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The Investigation of Setups and Development of Decision Support Model for Setups Selection to SMED Analysis

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Abstract: Setups are indispensable to a manufacturing process and they often significantly influence the lead time on an order. Simultaneously, the time spent on setup is wasted from the client's point of view because the activities performed don't add any value for the client. Companies, being aware of this fact, implement actions in order to reduce the setup times. Unfortunately, the authors experience is that many companies do not apply setup improvements. The research aimed at assessing the implementation of the SMED method. The authors try to find the answer to the question how important setups are and to what extent the companies are involved in the setup improvement. The analyses conducted enable to understand if the actions taken by companies are influenced by the factors such as the company's size, its industry, a type of the capital possessed or a production type. Finally, based on the researches results, decision support model for selection of setups to SMED analysis, is developed and presented in the paper. The model can help companies allocate resources to reduce setups times, where it is really necessary, to give a positive influence on sustainability.

Key words: setup; SMED; survey; industrial practice; sustainability
JEL codes: L230

1. Introduction

Setups are crucial to conduct manufacturing processes of different types of products. It is often that there are different products as well as different tools and instruments in the manufacturing processes. The performance of setups is nowadays even more important as in many companies the variety of products increases, and the size of production batches decreases. Every setup takes time and at the same time doesn't add value to a product. That is why every company should aim at the setup time reduction to the minimum. But, it is also necessary to take into consideration sustainability. To reduce setups time, the company's resources have to be involved. That is why the company should develop the setup processes, where it is necessary, and engaged resources in these setups, which are the most important from the company's point of view.

Unfortunately, the problem of long setup times is not noticed in many companies. It seems that this issue is insignificant from the business point of view for these companies. Setup related issues are the domain of operators who conduct the setups in their best way. No one notices it until the setup process influences negatively the

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quality of the manufacturing process and the product.

This paper presents the results of the research conducted in the production companies in which setups are implemented. On the base of the study results a decision support model for selection of setup to SMED analysis was developed and presented in the article.

The paper comprises six sections. The first section describes the development of the SMED method as well as it indicates where the setup shortening concept can be implemented. This section also shows the possibilities of enriching the SMED method with other methods and tools to get better results. In the second section, the SMED technique is described. In addition, it presents steps of a setups analysis. In the next section, the authors explain the necessity for the research which was conducted in production companies on the specified area of Poland in the period of 2010-2013. Section four presents the research areas and methodology, the structure of the surveyed companies, survey results, discussion and conclusions from the research. As the survey was performed only on a limited area of PadkarpackieVoivodeship, the results may not be relevant for the whole population. The survey results were used in developing a decision support model for the selection of a setup to SMED analysis. They are presented in the next section. The last section of the paper describes conclusions and the need of further research.

The added value of the paper is determining the state of SMED implementation in PadkarpackieVoivodeship. This information can be used in undertaking actions, for example by a university, in order to help local companies to develop with the SMED method for a setup shortening. The similar situation is also possible in other regions of Poland or other countries where the lean manufacturing concept is not so widely known yet. The added value of the paper included also the developed model which the authors recommend to use for selecting a setup to the SMED analysis. The model can support management in the decision making process on allocating sources to improve the certain setups.

2. Development of Setup Shortening Concept

In the forties of 20th century Toyota factories noticed the necessity of fast setups. It was the result of Toyota Production System used which indicated the necessity of over-production elimination and inventory minimization. In order to achieve it, it was essential to transform a production system from mass production to the production in small series. Long setups were an obvious obstacle in a short series production. Certainly, each setup is simply waste because it doesn't add any value. The time devoted for a setup could be spent on production (Ohno, 1998). A company can be more flexible when the setup time is shorter (Cousens et al., 2009). Improving setup should be one of the most common manufacturing practices (Laugen et al., 2005; Ottova et al., 2014; Ani & Bin Shafeit, 2014).

Development of the SMED method was a natural consequence of the necessity of short setups. Shigeo Shingo is the author of the method. According to Shigeo Shingo SMED (Single Minute Exchange of Die) as a technique was invented in 1969, when he first used it to shorten the setup time of the press in one of Toyota plants — Honsha. However, in 1950 in Toyo Kogyo (Mazda), Shigeo Shingo discovered that activities realizing a setup process consist of internal and external operations. In 1957 he used this observation in shipyard of Mitsubishi Heavy Industry in Hiroshima. He encouraged to do external activities before beginning the real setup. It resulted in the increase of productivity in 40% and in shortening the time for building a ship from 4 months to 2 months (Shingo, 1985). Regarding costs reduction, for example in the work (Moreira & Pais, 2011) authors achieved cost reduction of 2% of the company sales volume after the SMED implementation. Nowadays, the SMED method is

one of the methods used in lean manufacturing systems (Hines et al., 2004).

