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IMPROVEMENT OF MANUAL ASSEMBLY LINE BASED ON VALUE STREAM MAPPING (VSM) AND EFECTIVENESS COEFFICIENT

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Dorota Klimecka-Tatar[1] – *orcid id: 0000-0002-7458-1675*
Vishvajit Shinde[2] – *orcid id: 0000-0002-2085-4957*

[1]Czestochowa University of Technology, **Poland**
[2]University of Pune, **India**

Abstract:
In the paper the possibilities of process re-organizing in relation to simple principles for limiting waste in the production cycle have been presented. Based on value stream mapping and monitoring of performance indicators, the possibilities of changes identification of in the assembly line process have been presented. Furthermore, based on the availability, performance and quality values, it has been proved that relatively small changes can have a very positive effect on the assembly process. Based on the OEE coefficient, it has been found that the proposed changes improved the process's efficiency by more than 20%.
Keywords: OEE coefficient, VSM, vale stream mapping, assembly process, process improvement

1. INTRODUCTION

Reconfiguration of assembly processes refers to a quick change in the organization of the process in relation to its course and flow. Such a change may also be based on personnel changes and the possible transfer of technical equipment (Harari et al., 2018; Menn et al., 2018; Shim and Kim, 2018). However, reconfigurability should be designed to accomplish the change (Lee et al., 2019). When designing assembly processes, digital support tools are extremely helpful (Menn et al., 2018; Renu and Mocko, 2016; Roldán et al., 2019). Nevertheless, all such changes are intended to improve the process in terms of process efficiency increase. In this respect, the efficiency is characterized by three variables which are included in the OEE (Overall Equipment Effectiveness) coefficient.
Process improvement principles are related to the configuration and organization of the assembly sub-processes with an emphasis on their flexibility, while taking into account the use of space for diversity, lean production principles, custom assembly, production

organization, as well as actual planning and in consequence the effectiveness of management systems in the enterprise (Harari et al., 2018; Schmitt et al., 2019).
The designing course of manual, linear assembly processes is extremely difficult and requires considerable experience from people managing of them. In designing or in redesigning assembly processes, the client's requirements, type of used technology, technical capabilities, machine availability, materials and organization of the workplace are considered (Lee et al., 2019; Moreira et al., 2017; Schmitt et al., 2019; Shen, 2015). Improvement of assembly processes focuses on optimizing all tasks throughout the entire cycle of the process (Godina et al., 2018; Klimecka-Tatar, 2017; Jagusiak-Kocik, 2014; Naebulharam and Zhang 2013). The design (or re-design) of assembly lines is carried out in many ways, however, from the point of view of production engineering, the two most important approaches are considered: the simple assembly line balancing problem (SALBP) and the generalized assembly line balancing problem (GALBP). Both approaches apply directly to Assembly Line Balancing (ALB). Usually, each assembly line consists of linearly order assembly stations and the processed raw material / material / semi-finished product moves from station to station. In each assembly cycle, the same operations are repeated cyclically on the assembly station. Thus, the solution of problems with load balancing on the assembly line focuses on the optimization of operations at all assembly stations, but with respect to the main purpose of the process. SALBP (simple assembly line balancing problem) is important for the assembly line of a single product, where only the limitations resulting from the priority between tasks are considered. In the literature (Kriengkorakot and Pianthong, 2007; Tracht et al., 2015) four types of SALBP are distinguished:
- Type 1 (SALBP-1) - minimize the number of stations while maintaining the cycle time
- Type 2 (SALBP-2) - minimize cycle time (i.e. increase production rate) in the absence of variability in the number of assembly stations.
- Type E (SALBP-E efficiency) - to maximize the efficiency of the line while minimizing the number of stations and minimizing cycle time.
- Type F (SALBP-F feasibility) - evaluation of assembly line efficiency assuming the variability of the number of assembly stations and cycle time variability (searching for mutual dependences of these parameters).

Balancing and optimization of assembly lines with the elimination of SALBP assumptions is called the generalized assembly line balancing problem (GALBP). These techniques also include all problem enhancements that may be relevant in practice, including equipment selection, processing alternatives, task delegation restrictions, etc. Here, three types of balancing the assembly line work are distinguished, among others:
- MALBP - model assembly line balancing problem - its purpose is to assign tasks (operations) to the station, considering different operation times for different models in the product group - also analyzing the number of stations and the cycle time.
- MSP - model sequencing problem - the goal is to determine the sequence of all model operations to be produced in such a way as to improve efficiency.

