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IMPROVEMENT OF THE PRODUCTION PROCESS OF AN AIR HANDLING UNIT BASED ON VALUE STREAM MAPPING

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Aneta Masternak-Janus[1] – *orcid id: 0000-0003-1622-3754*
Marta Moćko[2]
[1]Kielce University of Technology, **Poland**
[2] student at Kielce University of Technology, **Poland**

Abstract: Value Stream Mapping (VSM) is a visual Lean Manufacturing tool for graphically illustrating material and information flows in processes, on production lines, and even across a factory. It makes it possible to identify activities that do not generate added value, and thereby creates opportunities for improvement by reducing or completely eliminating waste. This paper explores a real-work case study of the production process for an air handling unit. Thus, after analysing the activities undertaken in an enterprise operating in the HVAC (Heating Ventillation Air Conditioning) industry, a current state map was drawn that shows the actual flow of the value stream. Then, a future state map was developed with suggestions for eliminating the root causes of waste and those for improving processes. The proposed improvements allow for shorter lead time and faster order processing, which may increase competitiveness.
Keywords: Value Stream Mapping (VSM), waste reduction, improvement, lead time

1. INTRODUCTION

These days, enterprises involved in manufacturing of the customised products are compelled to seek ways to reduce prices and to comply with customers' requirements within the shortest possible period of time, all with an intention to increase their competitiveness. Thus, more and more businesses decide to introduce the Lean Manufacturing concepts and tools which enable them to rationalise resources and to improve upon processes, flows and management. One of such tools is Value Stream Mapping (VSM) which consists in charting maps helping to determine what makes an added value to a business, and what is a waste to be eliminated or reduced. This method allows to develop the guidelines for counteracting waste, and as a result, it creates the basis for the use of other Lean instruments enabling to implement indicated improvements (Kruczek and Żebrucki, 2012).
So far, VSM has already proven effective in variety of businesses and industries to map both production and service processes (Seth and Gupta, 2005; Piercy and Rich, 2009; Morlocka and Meier, 2015; Rohac and Januska, 2015; Kowalik and Klimecka-Tatar,

2017; Agarwal and Katiyar; 2018). It can be successfully used to perform classical analysis for mass production as well as production of unique units, although in the latter case the maps have to be changed according to the products scheduled for manufacture. However, there are few examples of its application in HVAC (Heating Ventilation Air Conditioning) industry (Alves, Tommelein and Ballard, 2005). Until now, it has not been used to map production of air handling units to be tailor-made for customers.

An air handling unit is equipment used in mechanical ventilation systems for the purpose of air exchange, treatment and distribution within a facility. Depending on needs, it may filtrate, heat up, humidify, dry or even cool relevant premises. The requirements concerning parameters of air handling units to be installed in non-residential buildings and public utility buildings are set out in PN-EN 13053 (2020), and the requirements concerning air handling units for residential buildings are set out in PN-EN 13142:2013-08 (2013). As air handling units are used in buildings with various needs, they may differ as to performance, functionality and size. Whatever its manufacturer, they are most frequently composed of a few basic components, i.e. a casing, heat exchangers, fans, filters, heaters. They may also hold some additional components related to their functionality, such as coolers, acoustic dampers, steam humidifiers, water humidifiers, air ionisers, UV disinfection sections etc.

The purpose of this paper is to present possibilities for improvement of the air handling unit production process in a selected enterprise operating in the HVAC industry. Thus, a current state map has been developed to display actual flow of materials and information. Its analysis has allowed to identify any wastefulness occurrences and to indicate areas requiring adjustments. Due to the production being of a unit nature special attention was paid to the production order lead time which has to be as short as possible. The second map presents a value stream flow with suggested improvements. Once implemented, these may reduce the flow time in the enterprise and expedite any orders.

2. METHODOLOGY OF RESEARCH

2.1. Value Stream Mapping

Value Stream Mapping (VSM) is a method of graphical visualisation of any flows, both information and materials, carried out during production process, from a purchase order to the distribution of finished products (Klimecka-Tatar and Shinde, 2019). Standardised graphic symbols are used to mark such flows. Mutual relationships between the resources, functions and areas are determined by talking to employees and measuring times of individual actions and operations within a specific process (Dudek, 2016). Thus, a value stream map is created, divided to three sections (Muniyappa and Prasad HC, 2014):

1. Material flow, i.e. start point and end point of a product, a process description, material movements, existing stock, operators' details.
2. Information flow, i.e. communication in an entire course of a production process.
3. Time line, i.e. flow time along a production process, with the upper line showing total lead time, and the lower one showing total cycle time.