Companies try to reduce setup time for example by a focused maintenance activity (McIntosh et al., 2001). However, for many years SMED has also been successfully used in many companies. Examples can be found in literature. In the work (Allahverdi & Soroush, 2008) the percentage of changeover time reduction in various industries is presented. Authors also indicate areas in which setup time is important for a scheduling process.

Many examples of using the SMED method can be found, e.g., in pharmaceutics industry (Pacana & Zaborowski, 2009), in casting machines changeover (Władysiak, 2007), in metallurgical sector (Grzybowska & Gajdzik, 2012), in setup time reduction of a press used in evaporator plates machining (Kumar & Abuthakeer, 2012).

In the works (Van Goubergen & Van Landeghem, 2002; Singh & Khanduja, 2012) authors indicate that one should think about setup time already during the tooling design, and in the work (Cakmakci, 2009) the author looks for the relation between SMED and the equipment design in an automotive industry using C_{pk} analysis. Additionally, in the work (Van Goubergen & Van Landeghem, 2002), rules for a better equipment design are presented. One should also remember about the necessary tooling regeneration. The control of tooling is one of the maintenance service tasks (Antosz & Sęp, 2010).

The concept of the SMED method was enriched by additional methods and techniques such as the FMEA method (Singh & Khanduja, 2012; Stadnicka, 2015), creative thinking techniques (Jagoda-Sobalak & Knosala, 2011), Taguchi experimental design (Karasu et al., 2014) or multiple criteria decision-making techniques (Almomani, 2013).

In the work (Van Goubergen, 2009) the author developed the SMED method and proposed a broader methodology of TransMeth for Set-Up Reduction which is based on changes.

Some authors also recommend using computer systems, e.g., in the work (Cakmakci & Karasu, 2007) authors suggest integrating SMED and MTM analysis to develop standard documents in MTM-UAS codes in order to sustain the results of SMED. Then, in the work (Trovinger & Bohn, 2005) authors extended SMED with a computerized information system and they used computerized tools such as barcode readers or wireless terminals.

It is also possible to minimize setup time using such a planning system which generates the right tasks sequence (Bansal & Reddy, 2011; Sherali et al., 2008).

Based on the literature review, it can be said that the necessity of setup reduction was discovered long ago. The SMED method is also well known in the industry. SMED was enriched by different methods, techniques and computer systems. However, the question is: if it is enough to encourage a company to use the SMED method for setup reduction and if the companies really use the method or just perform any activities to shorten setup time.

3. SMED Technique

Improvement of a setup process with the use of the SMED method is conducted in the fixed steps (Productivity Press Development Team, 1996). In short, the following steps can be distinguished (Figure 1):

Step 1: Recording the activities done in a setup process.

Step 2: Dividing the activities into two groups: internal and external activities.

Step 3: Converting internal activities into external activities.

Step 4: Implementing technical and organizational improvements into the setup process.

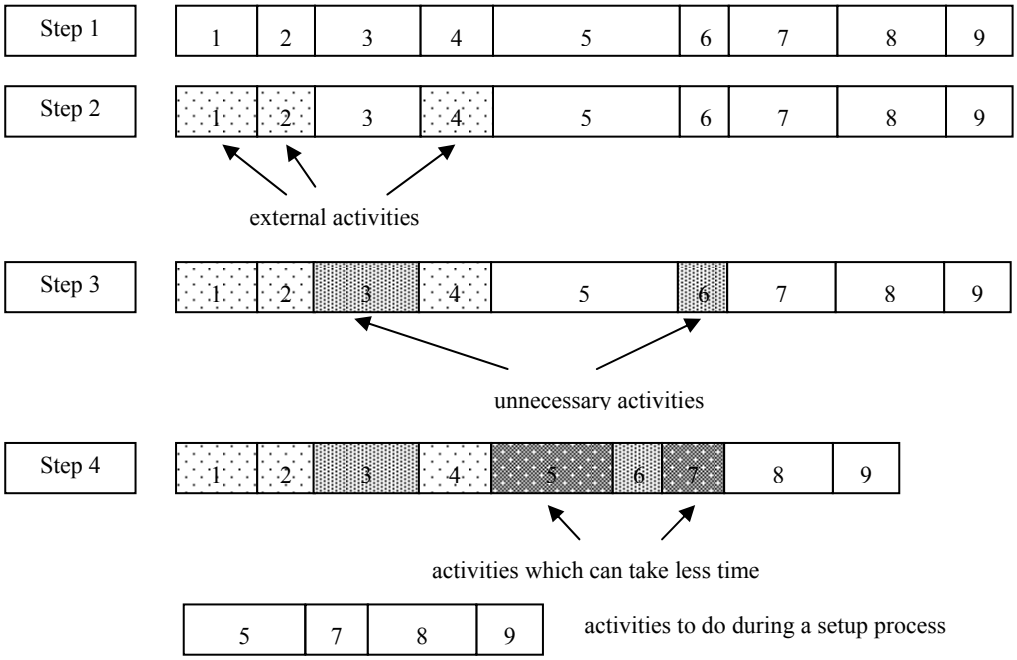

Figure 1 Scheme of the SMED Method. Based on (Shingo, 1985)

Step 1 consists of recording of all activities which are done by an operator or operators during the setup process. Activities are recorded on a prepared form. A person who makes observation writes down a kind and time of an activity. It is also possible to write down the moment of beginning and finishing of an activity. It can be easier to identify the activities if they are first recorded with acamera. For a visual presentation of an operator's movements the Spaghetti diagram can be used. In order to assess the distance an operator has to walk, a pedometer can be used.

