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A VALUE STREAM MAPPING IN ADVANCED MANAGEMENT SYSTEMS

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ABSTRACT
All efforts in advanced management systems should maximize value for the customer. One effective way to identify and realize this value is to map the product's flow from end customer to a supplier by visualizing the value streams of individual processes. This paper aims to analyse and propose the introduction of a lean value stream in vacuum pump assembly to achieve increased production output. Vacuum technology is the field of engineering concerned with creating and using a vacuum. It, therefore, deals with an environment in which the gas pressure is lower than the atmospheric pressure. A vacuum pump is a gas pump that extracts air from an enclosed space to create a vacuum. The basic parameters are the vacuum level achieved and the pumping speed. Several design solutions are available that meet the aforementioned basic parameters. A turbomolecular pump was selected for this study. The incentive to improve the material and information flow on the vacuum pump assembly line is the significant increase in orders from the customer. The technique used is production value stream mapping. Following the output of the Value Stream Mapping (VSM), a change plan is determined to optimize the assembly process, which will positively influence the future state of the value stream to meet the customer's requirements.

KEYWORDS: Toyota Production System, Lean Manufacturing, Lean Six Sigma, Value stream mapping, vacuum pump.

JEL CLASSIFICATION: C61, D29, L23,

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INTRODUCTION

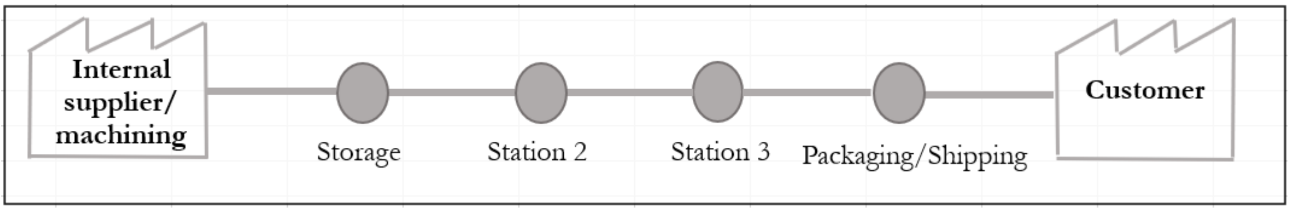
Ever-increasing customer demands, economic growth, a turbulent business environment, high level of competition, and many other aspects defining today's times place demanding requirements on manufacturing companies and service providers. In such a highly competitive environment, organization that has skilled staff, applies agile management, and continuously improves its performance by optimizing resources, eliminating non-value-added activities, and implementing lean value streams will succeed.

The Toyota Production System has become the basis for the current Lean Manufacturing philosophy aimed at eliminating waste in manufacturing processes. Lean production management focuses on eliminating non-value added activities and satisfying customer requirements by producing only what the customer needs. (Ohno, 1988)

Using one of the Lean Management tools – Value Stream Mapping – the turbomolecular pump assembly process will be analyzed to optimize the material and information flow within this process. The need to improve the value stream arose from the needs of the manufacturing organization under study following a dramatic increase in demand from an existing customer.

Based on the completion of input data reflecting the current state of the assembly process, a basis will be created for drawing up an implementation plan for changes, the implementation of which will lead to the optimalization of the future value stream so that the assembly line, whose substeps are shown in Figure 1 (own), will be able to increase the current output by 39 % measured in units per week and thus meet customer requirements.

Figure 1 **Focus area for value stram optimalization**



(Source: own, 2022*)*

1 REVIEW

Taiichi Ohno, a leading Japanese entrepreneur and founder of the revolutionary Toyota Production System, cites two ways how to increase efficiency: increasing product production or reducing the number of workers (Ohno, 1988). Unlike Ford's mass production system, which benefited from large numbers of cars produced and very low cost per unit of output, a decade later Toyota had to concentrate on producing different types of cars to meet the already low demand of the Japanese market. This situation forced Toyota to focus on reducing production times and responding flexibly to customer demands, ultimately resulting in higher productivity and an efficient layout of production areas and assembly lines themselves. Increasing productivity and eliminating waste has enabled Toyota to remain competitive with mass production in the US and Europe (Ohno, 1988). Toyota's production system is linked to the lean manufacturing philosophy, in which all sources of waste are identified and eliminated. The different sources of waste are listed in Table 1 (Hines & Taylor, 2000; Nenadál, 2018).

