SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2021
ORGANIZATION AND MANAGEMENT SERIES NO. 151

APPLICATION OF THE SMED METHOD FOR IMPROVING THE CNC MACHINE WORKPLACE PRODUCTION PROCESS IN THE SCOPE OF "WAITING" MUDA

Katarzyna HYS[1]*, Antoni DOMAGAŁA[2]

[1] Politechnika Opolska, Wydział Inżynierii Produkcji i Logistyki, Opole; k.hys@po.opole.pl, ORCID: 0000-0003-0800-2804
[2] Akademia WSB, Dąbrowa Górnicza: domagala.antoni@gmail.com, ORCID: 0000-0002-2040-6222
* Correspondence author

Purpose: The purpose of this work is to analyze the actual changeover time of a given machine and apply the developed changes.
Design/methodology/approach: Properly designed and implemented, the SMED method allows you to limit the setup time for a given machine. Retrofitting in Lean optics is one of the activities that does not add value to the organization, because of its waiting time.
Findings: As a result of the changes implemented, it was possible to determine measurable effects for the company in the category of "waiting" in the Muda aspect.
Research limitations: The presented analysis has a spatially and temporally limited dimension, which could be the trigger for expanding the research in the future.
Originality/value: This article presents actions leading to the optimization of the Computerized Numerical Control (CNC) machine production process by using one of the Lean Management concepts – in this case, it is the Single Minute Exchange of Die (SMED) method.

Keywords: Lean Management, SMED method, SMED methodology, Muda "waiting".

Category of the paper: case study.

1. Introduction

Continuous and sustained improvement of production processes is based on the elimination of all kinds of waste and standardization of solutions introduced for these processes. One of the ways to achieve the correct organization of work, together with a high level of quality and the required safety standards while taking into account the necessary costs, can be implementing activities in accordance with the philosophy of Lean Management (Bhamu, & Sangwan, 2014).

The concept of lean management is based on eliminating waste (from Japanese – muda) (Nicholas, 2016; Hys, 2016; Camuffo, & Gerli, 2018). Muda refers to all activities carried out in the organization that do not add value to the product, but exist due to the structure of the production process. The concept of waste is complex. Its literal translation means not utilizing things (in part or in whole), inefficient management or unreasonable wastefulness. From the Lean Management concept point of view - it is used to define activities in the process for which the client does not want to pay. In literature on the subject, several types of waste are distinguished, which are grouped into the following categories (Prasetyawan et al., 2019; Meng, 2019):

- overproduction – that is, manufacturing of products despite the fact that they have not been ordered, the result of which is the increase of fixed production costs (e.g. energy consumption, human labor, storage costs),
- unnecessary stocks – both finished goods and inter-operational products, which increase the costs of transport and storage,
- unnecessary employee movement – activities that are carried out during the production process, but they do not directly constitute any value to the product (e.g. starting the machine, searching for a tool to fix),
- unnecessary transport – the absence of optimization in the area of communication and transport routes (e.g. missing or incorrect marking, incorrectly determined/calculated routes),
- faulty and quality defective products – which means creating new and repairing defective ones,
- unnecessary and excessive processing – implementing subprocesses unnecessary from a qualitative perspective in the production process,
- waiting – wait time generated by downtime in an improperly optimized production process.

In literature on the subject for such categories, the acronym TIMWOOD is used, which means respectively: *transportation, inventory, motion, waiting, overproduction, overprocessing, defects*.

The given group of activities generating mismanagement is a classic set. Nevertheless, in literature it is postulated to supplement this list with categories of so-called soft muda. These include lost employee creativity (the so-called untapped employee potential) and lost benefits resulting from the company's lost reputation in a given market (De Boeck et al., 2019; Bicheno, & Holweg, 2009).