Step 2 concerns the evaluation of activities from the setup process. The activities, which can be done while the machine is still working, should be identified and indicated as required to be accomplished before the setup process starts.

Step 3 concerns the evaluation of remaining activities. The question should be answered if some of these activities could be transformed from internal into external operations, e.g., by using a standard holder for tools is it possible to put tools in holders in advance, thus during the setup process additional regulations can be avoided.

Step 4 consists of implementing new technical and organizational solutions which improve and make the setup process faster. Quick connectors can be the example of a technical solution and a set of tools for a certain setup can be the example of an organizational solution. In this step it is also assessed if in the setup process there are such activities which shouldn't be done at all.

It is possible to shorten much of the time necessary for a setup using the SMED method. Shigeo Shingo said that it was possible to reduce setup time to less than 10 minutes.

As it was found in the literature review, some authors developed the steps of the SMED method. For example Perinić and others in the work (Perinić et al., 2009) suggest the integration of the SMED method with 5S techniques in the following steps:

(a) Forming a team,

(b) Training the team members,

(c) Survey and evaluation of a current situation,
(d) Classification of activities,
(e) Transforming internal activities into external activities,
(f) Improvements and minimization of internal activities time,
(g) Improvements of external activities,
(h) Standardization and SMED procedures development,
(i) Keeping savings at the reached level,
(j) Continuous Improvement Process — CIP.

4. Necessity of Research

For many years it has been known that the setup process is important, especially for production flexibility. For many years companies have taken actions to decrease setup time. The issue concerning the setup process seems to be well recognized so that every company can take improvement actions. What's more, the SMED method exists and shows step by step what to do to decrease the setup time.

However, based on the authors' experience, there are companies which don't perform any activities to improve setups. They don't carry out any analysis and sometimes they don't even register setup times or don't use information about the setup time in a planning process.

The authors decided to do research to answer the question if companies identify a setup process as an important area to improve and if they take any actions to improve the process, particularly if they implement the SMED method.

The research aimed at the assessment of applying the SMED method in companies.

5. Research Results

5.1 Research Area and Methodology

In the research 320 production companies were asked to answer the questions of the survey. The survey was conducted among the companies located on a specified area (Poland, PodkarpackieVoivodeship). During the survey of the companies, the following categories for population identification were adopted: industry and production type. Any enterprise, plant or its department that had its own strategy and was accounted of its accomplishments could be the object of the survey. 89 questionnaires were obtained as a feedback.

As a detailed subject of the survey, the areas described in the Table 1 were analyzed.

The survey took the form of interviews. The subjects of the survey were the representatives of a medium and top level management as well as the employees directly responsible for the production processes and setups. The surveys were conducted in a conjunctive multiple choice form, and included a list of prepared, provided in advance, options presented to a respondent with a multiple response item in which more than one answer might be chosen. Additionally, a respondent could give other answers if they were not among the provided options.

For the data collected, the analysis of the impact of different factors on the SMED method implementation by the companies was conducted. For that purpose the Chi^2 analysis was conducted.

Table 1 Survey Areas

Survey area	The element surveyed
The SMED method implementation	Identification of the workstations and setups for which the SMED method was applied Percentage of the setups analyzed with the SMED method
Setup identification and standardization	Setup matrix
Assessment of the SMED method implementation	The way of the assessment of the SMED method implementation effects Setup times savings

5.2 The Structure of the Surveyed Companies

During the survey, the companies were classified according to the following criteria: company size, industry, production type, ownership (type of capital) and self-assessment of company's situation.

The percentage of the companies that participated in the survey, in respect of size, is as follow:

- Micro companies–8%,
- Small companies–17%,
- Medium companies–30%,
- Large companies–45%,

The percentage of the companies that participated in the survey, in respect of industry, is as follow:

- Metal processing–28%,
- Aviation–25%,
- Automotive–18%,
- Wood and paper–9%,
- Chemical–7%,
- Food–7%,
- Electric, electronic–6%,
- Furniture–3%,
- Other–12%.

One company can operate in few industries and can have few types of production.

The percentage of the companies that participated in the survey, in respect of type of production, is as follow:

- Piece production–31%,
- Small-batch production–29%,
- Medium-batch production–25%,
- Big-batch production–19%,
- Mass production–8%.

