_2, u_1 u_2) \tag{3}$$

$$M^{-1} \approx (1/l_1, 1/m_1, 1/u_1) \tag{4}$$

In table 1 the triangular fuzzy scale implemented in the current study has been introduced.

Table 1. The scale of fuzzy AHP pair-wise comparison

The relative importance of the two sub-elements	Fuzzy triangular	Reciprocal fuzzy
Equally important	1 1 1	1, 1, 1
intermediate value between 1 and 3	1 2 3	1/3, 1/2, 1
Slightly important	2 3 4	1/4, 1/3, 1/2
intermediate value between 3 and 5	3 4 5	1/5, 1/4, 1/3
Important	4 5 6	1/6, 1/5, 1/4
intermediate value between 5 and 7	5 6 7	1/7, 1/6, 1/5

Strongly important	6 7 8	1/8, 1/7, 1/6
intermediate value between 7and	7 8 9	1/9, 1/8, 1/7
Extremely important	9 9 9	1/9, 1/9, 1/9

For example, let us assume that the criterion i has been ranked by expert as strongly important in comparison with criterion j. In latter case, based on values given in table 1, the criterion i will be evaluated with fuzzy number M = (6, 7, 8). Alternatively, in the case where criterion j appears less important than criterion i, the pairwise comparison between criteria j and i could be represented by the reciprocal fuzzy number M = (1/8, 1/7, 1/6).

4. Case study

4.1 Introduction

The aim of the case study is to assign priority/rank indexes to metrics, which in its own turn should help managers to simplify the choice of metrics that should be followed at first place in company. Furthermore, it's not only the simplification of a process but also prioritization of tasks. It is worth mentioning, that the success of proposed steps for acquiring ranks for KPI's is in direct relation to the selection of expert group.
The whole process of acquiring priority indexes for KPIs can be divided by next steps:

1. Developing of hierarchy tree based on goal, criteria (SMARTER goal settings) and sub-criteria (13 KPIs);
2. Preparation of matrices for data collection (pair-wise comparison);
3. Data collection from expert group;
4. Consistency check of matrix (fuzzyfication of the data);
5. Calculation of criteria (SMARTER goal settings) and sub-criteria (13 KPIs) weights;
6. Prioritization of sub-criteria (KPIs).

4.2 Development of hierarchy tree

The Fuzzy AHP hierarchy has been built based on SMARTER criteria with combination of main goal of the research and 13 KPIs (Table 2), which were evaluated by group of experts. In [23] the outlier's detection methods were employed (Tukey's, Adjusted Boxplot, Standard deviation method, Z score and Modified Z score) and optimization of KPI-s was performed (13 KPI from initial 41 were selected). The goal, which was established for this approach, is the acquiring of sustainable KPIs for improvement of productivity, effectiveness and finding out optimal parameters to check and monitor with production monitoring system. In the Fig. 1 the hierarchy tree has been illustrated.

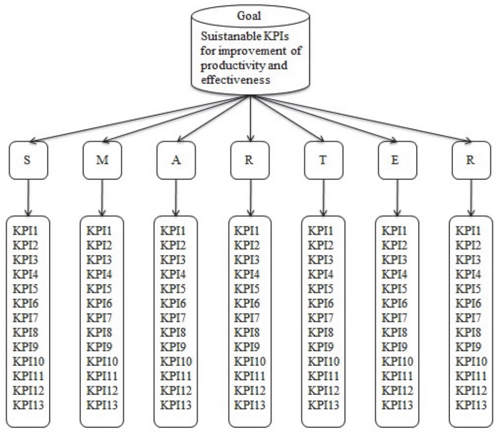

Fig. 1. The hierarchy tree for pair-wise comparison.

During first step, the comparison on first level between SMARTER criteria and main goal was established. On the second level, the pair-wise comparison between sub-criteria (KPIs), with taking into account each SMARTER goal setting, was performed l (Fig. 1).

Table 2. KPI's selected for current study

KPI abbreviation	Definition
KPI1	Inventory turnover
KPI2	% of additional freight costs
KPI3	Product quality/quality ratio
KPI4	FPY (firs pass yield)/Throughput yield
KPI5	DPU (defects per unit)
KPI6	Employee's efficiency
KPI7	changes implementation time
KPI8	Actual production Time
KPI9	OEE (Overall Equipment effectiveness)
KPI10	NEE (Net Equipment effectiveness)
KPI11	OTD (On time delivery)
KPI12	Tact time
KPI13	Unit/Line Reliability

4.3 Pair-wise comparison and consistency test

The pair-wise comparison was done by the expert group of 10 members, who have experience in field of production and process optimization more than 5 years. The hierarchy tree subject is to establish pair-wise comparison between goal-criteria, criteria-sub-criteria. After pair-wise comparison the corresponding matrices have been composed. In order to ensure the quality and trust ability of collected data, the consistency check was performed. During this case study, the deffuzification method for converting of triangular fuzzy numbers to crisp numbers was used. The defuzzification has been performed according to the following formula ([24])

$$M_{crisp} = (4m + l + u) / 6, \quad (5)$$

where M_{crisp} is the crisp number, m is a medium bound, l and u stand for the lower and upper bounds of triangular fuzzy number, respectively.