2. SMED method and methodology

In the majority of enterprises, not only associated with industrial production but also other branches of industry, production processes are becoming increasingly more automated (Hys, 2014). The SMED (Single Minute Exchange of Die) method is a set of techniques and tools that make it possible to shorten the changeover times of machines and devices involved in a given production process (Basri et al., 2019). The creator of the SMED methodology is Shingeo Shingo, who initiated the concept of quick retooling in 1950 (Shingo, & Dillon, 1985). The purpose of SMED is to design the production process in such a way that the changeover of machines and devices is carried out using the least number of tools.

From the practical point of view, the idea of SMED consists in transferring as many operations as possible "outside" (i.e. carrying out changeover operations during machine operation) and simplifying and increasing the efficiency of the implementation of individual steps of retooling machines and equipment (Cakmakci, 2009; Da Silva, & Godinho, 2019). As the researchers note – in most of the cases studied, it is not technical factors that determine the duration of the changeover, but organizational factors (Sayem et al., 2014; Rosmaini, & Soberi, 2018; Godina et al., 2018).

The literature on the subject indicates four stages of organization of the machine retooling process. These include (Womack, & Jones, 2001; Moreira, & Campos, 2011; Bikram, & Dinesh, 2011):

- stage I – analysis of the current state of the given production cell,
- stage II – separation of internal and external retooling operations,
- stage III – transformation of internal processes into external processes,
- stage IV – improving all aspects of retooling.

STAGE 1 – Analysis of the changeovers process. At this stage, there are no physical improvements in the production process yet, and time is spent on in-depth analysis of the process. Here, particular attention is paid to the definition of individual steps in the process of retooling machines and devices and to the analysis of the required resources related to these shifts. The first stage consists of the following operational activities:

- Recording of all retooling operations (external and internal) with particular emphasis on the operator's movements, equipment used, workstation organization, transport routes, waiting for the next operation, etc.
- Analysis of retooling in a large team, which allows you to increase the perspective of analyses and a multifaceted look at the order and scope of activities carried out when retooling machines and devices.
- Preparation of documentation for analyses constituting a record of the current status of the changeover process.

As a result of such conclusions, an analysis of operator's motions is obtained in the form of a "Spaghetti diagram" and changeover progress report card.

STAGE 2 – External and internal changeover. This step in the SMED methodology is considered to be the most important, and its correct implementation allows for a decrease in changeover time [...]. The basic goal of this stage is a clear demarcation between internal and external retooling and elimination of all those activities that unnecessarily extend the retooling of machines and devices.

Among the techniques facilitating the implementation of this stage of SMED are the following:

1. Control cards that contain:
   - a list of employees trained and authorized to perform retooling of machinery and equipment,
   - a list of tools, instruments and changeover materials,
   - setting values on a machine that is being retooled or for a specific process,
   - a list of procedures and instructions to be used for the changeover.
2. Appropriate transport of parts and tools for changeovers (external operation).
3. Visual control techniques – using colors and labelling to mark machine equipment, appropriate arrangement and presentation of tools (e.g. in the form of shadow boards).

STAGE 3 – Transformation of changeovers. The primary purpose of this stage of the SMED method is to replace as many retooling operations as possible from internal to external. The introduction of the changeover transformation stage allows for a reduction in its duration, the tools and techniques used, which include:

- indirect clamping devices,
- standardization of functions – unification of assembly parameters in a machine or device, unification of tools and instrumentation,
- standardization of the changeover procedure itself through the precise changeover instructions, which contain photos or diagrams of the various stages of the changeover, set parameters, etc.

STAGE 4 – Improvements. The final stage of the SMED method is to take actions to reduce the duration of internal operations as much as possible. The potential of this stage is estimated at approx. 10% reduction in changeover time. The basic tools used in this step include:

- proper storage and management of tools and instruments,
- parallel operations,
- fixing grippers,
- elimination of regulations,
- mechanization.

The SMED methodology is a universal record of activities that can be directly related to research and analyses carried out in a given production environment.

3. Research methodology

The research presented in this article was carried out in a production company at an automatic CNC machine station equipped with a robotic pallet system. The study involved an employee implementing a retooling of a CNC machine in a robotized manufacturing cell, hereinafter referred to as a setting operator.