The present state map has been made to document actual state of processes in the enterprises. It allows to indicate the actions which add value and those which do not, including any actions which do not add value but remain essential (Dudek, 2016). It is important to ensure that the creation of this map is based on one's own observations and measures performed directly at the production line and not on the documentation available in the enterprise (Trojanowska, Kolińska and Koliński, 2011).

Next, a future state map is created that displays simplified flows by means of elimination of the root causes of waste (Rahani and al-Ashraf, 2012). While building it, it would prove worthy to take into account a few guidelines, i.e. manufacturing should be based on calculated takt time; if possible, pull system needs to be implemented, and if not, "supermarkets" should be used (Lisiński and Ostrowski, 2006). However, it should be remembered that any suggested improvements have to be adapted to a given type of production. For example, while the Kanban method is a good choice for products in serial production with high rotation rate, would not prove successful enough for unit production and customised products.

This paper presents the application of the VSM method in the production process of air handling units that are manufactured for an individual customer. Due to the above, the following stages have been carried out:

1. Inventory of data concerning the process.
2. Development of a current state map.
3. Identifying any problems and waste.
4. Proposing improving solutions.
5. Development of a future state map.

2.2. Data collection and process review

The enterprise under survey operates in production of large-sized air handling units with capacities in the range of 20 000 m^3/h to more than 100 000 m^3/h, which are tailor-made for customers. In an attempt to meet expectations of its customers, the enterprise offers options to provide various setups of functional components and their parameters while complying with all applicable legal regulations. Currently, there are also solutions being delivered which allow for efficient removal of fungi, bacteria or viruses (including Coronavirus 2019-nCoV).

Despite the fact that air handling units are designed in a customised way (with varied sizes and sections), all of them pass through the same workstations and are subject to the same manufacturing operations. As a part of the manufacturing process, the following operations are carried out: cutting, bending, welding, drilling, riveting and assembly. Table 1 shows all operations necessary to manufacture an air handling unit in standard setup and with basic sections which is mostly produced by the enterprise.

Table 1
Manufacturing process stages for a standard air handling unit

Stage	Operation	Cycle time [s]
Cutting	Cutting of profiles	270
	Cutting of metal sheet for joining elements	558
	Cutting of metal sheet for finishing elements	408
	Cutting of layered plate	780
Bending	Bending of joining elements	840
	Bending of finishing elements	750
Drilling and joining	Drilling holes	960
	Welding of structural elements	7560
	Riveting of structural elements	12600

Stage	Operation	Cycle time [s]
Assembly 1	Assembling of layered plate	4320
	Sealing	3360
	Assembling of heat exchanger	14400
Assembly 2	Assembling of fans and cabling	18000
	Assembling of filters	7200
	Assembling of heaters	9000
	Assembling of automation	16200
	Automation setup and check	7200
	Assembling of finishing elements and labels	9000

Source: own study

Once a purchase order is collected from a customer, the enterprise presents design background, most frequently within 2 working days. The investor is free to make appropriate adjustments within the next 7 days and, once finally accepted, such purchase order with design guidelines is provided to the production department. The lead time depends on to what extent customer's expectations deviate from standard available solutions (such as coating colour). Usually, a purchase order for a standard, medium-sized air handling unit is completed within 4 weeks. In case of purchase orders deviating from standard, production order lead time may extend to 8 weeks. Most frequently, 5 air handling units are completed per month.

The enterprise under analysis operates in a single shift system, 20 days per month on average. A shift lasts 8 hours, and overtime is applied, if necessary. During a single shift, employees are admitted to two 15-minute breaks, thus available work time is 27000 seconds (8h×60min×60sec–2×15min×60sec). Supplies of raw materials needed for production (sheets of aluminium, layered plates) are completed twice per month, while sub-assemblies (such as fans, filters, heaters, automation) are supplied by various manufacturers around 5 days before scheduled production start.

Machines and equipment used for production (guillotines for cutting sheet metal, press brakes, welding machines, cutting off machines for aluminium, hand guillotines and hand presses) are located in the production hall in groups, according to their function. The enterprise has implemented a system for simultaneous processing of a number of purchase orders, and any parts being manufactured are processed by the same equipment at different processing stages.