The percentage of the companies that participated in the survey, in respect of type of capital, is as follow:

- Foreign majority capital–47%,
- Polish majority capital–43%,
- Entirely Polish capital–10%.

The percentage of the companies that participated in the survey, in respect of self-assessment, is as follow:

- Developing situation–60%,
- Stable situation–36%,
- Difficult situation–4%.

Companies participating in the survey operated in different industries. The most common were metal processing (28%), aviation (25%) and automotive (18%) industries. 46% of the companies possess foreign

majority capital. Most of the companies (60%) described their situation as developing. Only 4% of the companies described their situation as difficult. 97% of the surveyed companies are privately owned, only 4% are state owned. The companies mostly realize a piece (31%) and small-batch production (29%). This fact indicates the necessity of the frequent setups.

5.3 Survey Results

Only 40% of the surveyed companies implemented the SMED method. The percentage of the companies, which implemented the SMED method in order to improve the setup process, in respect of size, is as follow:

- Large companies–28%,
- Middle-sized companies–9%,
- Small companies–3%.

None of the surveyed microenterprises applied the SMED method. Figures 2-12 present the results of the survey conducted.

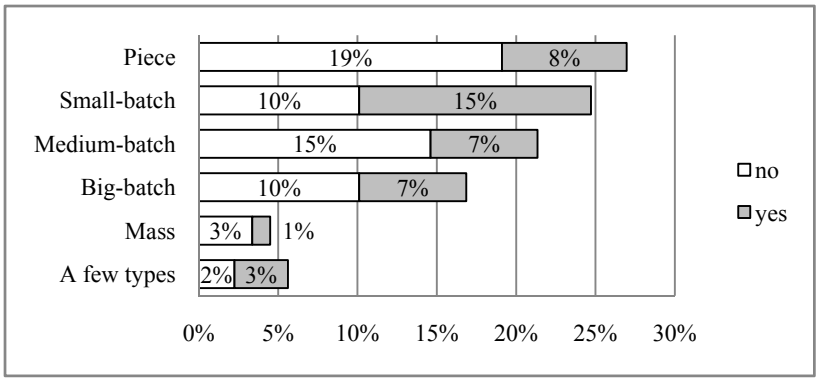

Figure 2 Percentage of the Companies Which Implemented and These Which Didn't Decide to Implement the SMED Method with Respect to a Production Type

According to the conducted Chi^2 analysis (P-Value = 0.111), a type of production did't have statistically justified influence on whether the companies decided to apply the SMED method. However, it can be noticed that the highest percentage of the companies which applied the SMED method was among those with a small-batch production (Figure 2).

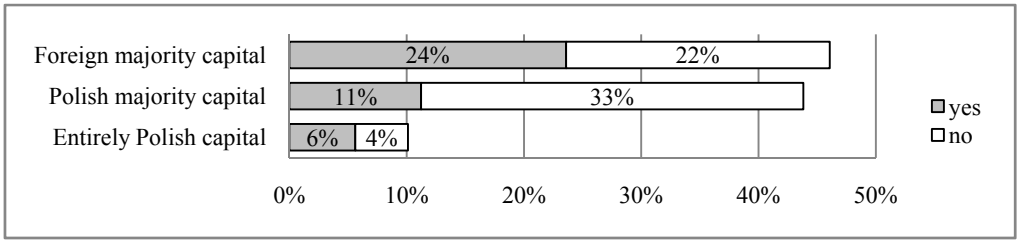

Figure 3 Percentage of the Companies Which Used the SMED Method with Respect to the Company Capital

However, in case of capital (Figure 3), the analysis proved the impact of the capital type (P-Value = 0.014) on the SMED method implementation. Possessnig the foreign capital by a company clearly influences the SMED mathod implementation. It may be due to the fact that the foreign capital brings to the Polish companies also the knowledge about the methods and tools of Lean Manufacturing which is not so widespread and well known in Poland.