The research was carried out during the first half of 2019 at an industrial production plant in southern Poland. The purpose of this work is to analyze the actual changeover time of a given machine and to apply the developed changes to the investigated production line. The analysis was carried out using the SMED Method for one of the Muda categories, i.e. the waiting time for the changeover of a CNC machine tool on a given production line. The expectation was set that the time analysis in the field of CNC machine tool changeover will allow optimization of the changeover time for that machine.

Attempting to achieve the research objective, one of Muda's losses was analyzed, i.e. waiting for the machine changeover using the SMED methodology and method. Typical activities constituting a loss (i.e. waste) during the retooling of machinery and equipment in the production process in the area of "waiting" include, among others:

- searching for tools by the employee and their unnecessary transport,
- repairing tools,
- waiting for the supervisor's decision,
- waiting for logistics,
- sorting and searching for information for retooling machines and devices (instructions, parameters, etc.),
- pondering and repeatedly controlling implemented activities and steps taken.

For the purpose of this study, tests were carried out at the CNC machine workstation using the following stages according to the SMED methodology:

Stage 1 – workstation analysis and selection of the workstation.

Stage 2 – selection of the research method.

Stage 3 – analysis of the operator's work during the change of instrumentation at the selected workplace, in particular:

a) determining the initial state,
b) verification of the initial state,
c) a proposal of changes to improve the operator's actions during the change of tooling at the CNC machine workstation.

Stage 4 – implementing changes.

Stage 5 – controlling the effects of changes introduced in a given workplace.

Stage 6 – analysis and verification of changes made and effects obtained. Making a decision to introduce permanent changes to the technology in the field of retooling, rejecting these changes or their partial implementation.

4. Research results

Stage 1 – workstation analysis and selection of workstation.

Figure 1. Robotic pallet system (illustrative example), source Metal Team advertising materials.

The work of the employee making the changeover and setting up the production process at a CNC machine workstation was the subject of the research. Due to the protection of the data of the examined organization, in (Figure 1) in exchange for presenting the original photo of the workplace, a catalog visualization of a compact, robotic pallet system with five pallets, called "Rexio® Drawer" is used. During the changeover process to another manufactured product, the so-called "separators" dedicated to each of the manufactured elements are mandatorily exchanged. The grippers on the Kawasaki robot and pneumatic equipment installed directly on the CNC machine are also subject to replacement.

Stage 2 – selection of the research method.

The research method was chosen. It was decided to film the changeover process, and then conduct frame by frame analysis. All actions performed were grouped into:

- internal activities – those that can be done only when the machine is stopped,
- external activities – activities that can be performed even when the machine is running.

The next step was transforming as many of the internal operations as possible into external ones, as well as improving all aspects of retooling. The obtained results were to be described and presented in the form of graphs.

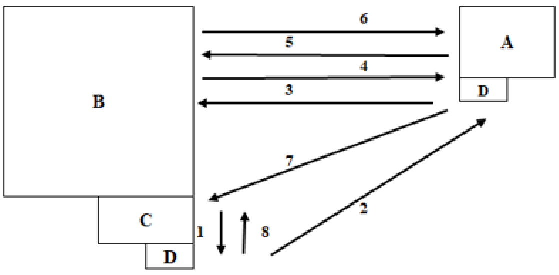
Stage 3 – operator's work analysis.

The set of all activities (the so-called initial state), along with the division into internal and external activities during the changeover, which the setting operator performs at the analyzed workplace, is presented in (Table 1).