3. RESULTS AND DISCUSSION

To create a current state map, appropriate interviews and observations have been carried out in the enterprise. All of these have enabled to comprehend actual applied practices in manufacturing air handling units. The current state map (Fig. 1) includes the process stages, starting with admission of a purchase order from a customer, and ending with direct shipping of a finished product. The map holds all the data concerning work time, number of employees, existing stock, and any interconnections within the production system.

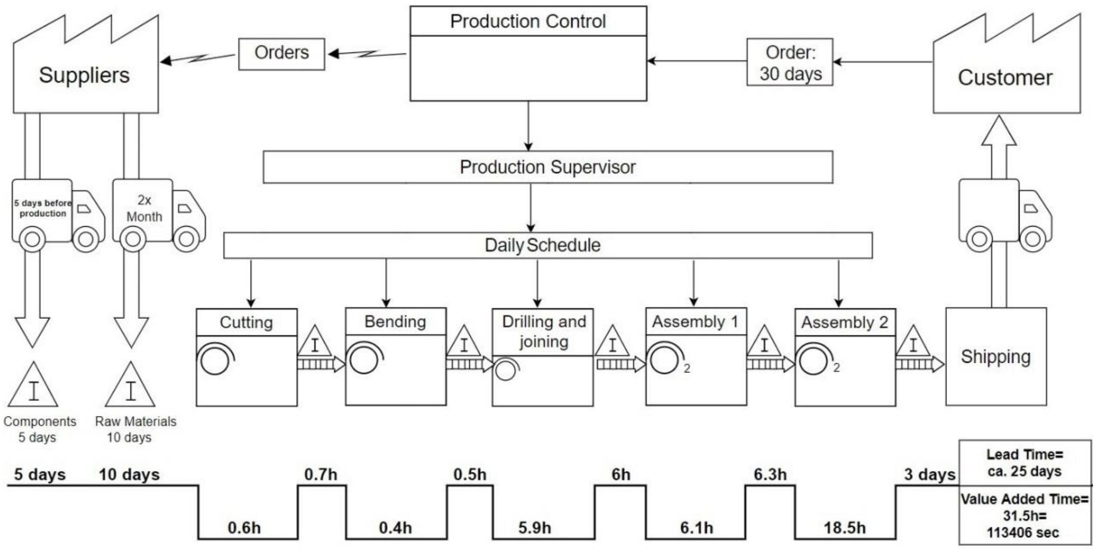

Fig. 1. A map depicting current state of the production process for a standard air handling unit
Source: own study

As shown in Figure 1, total lead time during production of a single air handling unit is around 25 days, and 18% of that time includes actions that add any value. Based on all analyses completed, and taking into account all information collected during visits at the production hall, the following problems in the production process of an air handling unit have been identified:

- large stock of materials, particularly raw materials for manufacturing,
- long waiting time for work in progress (WIP) before being moved to next stage, resulting in long time of the product's total lead time through the organisation,
- mistakes consisting in taking elements from previous work stations which do not apply for given order,
- unnecessary movement of employees resulting from deficiencies in assembly materials (silicon, screws, rivets) which need to be taken from storage during work.

To resolve the foregoing problems, the following improvements have been proposed, aiming to reduce production order lead time:

- to increase frequency of raw material supplies to four per month, with in-house transport, for example,
- to merge the Cutting workstation and the Bending workstation, resulting in a single workstation with a single operator,
- to use FIFO line,
- to schedule the cutting and bending processes,
- to establish a supermarket by the Assembly 2 workstation, to be used for assembly materials;
- to increase the number of employees at the Assembly 2 workstation to three persons,
- to carry out the Kaizen session to reduce time for shipping to customer.

Suggested improvements are displayed in the future state map, shown in Figure 2.