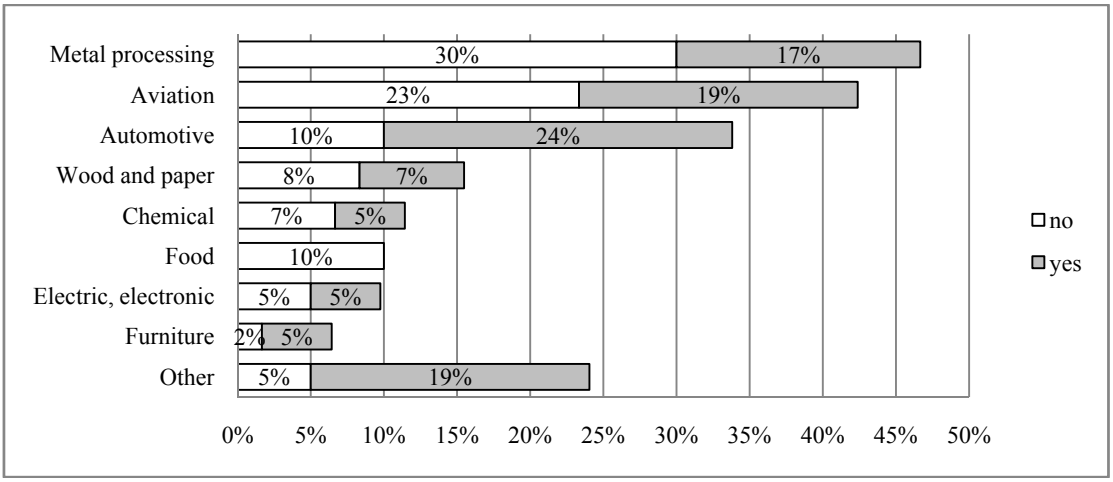

Figure 4 Percentage of the Companies Which Implemented the SMED Method Based on the Industry They Operate in

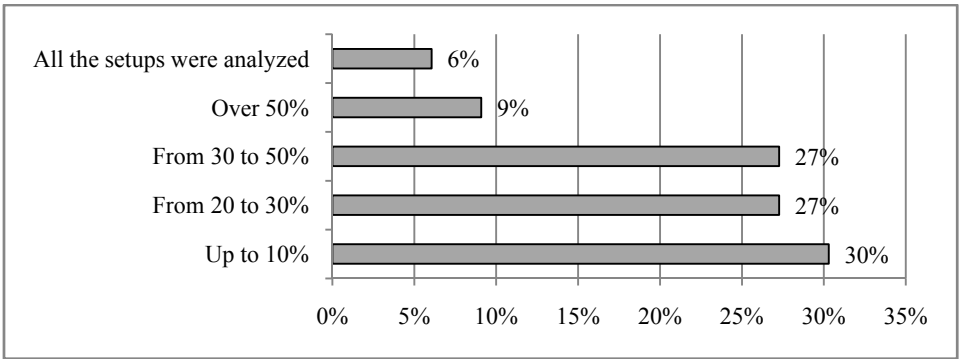

Figure 5 Percentage of the Setups Analyzed with the SMED Method

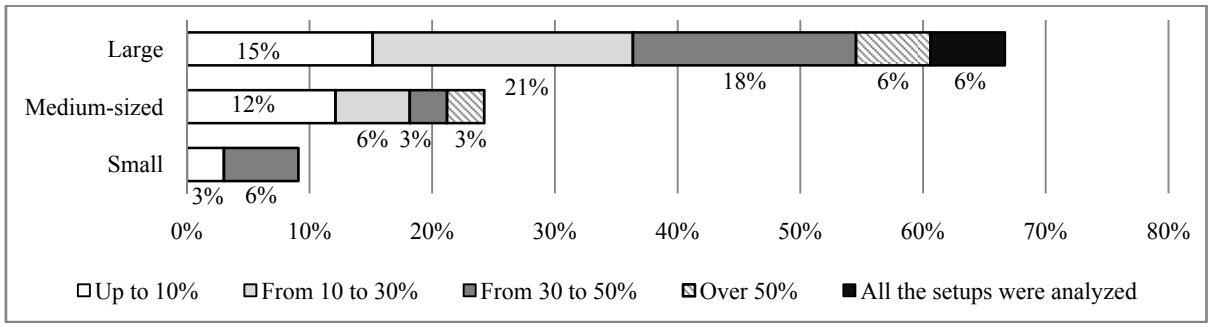

Figure 6 Percentage of the Setups That Were Analyzed in Respect of the Enterprise's Size

Chi^2 analysis reveals the statistically justified impact of the industry on the SMED method implementation (P-Value = 0.005). The highest persentage of companies from automotive industry implemented SMED method to shorten setups time (Figure 4). It can be also noticed that none of the surveyed companies of the food industry used the SMED method.

In the investigated companies the SMED method was applied in the folowing workstations and setups:

- For the workstations being bottleneck in the process–61%,
- For the longest setups–56%,
- For the most frequent kinds of setups–39%,
- In the work stands, where the setups are frequent–36%,

- In the work stands, where the operation timesare short and the setup times are long–19%,
- In the work stands, where the production time is required to be short–19%.

Only 6% of the companies which applied the SMED method analyzed all the setups with the help of that method (Figure 5). 30% of the enterprises analyzed only 10% of the setups. It can also be noticed that only among large companies there were such enterprises which analyzed all the setups. None of the small companies analyzed more than the half of the setups (Figure 6).

On the base of results presented in the Figures 5 and 6 we can draw a conclusion that if the company is larger analyzes more setups. The small companies have not enough motivations to develop setup processes.