Table 3. Example of defuzzified numbers vs fuzzy triangular numbers

	Specific	
Criteria	Fuzzy triangular numbers	Defuzzified numbers
Specific	1, 1, 1	1
Measurable	2, 3, 4	3
Achievable	1/4, 1/3, 1/5	0,3472
Relevant	2, 3, 4	3
Timely	1, 1, 1	1
Explainable	1, 1, 1	1
Relative	1/6, 1/5, 1/4	0.202778

In next step, the consistency check methodology proposed by Saaty in [25] can be applied for each matrix. The consistency ratio (CR) can be calculated as ([25])

$$CI = (\lambda_{max} - n)/(n-1), \tag{6}$$

$$CR = \frac{CI}{RI}, \tag{7}$$

where, λ_{max} is the largest eigenvalue of a matrix, n is the dimension of the matrix and RI is a random index, that depends on n (Table 4).

Table 4. RI according to Golden and Wang [65]

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
RI	0.58	0.89	1.12	1.24	1.33	1.40	1.45	1.49	1.51	1.54	1.56

The value of the RI is acceptable, if it will not exceed 0.1. Otherwise, the experts should redo the whole process. If the crisp matrix is consistent then the resulting fuzzy matrix is also consistent [27].

4.4 Calculation of weights and KPI ranking

The weights are required for prioritization of metrics. In conformity with weights the ranks would be assigned to criteria and sub-criteria. According Buckley [28], the geometric mean $\tilde{r}$ of fuzzy comparison values for each criterion can be calculated according to next equation:

$$\tilde{r} = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{\frac{1}{n}}, i = 1, 2, \dots, n, \tag{8}$$

where $\tilde{d}_{ij}$ is an average fuzzy triangular number, n is the dimension of the matrix.

The fuzzy weight $\widetilde{w}_i$ of criteria or sub-criteria can be obtained by multiplication of each $\tilde{r}$ with the reverse vector:

$$\widetilde{w}_i = \widetilde{r}_i \times (\widetilde{r}_1 + \widetilde{r}_2 + \dots + \widetilde{r}_n)^{-1} = (lw_i, mw_{i,}, uw_i). \tag{9}$$

In addition, the two more steps are required before starting calculation of fuzzy weights: the sum of each $\tilde{r}$ should be calculated and the reverse sum of vector with placing values in increasing sequence should be performed.

Worth to mention, that $\widetilde{w}_i$ is still triangular fuzzy number and need to be defuzzified according to Chou and Chang "Centre of area" method [29]

$$M_i = \frac{lw_i + mw_{i,} + uw_i}{3}. \tag{10}$$

Finally, the M_i can be normalized by applying next equation:

$$M_i = \frac{M_i}{\sum_{i=1}^{n} M_i}. \tag{11}$$

4.5 Numerical results

In Fig. 2 the comparison between SMARTER criteria and goal of the study performed by one of the experts is depicted.

	Goal																				
	Specific			**Measureable**			**Available**			**Realistic**			**Timely**			**Explainable**			**Relative**		
S	1	1	1	0.17	0.2	0.3	0.17	0.2	0.3	0.17	0.2	0.25	0.17	0.2	0.3	1	1	1	1	1	1
M	4	5	6	1	1	1	0.17	0.2	0.3	2	3	4	1	1	1	4	5	6	4	5	6
A	4	5	6	4	5	6	1	1	1	1	1	1	1	1	1	1	1	1	2	3	4
R	4	5	6	0.3	0.33	0.5	1	1	1	1	1	1	1	1	1	2	3	4	2	3	4
T	4	5	6	1	1	1	1	1	1	0.33	0.5	1	1	1	1	0.33	0.5	1	1	1	1
E	1	1	1	0.17	0.2	0.3	1	1	1	0.3	0.33	0.5	1	2	3	1	1	1	1	1	1
R	1	1	1	0.17	0.2	0.3	0.3	0.33	0.5	0.3	0.33	0.5	1	1	1	1	1	1	1	1	1

Fig.2. The fuzzy comparison matrix at first level by one of the experts.

The average consistency ratio CR at first level has been introduced in table 5. The average value CR=0.133 obtained is slightly higher than permissible value 0.1 However, considering that we are dealing with average mean and the calculated ratio is allocated near to 0.1, we can draw conclusion of consistency of matrices.