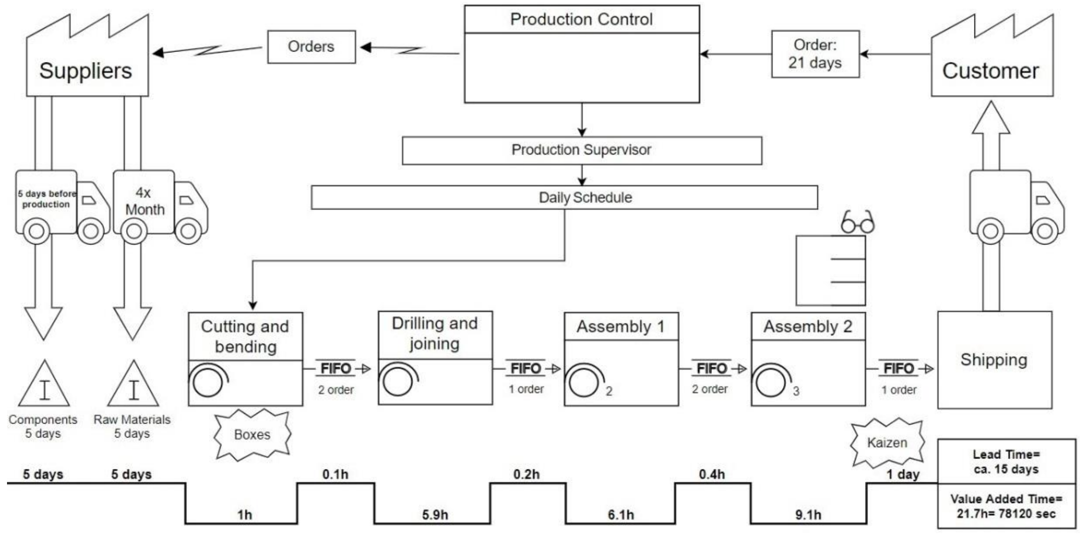

Fig. 1. A map depicting future state of the production process for a standard air handling unit
Source: own study

In the enterprise under research, a production process begins once a customer accepts design background for required air handling unit. A customer submits a purchase order well in advance allowing to purchase necessary materials once demand is recorded. All components for production are ordered and completed 5 days before an order begins to be processed, while raw materials for production are stored for 10 days. Therefore, raw materials are major cause for costs, such as storage costs. Due to the above, it is suggested to increase frequency of raw materials supplies to four per month, using in-house transport if necessary.

Another proposition involves merging Cutting and Bending workstations, establishing a single manufacturing cell, thus allowing to reduce unnecessary stock as well as waiting time and transport time. A single operator will be sufficient to work at these workstations. After manufacturing, the parts will be packed in specially marked boxes. This simple way should prevent any mistakes resulting from wrong collection of parts by a person from the next workstation.

The first process, namely cutting and bending, should be followed by application of the FIFO line. Once FIFO spaces are filled, the workstation delivering parts should halt production. It is also important to proceed to appropriate actions in the order of incoming purchase orders. The process of cutting and bending will be a stimulator for the entire value flow, and any semi-products would flow continuously through subsequent processes. By application of such approach, lead times between workstations will be reduced, and will only include transport times.

By the Assembly 2 workstation, unnecessary movement has been identified, related to the necessity of collecting assembly materials such as silicon, screws or rivets demanded on the workstation from storage. Such movement time is about 0.35h. The problem may be solved by establishing a supermarket. Thus, a small-sized rack would be enough to store assembly materials for the assembly processes, to be refilled with required items by a warehouse operator at least once per shift, to eliminate any need to interrupt assembly operations.

The product's lead time takes long time in the enterprise due to actions being carried out at the Assembly 2 workstation. To speed up operations, it has been suggested to

increase the number of employees to three persons. Thus, with two employees busy with assembling fans or filters, the third one could connect automation (valves, actuators etc.) at the same time.
Once assembled, an air handling unit is transported by a fork lift truck to the finished product storage (release area) where it may wait for up to 3 days to be shipped to a customer. Therefore, the Kaizen session should be carried out to reduce this time to 1 day.
Implementation of the above improvements would undoubtedly allow to speed up completion of standard purchase orders, and total lead time in the production process of an air handling unit would be reduced to around 15 days. Consequently, customers will be welcome to submit purchase orders 3 weeks before expected completion.

4. CONCLUSION

To ensure effective competition at the market, businesses have to comply with customers' expectations and requirements, and to reduce costs as well as to raise efficiency. To do so, they have to perfect their production systems and to ensure continuous improvement of operations. Value Stream Mapping (VSM) is an effective tool allowing to identify waste in in-house operations, and to design ways to reduce or eliminate it in the next stage. VSM may be applied at the level of a single process, a workstation, a production line or even an entire factory or a supply chain.
This research proposes to use VSM to identify any waste in the production process of a standard air handling unit which extend the lead time. Projection of current circumstances has allowed to develop guidelines for perfecting value stream flow such as using FIFO, involving additional installer and establishing single manufacturing cell. Once all suggested improvements are implemented, total lead time would be reduced from 25 to 15 days, thus allowing customers to submit purchase orders 3 weeks before expected completion time.
Finally, it should be added that proposed concept of the production process organisation for a standard air handling unit is only one of possible options, and should be an inspiration for more analyses, taking into account costs, production capacities and possibilities for standardisation of processes and workstations.

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