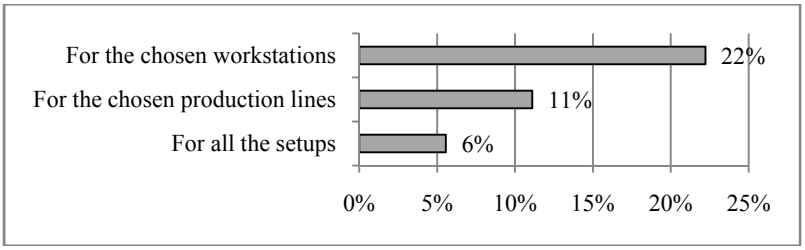

Figure 7 Setup Matrices Development

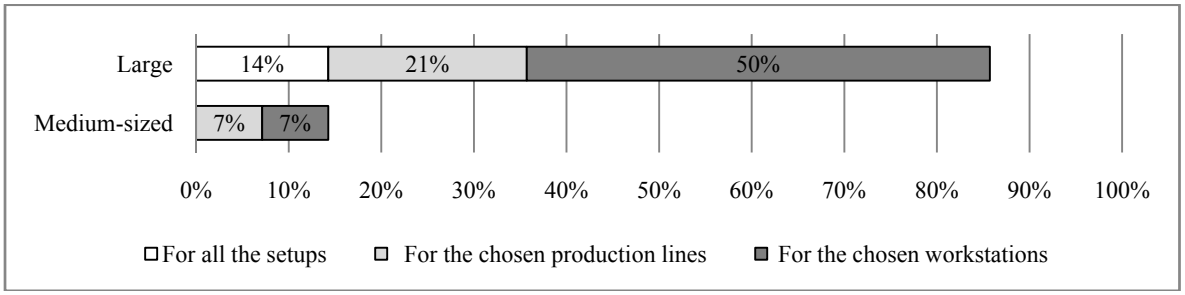

Figure 8 Percentage of the Companies Which Developed a Setup Matrix Including Large and Medium-sized Enterprises

Only 6% of the companies which applied the SMED method developed a matrix for all the setups (Figure 7). 22% of the companies designed a matrix only for the chosen workstations.

None of the small enterprises which used the SMED method developed the setup matrices (Figure 8).

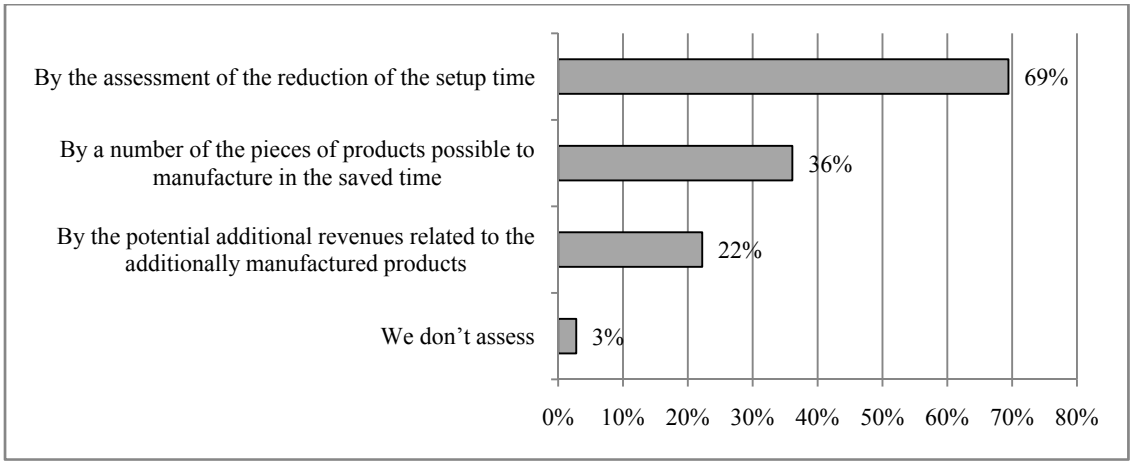

Figure 9 The Means of Assessing the Effect of the SMED Method Implementation

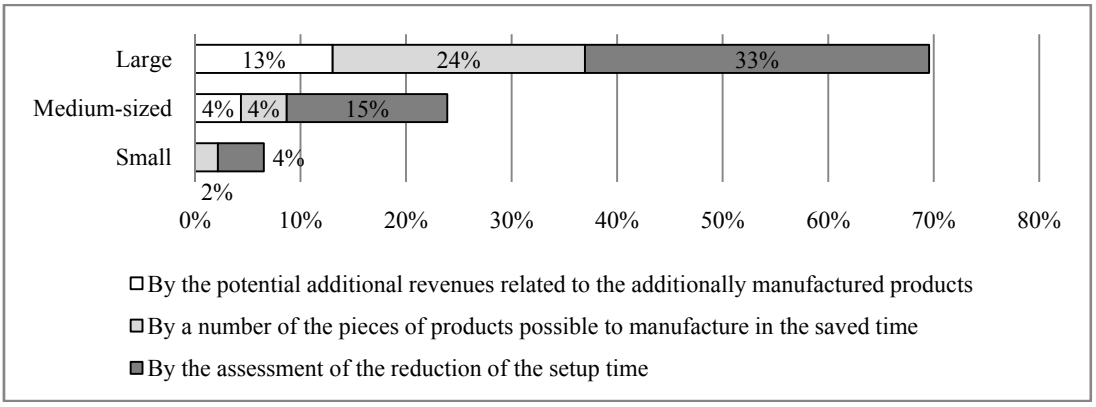

Figure 10 The Means of Assessing the Effects of the SMED Method Implementation Based on the Company Size

3% of the companies which implemented the SMED method didn't assess the effects of its implementation at all (Figure 9). 69% of the companies assessed the reduction of setup time after applying the SMED method. Probably, that is because a time is the most valuable resource for the company. And it is because of continuously growing number of competitors in the global market.