Table 5. Consistency ratio for comparison at first level

Goal: KPIs for improvement of productivity and effectiveness							
Criteria	Specific	Measurable	Achievable	Relevant	Timely	Explainable	Relative
CR				0.133			

The average consistency ratio CR at second level (comparison between sub-criteria to criteria) has been introduced in table 6. The average value for "Measurable vs KPIs" has been calculated as CR =0.154>0.1. However, it is around 85% which can be considered as acceptable result. The "Timely vs KPIs" CR=0.104>0.1 has also been accepted.

Table 6. The average consistency ratio for comparison at second level

	Criteria						
	Specific	Measurable	Achievable	Relevant	Timely	Explainable	Relative
CR sub-criteria vs criteria	0.857	0.154	0.067	0.095	0.104	0.064	0.044

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In table 7 the normalized weights on criteria and sub-criteria levels with assigned ranks are introduced. To acquire the final weights for KPIs, they were summarized by SMARTER criteria weights. Final results are given in table 8.

Table 7. The normalized weights of sub-criteria and ranks

Criteria	Normalized weight	Rank
Specific	0.117933191	5
Measurable	0.189824875	2
Achievable	0.137347325	4
Relevant	0.226618511	1
Timely	0.102053705	6
Explainable	0.169461049	3
Relative	0.056761343	7

Table 8. The weights and ranks for KPIs

KPI n	Name	Specific	Measureable	Achievable	Relevant	Timely	Explainable	Relative	Total	Rank
KPI1	Inventory turnover	0.00803	0.01303	0.02151	0.01604	0.01157	0.02875	0.00647	0.10540	4
KPI2	% of additional freight costs	0.00285	0.00789	0.01061	0.00395	0.00377	0.00650	0.00249	0.03805	13
KPI3	Product quality/quality ratio	0.01969	0.02452	0.01021	0.01742	0.00715	0.02496	0.00568	0.10963	2
KPI4	FYP (first pass yield)/Throughput yield	0.01185	0.01122	0.00787	0.01279	0.00803	0.00730	0.00287	0.06194	10
KPI5	DPU (defects per unit)	0.01150	0.02160	0.01243	0.01264	0.00597	0.01953	0.00393	0.08760	5
KPI6	Employee efficiency	0.00664	0.00996	0.00565	0.01537	0.00561	0.01585	0.00433	0.06340	8
KPI7	Changes implementation time	0.01343	0.01669	0.00685	0.00658	0.00640	0.01084	0.00288	0.06368	7
KPI8	Actual production time	0.01403	0.02582	0.01474	0.03128	0.01454	0.01811	0.00787	0.12639	1
KPI9	OEE (Overall Equipment effectiveness)	0.00852	0.01148	0.00674	0.01768	0.00580	0.00915	0.00309	0.06247	9
KPI10	NEE (Net Equipment effectiveness)	0.00520	0.00707	0.00544	0.01584	0.00434	0.00640	0.00322	0.04750	12
KPI11	OTD (On time delivery)	0.00971	0.01983	0.01674	0.02932	0.01278	0.01242	0.00636	0.10716	3
KPI12	Takt time	0.00318	0.01436	0.00934	0.02612	0.01103	0.00461	0.00334	0.07197	6
KPI13	Unit/Line Reliability	0.00332	0.00635	0.00920	0.02160	0.00507	0.00506	0.00422	0.05482	11

According to results obtained, the metrics should meet the next goal setting criteria: indicators should be relevant, measurable and explainable. Considering the ranks, assigned to metrics, managers should pay attention to the following KPIs: Actual production time, product quality/quality ratio, OTD (on time delivery). However, it doesn't mean, that OEE, FPY and other metrics shouldn't be considered as "non-important" metrics.

5. Conclusion and future study

The proposed Fuzzy AHP for prioritization of metrics from point of company's goal and SMARTER goal settings should help to better understand the nature of metrics and also simplify the choice of them.

Based on proposed approach and numerical results obtained in the case study, the TOP3 metrics (Actual production time, product quality/quality ratio, on time delivery) from package of 13 KPIs were selected. However, it doesn't mean, that other metrics have not impact on company. The proposed package should be taken into account as one useful tool. The final results are in connection to the input data-the package of metrics and can vary due to it. Also the main goal that has been used in comparison on first level can have an impact on the final ranks.

The suggested concept should be tested at real company to better understand its weak and strong sides. The acquired results should help managers to better understand the impact, which metrics could have at their enterprises. Data collection and whole EAM model testing on different companies are foreseen as next tasks. The optimization and improvement processes of EAM and KPI selection model should take part continuously. To summarize:

- Data collection from different SMEs;
- Optimization and improvement of EAM as continuous process and integration to the production monitoring system [30, 31].

The KPI selection model introduced provide powerful tool for analysing in management's hands, which would serve as main stone in decision making process. In addition, the proposed model helps to reduce time for analysis of the company, make processes more understandable and transparent.

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