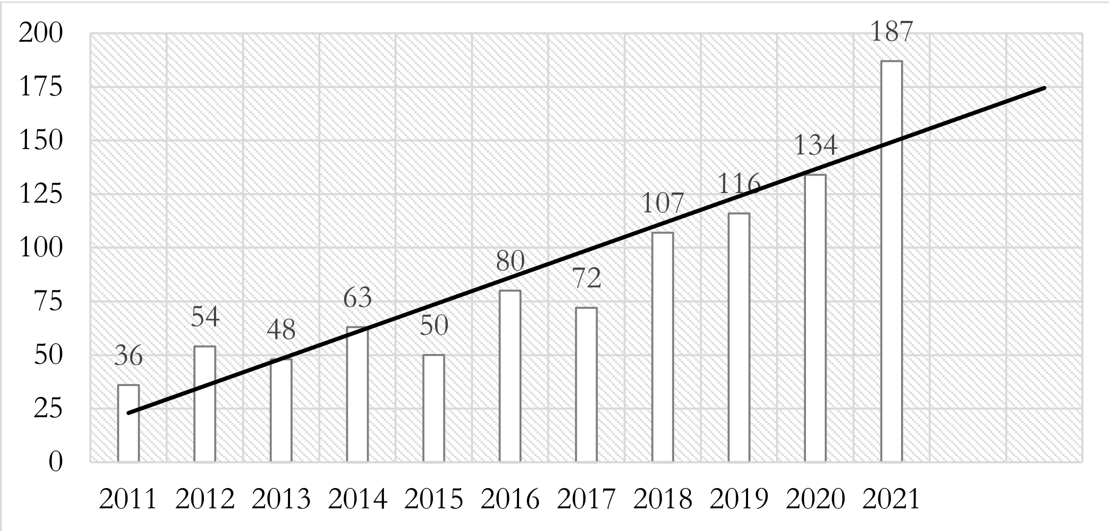
Table 1 **Types of waste**

Type of waste	Example
Overproduction	Production to stock, production of large quantities of products or at the wrong time
Defects	Quality issues related to input materila, products; production of products not meeting specified requirements
Inventory	Large safety inventory, information delays
Waiting	Waste of time, inactivity of people
Motion	Inappropriate workplace layout
Overprocessing	Processing that is not required, progression in work processes using incorrect tools
Transport	Wasting time and costs - moving people, information and products

(Source: Hines & Taylor, 2000, Nenadál, 2018)

Lean Manufacturing (also called Lean Thinking or Lean Management) is associated with speeding up processes, achieving efficiency and managing inventory (Womack & Jones, 1996). Combined with the Six Sigma concept introduced by Motorola in the 1980s to reduce process variability, the Lean Six Sigma philosophy emerges (Taghizadegan, 2006). The joint integration of these two concepts into the organization contributes to maximizing customer satisfaction through high quality products and services, reducing costs and waste and achieving higher organizational performance (Erdil et al., 2018). This concept has also gained the attention of the wider scientific community, where the keyword "Lean Six Sigma" alone can be used to find 947 documents in the Scopus database over the last 10 years (see Figure 2). A revolutionary approach called Lean Six Sigma 4.0 is currently being developed (Kharub et al., 2022) as well as exploring the relationship between Industry 4.0 and Lean Manufacturing. (Rajab et al., 2022; Ejsmont et al., 2020; Prinz et al., 2018; Wagner et al., 2018)

Figure 2 **Search results for "Lean Six Sigma"**



(Source: own, 2022*)*

To start any improvement effort, the key starting point is to specify the value of the product as perceived by the customer (Rother & Shook, 1999). Both the end user and the internal customer or the following process, can be considered as a customer. Considering this, how can we set up the material and information flow so that our customers get only what they need at the moment?