The size of the company (Figure 10) doesn't have a statistically justified influence on the means of assessing the effects of the SMED method implementation (P-Value = 0.395).

44% of the companies gained time savings of 10-30% (Figure 11). It seems interesting that 9% of the large companies do not assess setup time savings after the SMED method was implemented (Figure 12). The reason of that can be that SMED analysis solved other problems with setups, which are more important than setup time, e.g., accessibility of tools and devices for setup processes, repeatability of setups, and difficulties in planning processes caused by lack of setup standards.

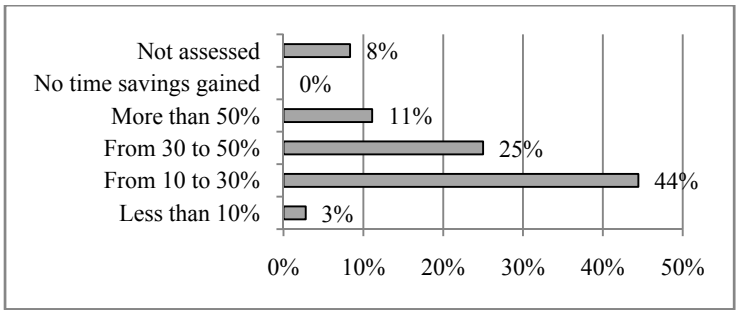

Figure 11 Setup Time Savings

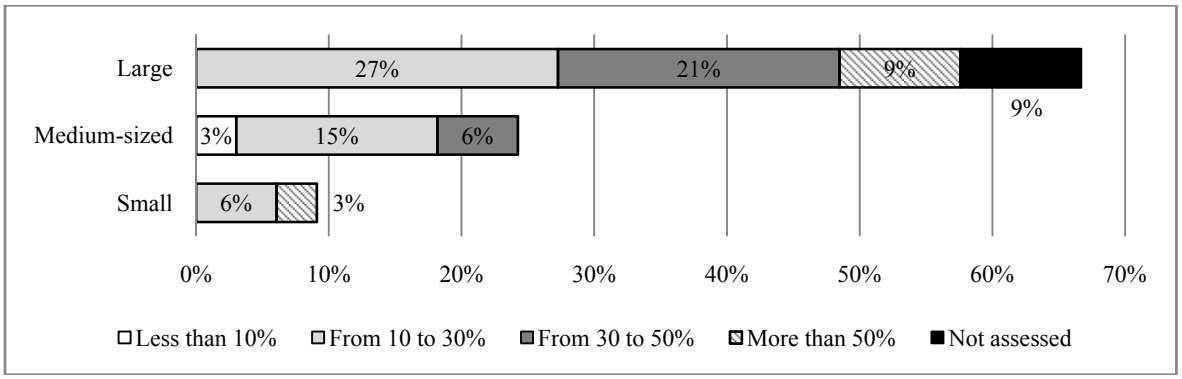

Figure 12 Setup Time Savings in Relation to the Size of an Enterprise

None of the companies stated that the SMED method implementation didn't bring time savings.

5.4 Discussion and Conclusions from the Research

The research shows that most of the companies decide to implement the SMED method in case of any problems with order processing. SMED is then used for those workstations which are bottleneck. However, a conclusion can be drawn that the approach towards setup improvements is passive, and the companies do not decide to take up improvement actions unless they are forced to do it. Only 6% of all the surveyed companies implemented the SMED method for all setups. It is probably because the analyses of all setups take much time and engage many resources. A company to support sustainability has to optimize resources' engagement. The model of optimization of costs concerning setup process is presented in Figure 13. Equations of curves still remain unknown and related researches have to be done to find out the equations.