Table 1.
Setting operator's actions performed during the changeover – initial state

Action No.	Activity Description	Type of activity internal/ external	Time [min.]
	Production stop		
1	walking up to tool trolley	int.	1
2	taking the tool trolley	int.	1
3	moving on to the robotized manufacturing cell with the tool trolley	int.	3
4	unscrewing the separators from all drawers	int.	48
5	dismantling the grippers from the robot	int.	6
6	dismantling the tooling from the CNC machine	int.	7
7	moving on to the tool holding storage with separators, grippers and other instrumentation	int.	3
8	putting the separators, grippers and instrumentation on rack No. 1	int.	3
9	collecting separators, grippers and instrumentation from rack No. 2	int.	3
10	transition with collected separators, grippers and instrumentation to the robotized manufacturing cell	int.	3
11	screwing separators onto all drawers	int.	60
12	mounting grippers on the robot	int.	10
13	mounting the tooling on a CNC machine	int.	13
14	selecting the appropriate program on the HMI panel	int.	1
15	performing the entire cycle of exchanging pieces for 20% of the working capacity of the robot	int.	15
16	performing measurements of the first correct piece	int.	5
	Resumption of production		
17	moving the tool trolley to its designated parking place	ext.	3
18	return to the workstation	ext.	1
		Total	186

Source: own study.



Route no.	Number of steps
1	2
2	14
3	11
4	11
5	11
6	11
7	14
8	2
Total	**76**

Legend:

A. Robotized manufacturing cell
B. Tool holding storage
C. Setting operator's workstation
D. Tool trolley

Figure 2. Workplace overview graph - initial state source own study.

Using the Spaghetti Chart diagram in (Figure 2), at a semi-automatic workstation, the initial state of the setting operator's movements during the changeover of the robotic pallet system was presented.

Stage 4 – implementing changes.

The analysis conducted indicated that there is a possibility of rationalization in this area. In order to limit the number of steps performed by the employee, the activities and area of the workplace were reorganized. The scope of changes that were introduced is presented in (Table 2).

Table 2.
Introduced activities for the analyzed workstation

No.	Actions introduced
1	division of activities performed during changeover into external and internal
2	changing the parking position of the tool trolley
3	determining new travel paths for the setting operator during the changeover
4	resignation from replacing separators in all drawers and permanent assignment of three drawers for the first product and two drawers for the second manufactured product
5	in order to eliminate the robot's faults while in operation, special covers were made for buttons confirming the readiness of the pallet for production for the drawers designated for the product that is not currently being manufactured

Source: own study.

Stage 5 – verification of the implemented changes and their effects at a given workstation.

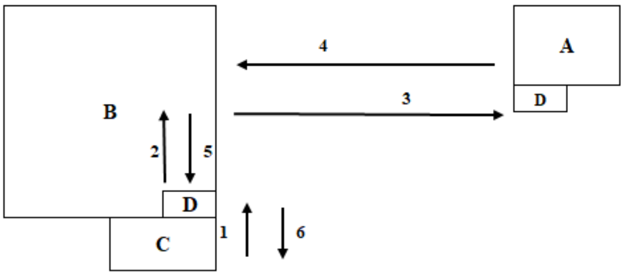
The list of the setting operator's activities after the reorganization and their workstation area after the changes is presented in (Table 3).

Table 3.
Setting operator's actions performed during the changeover – status after changes

Action No.	Activity Description	Type of activity internal/ external	Time [min.]
1	walking up to a tool trolley	ext.	1
2	taking the tool trolley	ext.	1
3	collecting grippers and tooling from rack 2	ext.	2
4	placing grippers and tooling on the tool trolley	ext.	1
5	transition with the tool trolley to the robotized manufacturing cell	ext.	3
Production stop			
6	removing grippers from the robot and installing new ones	int.	14
7	removing the tooling from the CNC machine tool and installing a new one	int.	17
8	selecting the appropriate robotized manufacturing cell's program on the HMI panel	int.	1
9	performing the entire cycle of exchanging pieces for 20% of the working capacity of the robot	int.	15
10	measurement of the first correct piece	int.	5
Production resumes			
11	change of the position of the buttons covers confirming the readiness of the pallet	ext.	5
12	passage with the tool trolley to the tool holding storage	ext.	3
13	putting the grippers and tooling back on rack no. 1	ext.	2
14	passage with the tool trolley to its designated parking place	ext.	1
15	return to the workstation	ext.	1
		Total	72

Source: own study.

Figure shows the Spaghetti Chart of the setting operator's movement during the changeover of a robotic pallet system at a semi-automatic workstation, after introducing the proposed improvements (Figure 3).