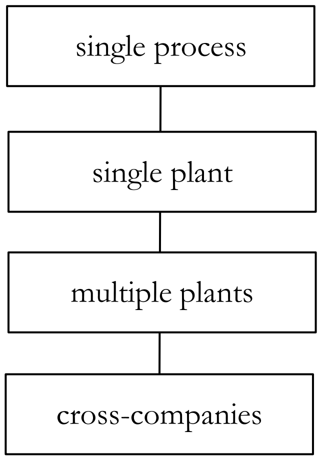
In parallel with Industry 4.0 element of digitalization, there is a demand for methods to improve the flow of data and information (Roh et al., 2019; Thiede et al., 2019). As one of the tools of lean manufacturing, value stream mapping allows us to track a product from the end customer to the supplier by visualizing the process and its material and information flow. The mapping is usually subjected to the current state and the future state, with an emphasis on value-added and non-value added time. Value-adding activities in the process are improved and non-value adding activities are eliminated (Taghizadegan, 2006; Rother & Shook, 1999). Today's manufacturing data and information practices are dominated by non-value added activities. However, most companies do not detect this waste. (Yarbrough et al., 2022)

VSM can be used both when introducing a new production line and when facing capacity problems, optimizing value flow or reducing variability of an existing production line (Roser, 2022). VSM is successfully used to eliminate waste (Kumar et al., 2018; Florescu & Barabas, 2018; Stadnicka & Litwin, 2019; Zahraee et al., 2020; Schoeman et al., 2020; Salwin et al., 2021) and supported Industry 4.0 initiatives (Hartmann et al., 2018; Martin et al., 2020, Arey et al., 2021; Klimecka-Tatar & Ingaldi, 2022; Ferreira et al., 2022). In contrast, VSM is not appropriate in the wake of quality issues, development of external suppliers, machine and equipment breakdowns, or employee morale issues. (Roser, 2022; Salwin et al., 2021)

Based on a survey of 90 Czech companies, it was confirmed that VSM is used for process improvement especially by large companies. From the perspective of small and medium-sized companies, it was concluded that there is a significant potential for usins this modern method of improving production processes. (Pech & Vaněček, 2018)

The idea of production flow mapping has been around since before Toyota. In the first half of the last 20th century, a book called Installing Efficiency Methods was published which offered diagrams very similar to those used today (Knoeppel, 1918). Learning to See, as a guide for implementing a VSM tool in a manufacturing organization, is considered a key publication focusing on VSM. It defines the concept of VSM and its related elements, draws up a map of the current state, defines the types of waste, draws up a map of the future state and lists the individual process steps in order to achieve the defined desired state of the monitored process. The process of value stream mapping begins with plotting the current state, followed by the development and execution of an implementation plan that lays out how the future state is planned to being achieved. Once this plan becomes a reality, the future state is plotted. The mapping levels are shown in Figure 3 (Rother & Shook, 1999).

Figure 3 **Levels of mapping the value stream**



(Source: own, 2022*)*

The VSM tool has been successfully implemented in various industries. Regardless of the nature of the final product, the expected outcome is the improvement of a sub-process, several downstream processes or complex systems. For example, the VSM method has been used to eliminate waste in a precast component manufacturing (Sirajudeen & Krishnan, 2022), to reduce the cycle time in the carton manufacturing business (Dinesh et al., 2022), to improve environmental performance of manufacturing organization (Garza-Reyes et al., 2018), and also in the healthcare sector, in order to design a patient-centered discharged process (Dittmer et al., 2021).