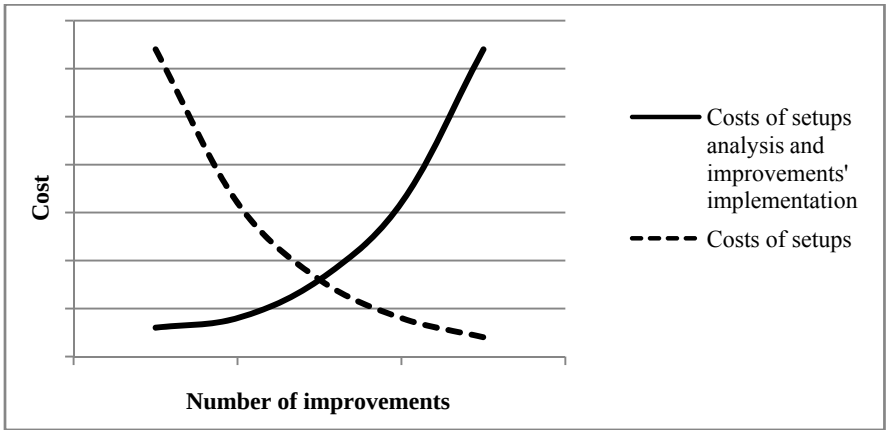

Figure 13 Optimization of Costs Concerning Setup Process

6% of companies, the same which analyzed all setups, also developed a setup matrix. The setup matrix facilitates task planning because it provides information on the time of particular setups. The lack of such a matrix may indicate the fact of taking the estimated time or not taking into consideration the setup times in a process planning.

It should also be emphasized that the companies with the foreign capital are more willing to implement the SMED method.

6. Decision Support Model for Selection of Setup to SMED Analysis

On the base of the researches it can be concluded, that the most of companies use SMED method just for chosen setups. In the work a model for selection of setups for SMED analyses is presented. The criteria used in the model were chosen on the base of the researches and these are:

(1) If the machine is a bottleneck machine — it is very important do shorten setup time for machines, which causes that we aren't able to produce on time, according to client requirements.

(2) Setup time — first of all we should improve these setups, which are the longest.

(3) Setup frequency — frequent setups take totally much time.

(4) Setup time in comparison with cycle time of production process.

(5) Accessibility of setup procedure — it is possible to ensure repeatability of setup process when a procedure exists.

Descriptions of criteria are presented in Table 2.

Importance of a setup development for the company's functioning can be presented as a function (1).

$$I_{SD} = f(B_N,\ S_T,\ S_F,\ C_T,\ A_P) \quad (1)$$

The determined criteria can have different importance for I_{SD}. To identify the importance of criteria a group of experts consists of 10 persons from automotive and aviation companies were asked to assess the criteria with the use of in pairwise comparison method. On the base of the analysis the formula (2) was developed.

$$I_{SD} = 0.33B_N+0.27S_T+0.13S_F+0.2C_T+0.07A_P \quad (2)$$

Table 2 Descriptions of Criteria

Symbol	Criterion	Criteria alternatives	Points
B_N	The machine is a bottleneck machine	Yes	5
		No	1
S_T	Setup time	More than 8 hours	5
		4-8 hours	4
		1-4 hours	3
		10-60 minutes	2
		Less than 10 minutes	1
S_F	Setup frequency	More than 10 times per a day	5
		A few times per a day	4
		At the most once a day	3
		Once a week	2
		More rarely	1
C_T	Setup time and cycle time of production process	Setup time is longer than cycle time of production process	5
		Setup time is similar to cycle time of production process	3
		Setup time is shorter than cycle time of production process	1
A_P	Accessibility of setup procedure	There is no setup procedure	5
		Setup procedure is available for an operator	1

An importance of a setup development can be calculated according to the formula (2). Results of calculation can help a company to assign priority to a certain setup to know, which setup should be analyzed with the use of SMED method first. I_{SD} can have a value in the range: 1-5.

7. Conclusions and the Need for the Further Research

The research aimed at assessing the SMED method implementation. It turns out that the companies don't attach much importance to the setup process because only 40% of the surveyed companies decided for the process improvement with the use of the SMED method, and they were mostly the companies with the foreign majority capital. That fact indicates the need to disseminate, among the Polish companies, the knowledge on the possibility of the SMED method implementation for improving the setup process. It is obvious that the SMED method is mainly applied by the automotive companies, and that derives probably from the fact that as a Lean Manufacturing tool, it is present in Toyota Production System. Primarily, large companies implemented the SMED method, and 14% of them applied it to all the setups performed. It certainly required a lot of effort which often small and medium-sized enterprises cannot afford.

Companies operating nowadays realize that their market survival depends on the production quality lead time of the clients' orders. Based on the conducted researches and authors' experience, it can be concluded that the

companies take up improvement action only when they feel threatened, therefore most often when there is most work and most delays, except then it can be too late. In the authors' opinion, it is vital to encourage companies to take action to improve production processes and production organization when they are not under pressure in order to be prepared for more difficult times. Decision support model for selection of setups to SMED analysis, developed and presented in the paper, can help companies allocate resources to reduce setup time on the work stands, where it is really necessary.

For the future researches authors are planning to implement the developed decision support model for selection of setups to SMED analysis in chosen companies, to assess the advantages of its application.

It would be also important to investigate in the future, what development strategies are used by companies and what are their main incentives to use improvement methods and tools. That could constitute the field for further research.

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