2. METHODOLOGY OF RESEARCH

The aim of this article is to present a comprehensive technique of the manual assembly process improvement. For this purpose, two research tools have been used. The first instrument used in the process evaluation is VSM – Value Stream Mapping. VSM is a

tool from the group of Lean tools, which regardless of the level of technological development of the company, in search of opportunities to improve processes, should be used as a first. By process mapping, it can be easily visualized the flow of streams (material and information) in the whole process, from the stage of order creation to the distribution of products. Based on process mapping, it is possible to rank all operations in the process, operations that add values (AV) and operations that do not add value (N-AV) (Favi et al., 2017). On this basis, it is also possible to identify different types of waste (*muda*). Therefore, due to the information gathered on the basis of the VSM analysis, it is possible to identify areas that should be subjected to detailed observations in the first place. The second tool used in process improvement can be the measurement of the OEE indicator. The OEE indicator is included in the instruments supporting TPM techniques (Total Productive Maintenance) (Brzeziński and Klimecka-Tatar, 2016; Maszke, 2019; Krynke et al., 2014). Its main task is, parallel to the process, to monitor the three components: performance, availability and quality of products.
In the case of a comprehensive application of VSM and measurement of OEE indicator, it should be noted that the efficiency index is in this case a factor that calibrates the course of changes, and what is more, it is an indicator informing about the favorable or unfavorable impact of changes on the process flow. Whereas the VSM is used as a tool for identifying critical areas for process efficiency.

3. RESULTS AND DISCUSSION

Value stream mapping analysis of the manual assembling process had been started from collecting input data (technological and numerical data) in five operational areas (Klimecka-Tatar, 2018):
Area 1. Determination of customer requirements:
- customer's requirements regarding the product's eligibility as qualitatively compatible,
- customer requirements for frequency and delivery mode,
- inventory buffer in the subsystems under consideration.

Area 2. Identification of information flows:
- establishing production forecasts based on previous orders, concluded contracts or market research,
- defining recipients of information (the owner and participants of the process), responsible for the implementation of orders, exchange of information between suppliers and recipients,
- analysis of the formal information flow time.

Area 3. Determination of materials flows:
- identification of the company's requirements regarding the demand for raw materials, semi-finished products and products,
- identification of the deliveries size and frequency,
- identification of the process flow and assigning tasks to the assembly stations - identification of the types of activities, duration of operations;
- imaging of the task layout taking into account the time of each task, as well as the additional times of each task (changeover or set-up time, preparation and transport between operations)

Area 4. Determination of the relation between material and information flows.

Area 5. Summary and supplement of operations that add values (AV) or do not add values (N-AV) during the cycle.

In this work, only the selected element of the entire production cycle has been taken into account. Figure 1 shows only the sampling of a complete process map, which has been thoroughly analyzed. The process lead time (L/T) and value adding time (VA) correspond for a series of details in the amount of 100 pieces.

The element produced on the assembly line is part of the guide for the car seat headrest. The detail, apart from the housing, consists of a fastening ring, a button with springs, a steel lock plate and a closing cover. According to the current state map (Figure 1), the assembly process consists of 5 tasks (*T* = 5) that are performed by five operators (*O* = 5) independently. Each operator is assigned a separate assembly station (*S* = 5), on which performs five tasks (in accordance with the sequence).