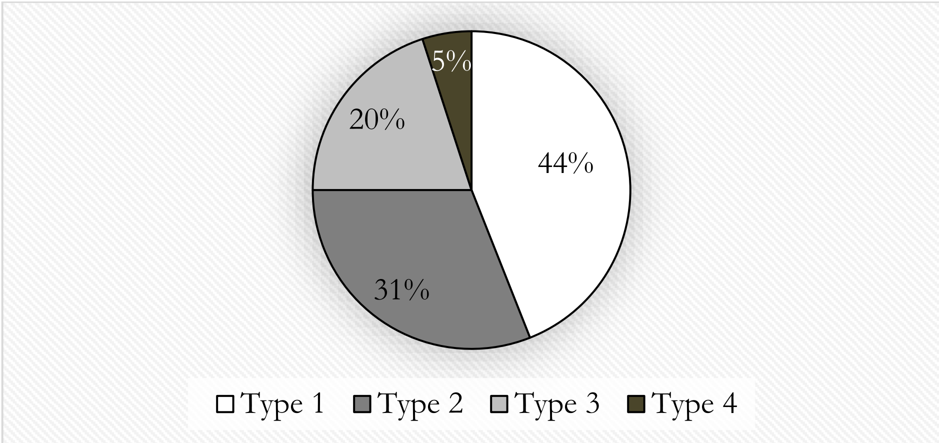
2 CASE STUDY

The subject of this study is the analysis of the assembly process of a turbomolecular pump representing an axial turbine in which rotating blades provide gas compression in the pumping direction. The selected model is manufactured in four sizes according to the pumping volume of the medium. Nearly 100 different pump variants are produced in this product family to enable end customers to always find the most suitable vacuum solution for their application.

2.1 Methodology and inuput data analysis

The analysis will be performed on data for the vacuum pump, which accounts for 44 % of the total number of units produced in the product family. The production share of each type is shown in Figure 4 (own). The maximum production capacity of the assembly line is 360 units per week. Based on customer demand, production forecast is to increase by 39 % units per week to 500 units per week in the second half of 2022, with a three-shift operation on weekdays.

Figure 4 **Share of production of individual types of pumps in the product family**



(Source: own, 2022*)*

Equation 1 expresses the takt time as the ratio of the available time for a given time unit and the required quantity of outputs for the same time period (Rother & Shook, 1999).

$$Takt\ time = \frac{available\ work\ time}{customer\ demand\ rate} \tag{2.1}$$

In the case of a three-shift operation, the available time is 1290 min (21.5 h), minus the statutory breaks and the regularly scheduled team briefings with a time pool of 75 min. The production runs only on working days (24/5). The operating time is therefore 6075 min per week, i. e. 6,75 h per shift.

After substituting into the formula:

$$Takt\ time = \frac{(1\ 290\ min - 75\ min\ )\ x\ 5\ days}{500\ pcs} = \frac{6\ 075\ min}{500\ pcs} = 12{,}15\ min$$

The time interval of 12.15 min expresses the target takt time for the production of one unit on a given assembly line.

Figure 5 (internal source) shows the current state of the value stream together with the defined process lead time, i. e. the time required to produce one unit, namely 1380 min (23 h), with 540 min (9 h) belonging to value-added activities.

Figure 5 **Map of current state for the assembly line**

(Source: own, 2022*)*

The assembly process, including testing, consists of 16 operations. Table 2 (own) lists some of them.

Table 2 **Partial technological process of the vacuum pump**

Process operation number	Name of process operation
10	Rotor Assembly
50	Stacking
70	Electrical Test
80	Claretest
130	Leak output
150	Finishing off
160	Vision System

(Source: own, 2022*)*

The longest operation is the rotor assembly, where the lead time for the production of one assembly is 165 min (2.76 h) and the operator time is 8.5 min.

The pumping speed and the compression depend on the rotor geometry and rotational speed, including the dynamic balancing of the rotor assembly, which is necessary to minimise vibration and noise.

2.2 Results

As a part of the follow-up preparation of the implementation plan, bottlenecks and areas for improvement are identified as a result of brainstorming sessions between project team members and assembly line operators. 40 opportunities for improvement have been identified in the form of changes that are a prerequisite for achieving the required capacity. Individual changes are categorized into 12 areas that reflect significant parts of the assembly process and supporting activities. Table 3 shows these major improvement areas, including the percentage of achievement (for the period June 2022). For each area a detailed action sheet with individual tasks is developed, including responsible parties and implementation dates.

For example, for the improvement of the washing process (part of area supplementing the capacity of machinery and equipment for assembly and final testing), the sub-actions of the action plan are shown in Table 4.