Route no.	Number of steps
1	2
2	4
3	11
4	11
5	4
6	11
Total	**34**

Legend:

A. Robotized manufacturing cell
B. Tool holding storage
C. Setting operator's workstation
D. Tool trolley

Figure 3. Workstation overview diagram – state after implemented improvements source own study.

Stage 6 – analysis and verification of changes made and effects obtained.

Illustrating the setting operator's actions in the tested robotized manufacturing cell using the Spaghetti Chart diagram allowed for the verification of the initial state and subsequently, the presentation of a new way of employee movement during the changeover of the robotized pallet system. As a result of the introduced changes, the number of steps performed by the setting operator was reduced during one changeover by the value of 42 steps[1]. The indicated change is presented in (Figure 4).

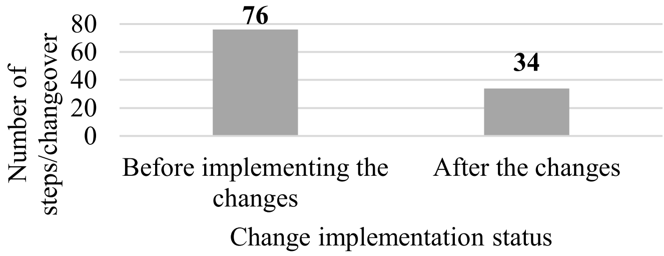


Figure 4. Number of steps performed by the setting operator before and after introducing improvements during a single changeover source own study.

The analysis of the actions performed by the setting operator after introducing improvements at the tested workstation, according to the data in (Table 2), showed a reduction in the time of one changeover of the robotized pallet system by 114 min. The duration of the changeover before and after the improvements made is shown in (Figure 5).

[1] Number of reduced steps – the total number of steps during one changeover performed by the setting operator before changes, minus the total number of steps made by him after the changes; 76 steps – 34 steps = 42 steps.

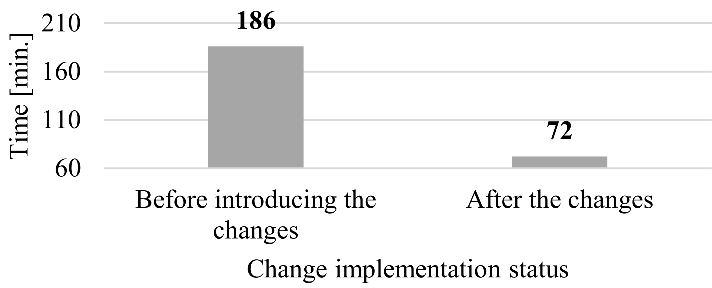


Figure 5. Change in the duration of the retooling of a semi-automatic workstation with a robotic pallet system as a result of improvements source own study.

5. Conclusions from the research

The analysis of the examined workstation allowed for drawing the following conclusion: as a result of the rationalization introduced at the semi-automatic workstation, the working time of the analyzed workstation was increased by 114 min./month. According to customer demand, the tooling changeover is performed once per month. Converted into the annual production plan, the availability of a semi-automatic workstation with a robotic pallet system has been increased by 1368 min/year, which amounts to 22.8 hours/year[2]. Figure presents the time change in annual terms, in which the analyzed semi-automatic workstation is stopped as a result of changing the tooling for subsequent manufactured products, before and after the introduced rationalizations (Figure 6).

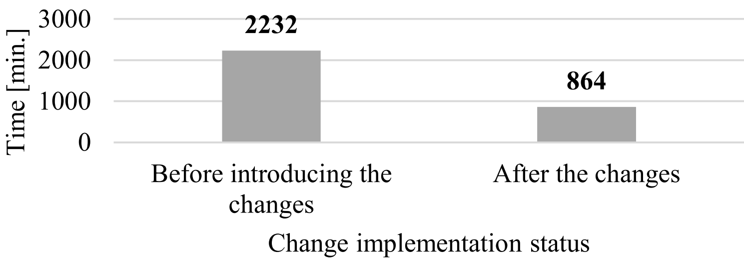


Figure 6. Change of the working time of the workstation on an annual basis resulting from the introduced rationalizations source own study.