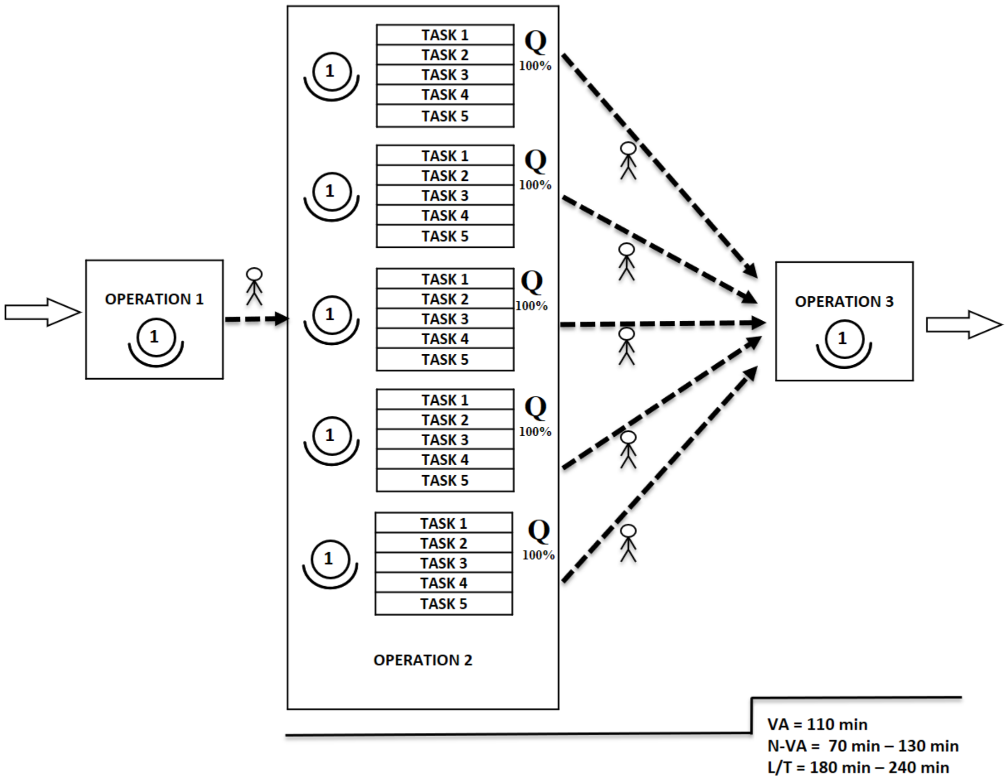

Fig.1. Selected area of the assembly process map for the seat headrest guide - current state map (CSM)

Source: own study

The process curried out in such a way is characterized by a significant number of downtimes caused by the components searching and, unfortunately, a significant amount of waste (especially incorrectly assembled details), i.e., unsatisfactory level of quality. It should be noted that each of the operators performed all tasks individually, performed quality assessment and transport details between operation 2 and operation 3. As it can be seen, the lead time (L/T) of operations 2 varied between 180 and 240 minutes, whereas time required for adding values are only 110 minutes (VA = 110 min). Therefore, can be presume that 70 - 120 minutes is the time of non-adding value actions (N-VA). While a part of time is required to prepare assembling of details, a significant part is treated as a waste (*muda*) caused by improper work organization.

To ensure greater repeatability of the process and increase the efficiency of this assembly process, changes in process balancing have been proposed. From the point of the process organization view, it is important to do not to change the number of tasks (T = const.) and to do not to change the number of assembly stations (S = const.), as well as to do not to change the number of operators (O = const.). The task time, cycle time, process efficiency and process quality level have been improved (Figure 2).

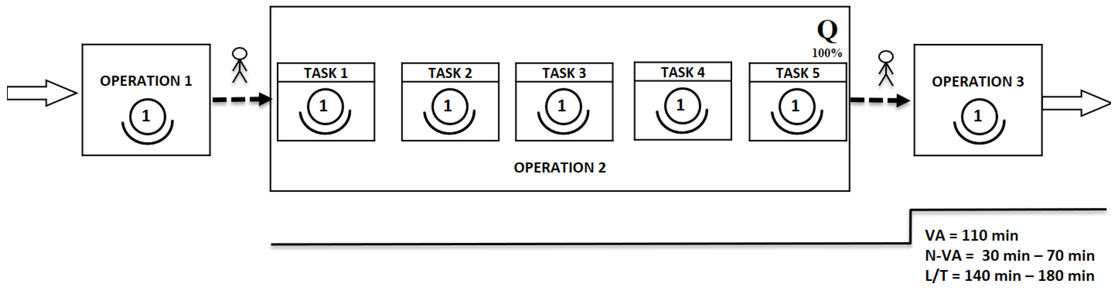

Fig.2. Selected area of the assembly process map for the seat headrest guide - future state map (FSM)

Source: own study

On the assembly line, changes in the organization of the process have been made based on the diagram presented in the selected area of the future state map (Fig. 2). Performed specialization of tasks has contributed to the increase of the process rate of the workpiece (100 pieces) cycle. There has been observed a significant reduction in the time of details (100 pieces), flow by all tasks. Despite the fact that the adding value time has not been shortened, a significant reduction in time (waste - *muda*) for non-adding value operations has been observed. Such a change effect is in line with the principles of process improvement according to Lean Management.

In order to confirm (process monitoring) the benefits of the introduced changes, the process effectiveness indicators for the course of the operation 2 in accordance with the stream flow record presented in Figure 1 and Figure 2 (respectively) have been compered (Figure 3 and 4).