Table 3 **Improvement plant areas and percentage of completion**

Improvement area	Achievement of the target (in %)
Supplementing the capacity of machinery and equipment for assembly and final testing	85%
Increasing the number of operators on the assembly line	80%
Reduction of C/T process steps	100%
Reengineering - workflow modification and process reduction	100%
Operator training	100%
Workplace layout modification	90%
Kanban system implementation	100%
Automation of inter-operation inspection	20%
Changing the storage of packaging material	100%
Extending the poka-yoke system	60%
Material traceability	100%
Tool modification	100%

(Source: own, 2022*)*

Table 4 **Action plan steps for the washing process**

Improvement area	Partial action of the area	Partial action achievement (in %)	Target date (year-month)	Responsible
Capacity of machinery and equipment - washing equipment	Renewal od washing equipement	100%	2022-02	technical support
	Price calculation of the need for new baskets	100%	2021-11	purchasing
	Commissioning of new baskets for production	100%	2021-02	cell support
	Repair of existing baskets	100%	2021-02	cell support
	Redesign of problematice fixtures for washing machine	85%	2022-08	designer
	Construction of an inspection zone	50%	2022-08	R&D

(Source: own, 2022*)*

It is impossible to implement all improvement activities at once as they are very time consuming and some of them require significant financial investment. The individual items of the action plan are grouped into similar areas, called segments, which divide the implementation of the whole concept into manageable parts.

2.3 Discussion

In order to be ready for the announced customer demand growth, the output from the assembly line must be 500 units per week, i. e. 2000 units per month. Out of the 40 activities identified, 34 have been implemented, which is 80 %.

The defined framework is still in the implementation phase, but it is possible to summarize the expected benefits already at this stage.

Out of the 12 areas, representing the sum of the activities of the 34 sub-improvement steps, activities covering 7 areas have been fully implemented (see Table 3), the others will be fully completed by the end of 2022. Table 5 provides a comparison of the current and future state after completion of all activities mentioned in the implementation plan, where the value stream should be optimised and the process lead time reduced by 26 % from 1380 min to 1020 min.

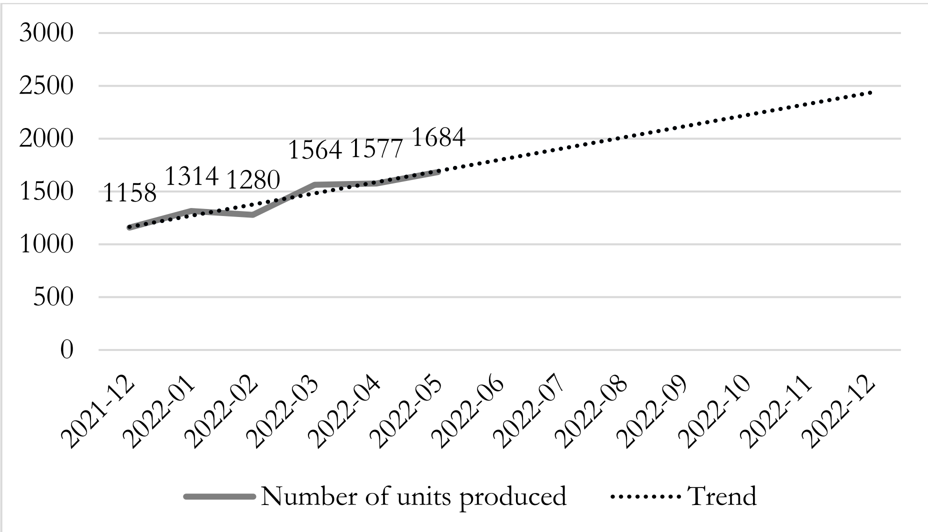
Table 5 **Comparaison of the Current state and Future state**

Description	Current State	Future State
Value-added time	540 min	450 min
Non value-added time	840 min	570 min
Process lead time	**1 380 min (23 h)**	**1 020 min (17 h)**

(Source: own, 2022*)*

The project was launched in December 2021, with 1158 produced units. In May 2022, the output was already 1684 units produced. The number of units produced in each month under review, including trend, is shown in Figure 6.