[2] Improved accessibility of the workstation after the introduced rationalization – time limited during one changeover of tooling multiplied by the number of changeovers performed during one month and multiplied by the number of months during one calendar year; 114 min X 1 changeover X 12 months = 1368 min./year.

6. Discussion

The SMED methodology is universal and can be used to optimize production processes. In this article, the SMED Method was successfully used in the field of industrial production at the setting operator's workstation, who was performing a changeover at a semi-automatic workstation with a robotic pallet system.

The analysis carried out in accordance with the SMED methodology showed that its use at a given workplace allowed optimization of the waiting time associated with the changeover of a CNC machine tool. However, doubts are raised by the researchers as regards the problem that they noticed during their research, which could affect this study, as it points out certain limitations. Namely, while the nature of the SMED Method is universal, the following limitations were revealed during the study. In the SMED method, the Spaghetti Chart diagram is used in the third stage. The basis here is the calculation of employee steps. However, researchers note that the physical conditions of an employee are not included here. That is, will the number of steps for a 1.50 m tall employee be the same as for a 2.0 m tall employee? If a given workstation is served by several people (e.g. during three shifts), should the step values be determined as the arithmetical mean value in this situation, or should another methodology be used? What are the consequences for the value of the designated improvements? Another question is the employee's age criterion, because age has a direct impact on the efficiency of manual movements and elasticity of movement. Will a 64-year-old employee be able to manually unscrew/screw individual tooling attachments with the same work rhythm as a 19-year-old employee? Does the time needed to complete each step coincide between the indicated age groups of employees?

These doubts suggest that when performing analyses using the selected research method, there is always a necessity to look at the results obtained from a broader perspective, so that the implemented improvements are optimal due to the wide spectrum of analysis, and not only through the prism of the selected criterion.

7. Summary

During the conducted tests, an analysis of the real time changeover of the CNC machine station was carried out. Changes were proposed, and then the course and time of the setting operator's work after their application were verified. By carrying out the indicated activities, the intended objective of this work was achieved.

Conducting the analysis of retooling of the robotic pallet/palletizer system by the SMED method and applying to it the solutions resulting from the analyses carried out allows for the rationalization of the results obtained by different organizations on many levels. The work on the changeover of semi-automatic workstations, in particular in the context of MUDA, is a continuous type of work. Technological progress and development of the organization allows for continuous improvement of production processes also in the aspect of the necessary machine changeovers.

Working within the "continuous improvement" optics, development instruments are launched in all areas and planes of the organization (Hys, & Domagała, 2018). When analyzing the possibility of reducing the changeover time, the SMED method is used for this purpose. Appropriate application of it allows the development of a competitive advantage by obtaining greater availability of your machine park, increasing flexibility in production planning and makes it possible to reduce real and potential losses in the production process.

References

1. Basri, A.Q., Mohamed, N.M.Z.N., Yasir, K.A.S.H.M., Fazi, H.M., & Fudzin, A.F. (2019). The validation of productivity on the changeover activity at the automotive stamping press line by comparing the embedded SMED frame-work versus SMED approach: A witness simulation case study. *IOP Conference Series: Materials Science and Engineering, Vol. 469(1),* DOI: 10.1088/1757-899X/469/1/012005.
2. Bhamu, J., & Sangwan, K.S. (2014). Lean manufacturing: literature review and research issues, *International Journal of Operations & Production Management, Vol. 34(7),* pp. 876-940, DOI: 10.1108/IJOPM-08-2012-0315.
3. Bicheno, J., & Holweg, M. (2009). *The Lean Toolbox. The Essential Guide to Lean Transformation.* Buckingham: Production and Inventory Control, Systems and Industrial Engineering Books, p. 24.
4. Bikram, J.S., & Dinesh, K. (2011). SMED: for quick changeovers in foundry SMEs. *International Journal of Productivity and Performance Management, Vol. 59*, pp. 98-116.
5. Cakmakci, M. (2009). Int. J. Adv. Manuf. Technol., no. 41, p. 168. https://doi.org/10.1007/s00170-008-1434-4.
6. Camuffo, A., & Gerli, F. (2018). *Modeling management behaviors in lean production environments. International Journal of Operations & Production Management, Vol. 38(2),* pp. 403-423, DOI: https://doi.org/10.1108/IJOPM-12-2015-0760.