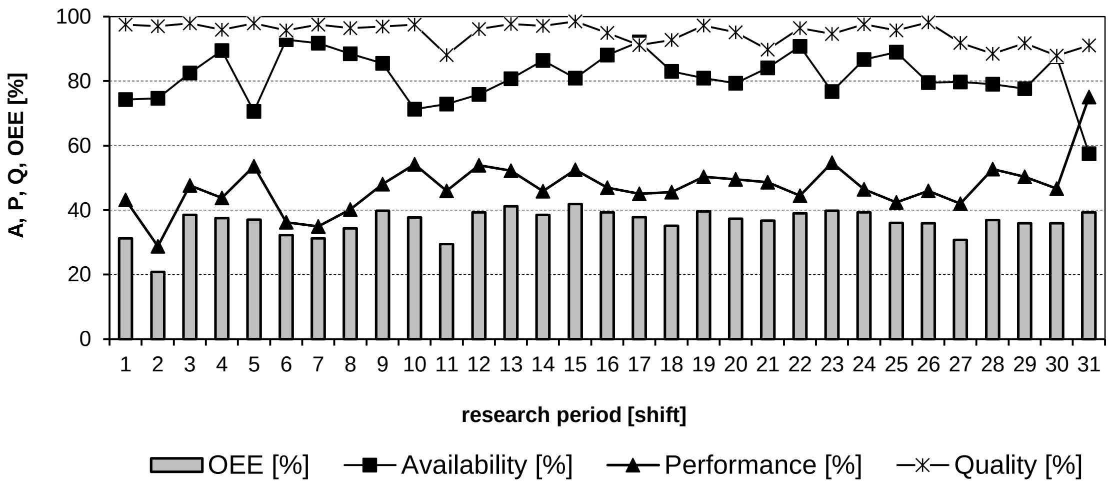

Fig.3. Distribution of TPM values in the analyzed research period – for process according to current state map (CSM)

Source: own study

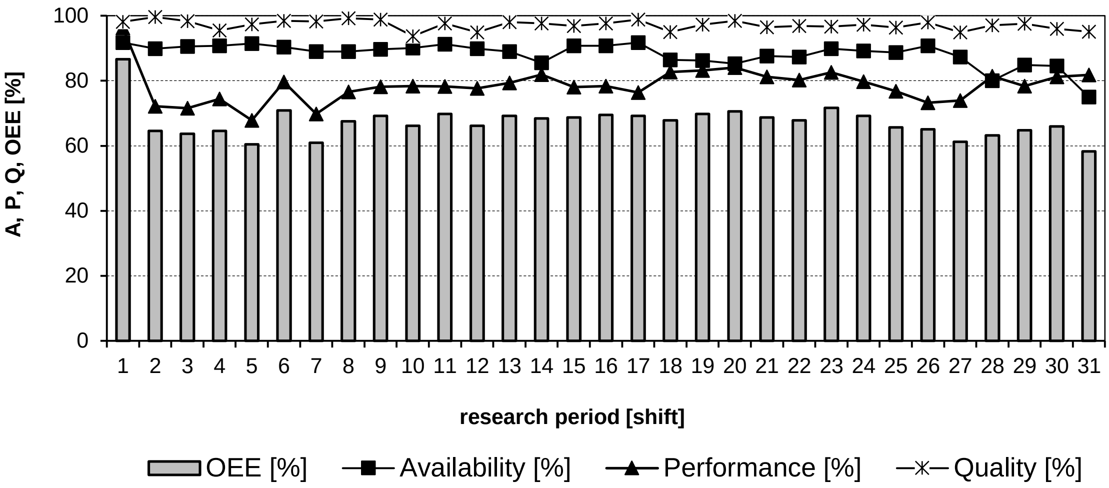

Fig.3. Distribution of TPM values in the analyzed research period – for process according to future state map (FSM)

Source: own study

The OEE coefficient has been registered during 30 of eight-hour work shifts. The component values: availability (A), performances (P), quality (Q) and the OEE indicator for two types of process organization have been presented on the basis of SPC. The OEE coefficient for the process initially fluctuated around 40%, which is definitely unsatisfactory. The world class assumes a ratio of about 90%, in small and medium-sized enterprises it is assumed that this value should be greater than 60%, what has been achieved after introducing changes to the process organization.

On the basis of the results presented in the Figure 3 and 4, it can be clearly stated that the proposed changes in the organization of the production process have a beneficial effect on all the important parameters of the process efficiency. It should also be noted that such a system of assembling process makes it possible to compensate for losses (during the course) through subsequent tasks. Additionally, to avoid monotony of work, operators have been asked to discount the assembly station after every hour of work, which has been met with great acceptance.

4. CONCLUSION

Manual assembly processes are burdened with the possibility of creating large losses, waste (*Muda*). Such losses include the loss of time, the occurrence of a large number of non-conformities (qualitatively incompatible details). Seemingly minor changes in the organization of the assembly process allowed for a significant improvement in the statistical parameters of the assembly process. Due to the initial mapping of the process (flow of the value stream) a loss of time due to insufficient work specialization, introduction of additional (excessive) forms of inter-operational transport, and most importantly, the lack of possibility to compensate the start on assembly stations has been observed.

The organizational changes introduced into the process allowed for a significant increase in the efficiency of the process - without the number of operators change, without the number of stations change and without the number of tasks change. Due to the changes, work efficiency of the manual assembly line increased, and the OEE indicator for a comprehensive operation from the value not exceeding 40% increased to over 60%.

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