Figure 6 **Number of units produced and trend curve**



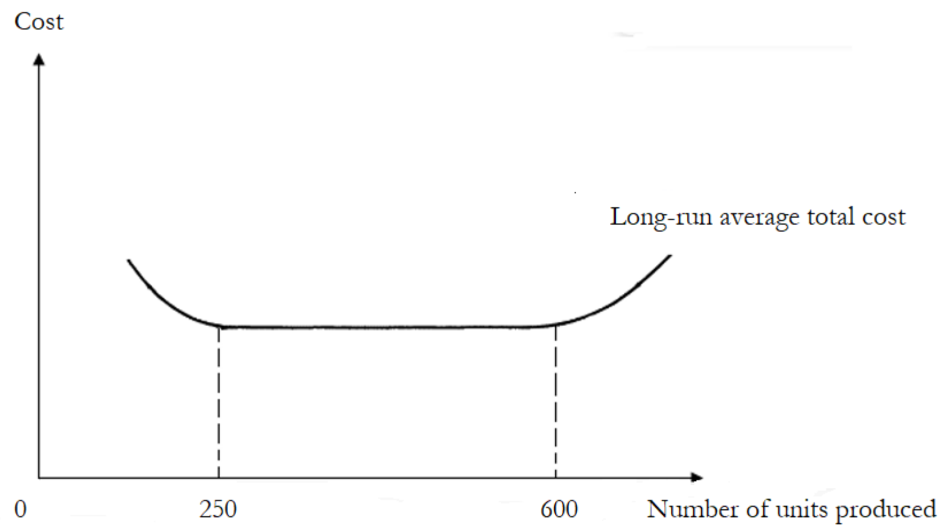
(Source: own, 2022*)*

The shortfall in output in December 2021 to February 2022 was due to material shortages faced by most manufacturing companies worldwide in recent months (Masters, 2022). The necessary material was secured towards the end of the first quarter of 2022. Next non-completed actions are supply of new machinery and equipment for assembly and final product testing, assembly operators hiring and last but not least expansion of the poka-yoke system and the automation of the inter-operation inspection.

An upward trend in the number of units produced can be observed from March 2022. According to the trend curve, the required number of 2000 units produced should be reached in August 2022. The target in that month can only be achieved if the assembly line is already equipped with all machinery and test stations, including the allocation of human capacity. If the defined future state is achieved, the organization's sales will be increased by 39 %.

In terms of the cost function, increasing revenues will lead to a reduction in production costs, i. e. economies of scale. These include, for example, depreciation of machinery and buildings, heating or workers' wages. It is well known that there is an inverse relationship between output growth and cost reduction. As the volume of units produced increases, the consumption of raw material will rise, but the prices of some items will remain constant or will experience only very slight price increases. The graph shows that positive effects can be achieved up to 600 units produced.

Figure 7 **Economies of scale in vacuum pump production**



(Source: own, 2022*)*

CONCLUSIONS

Based on the input data on the assembly process, the value stream was mapped, including determining the total process lead time and identifying value-added and non-value-added activities. Also, the takt time representing the time it takes to complete one product on a given assembly line, was calculated. An analysis was developed to optimize the assembly process, and 34 sub-activities were categorized into 12 key improvement areas.

A leaner value stream in the manufacturing organization was achieved by modeling the implementation of specified changes to reduce the production lead time from 23 h to 17 h. Project implementation started in December 2021, and the first positive economic effects of the improvement activities were already observed in March 2022. Before starting the project, the capacity of the assembly line was 360 production units per week, i. e. 1440 production units per month.

In March 2022, this value was exceeded for the first time, and the output was 1564 units produced. It would be possible to achieve the required output of 500 units produced in just nine months from the start of the project, assuming the completion of all defined improvement activities. Economies of scale are also evident, with a positive financial effect up to a production of 600 units.

For the purpose of further investigation, the VSM tool, as well as the defined improvement activities, can be applied to optimize the assembly process and other assembly lines. Thus, the knowledge gained in this study can be used to eliminate waste or improve the performance of the assembly process of a similar type of vacuum pump.

It is also possible to further explore the adoption of lean manufacturing philosophy in combination with the trend of digitalization, automation, and other elements of Industry 4.0, providing organizations with ideal conditions for increasing their performance and moving towards excellence.

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