7. Da Silva, I.B. & Godinho, M.F. (2019). Single-minute exchange of die (SMED): a state-of-the-art literature review. *The International Journal of Advanced Manufacturing Technology, Vol. 102(9-10),* pp. 4289-4307, DOI:10.1007/s00170-019-03484-w.
8. De Boeck, G., Dries, N., & Tierens, H. (2019). The Experience of Untapped Potential: Towards a Subjective Temporal Understanding of Work Meaningfulness. *Journal of Management Studies, Vol. 56(3),* pp. 529-557, DOI: 10.1111/joms.12417.
9. Godina, R., Pimentel, C., Silva, F.J.G., & Matias, J.C.O. (2018). A structural literature review of the single minute exchange of die: the latest trends. *Procedia Manuf., Vol. 17,* pp. 783-790, DOI: https://doi.org/10.1016/j.promfg.2018.10.129.
10. Hys, K., & Domagała, A. (2018). Application of a spaghetti chart for streamlining production process. Case study. *Archives of Materials Science and Engineering, Vol. 89(2),* p. 71.
11. Hys, K. (2014). Tools and methods used by leading Polish automotive companies in quality management system. Results of empirical research. *Journal of Achievements of Materials and Manufacturing Engineering, Vol. 63(1).* International OCSCO World Press, pp. 30-37.
12. Hys, K. (2016). Inter mundus – designing the quality of hotel services: prospect of customer and manager. *Economics & Tourism, Book 2, Vol. 5,* pp. 393-400, 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM 2016, Doi:10.5593/SGEMSOCIAL2016/B25/S07.051.
13. Meng, X.H. (2019). Lean management in the context of construction supply chains. *International Journal of Production Research, Vol. 57(11),* pp. 3784-3798, DOI:10.1080/00207543.2019.1566659.
14. Moreira, A.C., & Campos Silva Pais, G. (2011). Single Minute Exchange of Die: A Case Study Implementation. *Journal of Technology Management and Innovation, Vol. 6(1),* pp. 29-46.
15. Nicholas, J. (2016). Hoshin Kanri and critical success factors in quality management and lean production. *Total Quality Management & Business Excellence, Vol. 27(3-4),* pp. 250-264, DOI: 10.1080/14783363.2014.976938.
16. Prasetyawan, Y., Suef, M., Rifqy, N., & Wardani, I.O.K. (2019). Manufacturing strategy improvement based on lean methodology. *IOP Conference Series: Materials Science and Engineering, Vol. 508(1),* DOI: 10.1088/1757-899X/508/1/012095.
17. Rosmaini, A., & Soberi, M.S.F. (2018). Changeover process improvement based on modified SMED method and other process improvement tools application: an improvement project of 5-axis CNC machine operation in advanced composite manufacturing industry *International Journal Of Advanced Manufacturing Technology, Vol. 94(1-4),* pp. 433-450, DOI:10.1007/s00170-017-0827-7.
18. Sayem, A., Islam, M.A., & Khan, M.M.A. (2014). Productivity enhancement through reduction of changeover time by implementing SMED technique – in furniture industry. *International Journal of Industrial and Systems Engineering, Vol.17(1),* pp. 15-33.

19. Shingo, S., & Dillon, A. (1985). *Revolution in Manufacturing: The SMED System*. Productivity Press Inc.
20. Womack, J.P., & Jones, D.T. (2001). *Odchudzanie firm. Eliminacja marnotrawstwa – kluczem do sukcesu.* Warszawa: Centrum Informacji Menadżera.