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Approach to Value Stream Mapping for Make-To-Order Manufacturing

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Abstract

This paper presents a new approach to the Value Stream Mapping (VSM), a proven tool of Lean Manufacturing (LM) in a Make-To-Order (MTO) manufacturing environment. The use of VSM in mass production has proven to be successful due to the predictable volume and repetitive product type. Within a MTO environment the product is tailored to specific requirements and varying volumes make it hard to balance production causing lean waste. The approach combines the classic VSM technique with commonality analysis to get a better understanding of the processes. Author illustrates this approach using a case study. Using VSM for MTO requires some changes to capture the attributes of product families required at different frequencies and volumes successfully.

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1. Introduction

Small and Medium Enterprises (SME) are continuously aiming to compete when it comes to the pricing of the products and reducing lead time. Time is money and using fewer resources could be a good strategy for an enterprise [1]. As described by Roberto Arbulu [2] shorter lead times are the main requirement of a customer in the manufacturing industry. Hence, a methodology to reduce the lead time and eliminate waste which would result in reduced production cost and faster Return On Investment (ROI) would be beneficial [3, 4].

Lean philosophy which is derived from the Toyota Production System (TPS) is the key to increasing productivity by eliminating seven wastes from production [5, 6]. Material and Information Flow Mapping referred to as “Value Stream Mapping” (VSM) is a method used by Toyota Production System (TPS) to represent the current product flow and the future product flow (ideal). VSM helps in identifying waste by depicting value-added time, non-value added time, the flow of the material, information and of the people [7]. VSM has been

a widely proven tool in a continuous manufacturing system where a single product is mass-produced over and over again [1, 7]. However, in Make to Order (MTO) environment each product is tailored according to the customer’s demand which means that it cannot be pre-manufactured [8, 9]. This could be an issue for the traditional VSM because of the fluctuating inventory levels with the customer demand and not all the products follow the same manufacturing path. The solution to this problem could be finding the common processes during the manufacturing using the commonality analysis. A detailed description about the commonality analysis is provided further in the paper.

A systematic approach is required to use VSM in the MTO environment. The objective of this paper is to use a case study based approach and demonstrate a methodology to use VSM for a MTO and intend to highlight some distinctiveness of the MTO environment. The approach in this paper uses commonality analysis to identify various common process which makes it unique. Upon the identification of the process various inefficiencies are identified.

2. Literature Review

2.1. Make-To-Order (MTO)

In MTO manufacturing the order is configured according to the customer's demand, which allows the company to stay competitive in the global market. According to Tyan [10], MTO is forcing manufacturers to reduce the lead time and speed-up product distribution. Since every order is original it could be hard to reduce inventories however Angappa [11] claim that by working closely with the suppliers an enterprise could work with zero Work in Progress (WIP) such as Dell (A well-known IT company) [11]. However, in case of low volume, highly variable demand and large product variety neither the original [12] TPS nor the pure takt time-controlled principle can be used [13]. For successful MTO, it is important to consider the varying demand, volumes, pricing strategies, product type and flexibility with the supplier to change the supply along with the consumer demand [11].

2.2. Overview of Value Stream Mapping (VSM)

As mentioned in the introduction, VSM is material and information flow mapping. It shows all the actions during the manufacturing process. A value stream can be defined as all the actions either Value Added (VA) or Non-Value Added (NVA) currently needed to bring a product through the full process, starting with raw materials and finally reaching the customer [7]. Eliminating all types of waste, reducing lead time and cost diminution after identification is the ultimate goal of VSM. VSM provides an inter-linked visual of information and material flow [14]. VSM is not a single process focused and as such it provides an overall picture of the production process, making it a powerful tool.

A VSM is drawn using a set of standardized icons as shown in Rother and Shook [7]. To make improvements in the production process, a snapshot of how things are currently being done called the current state map is drawn [14]. An ideal state map that shows the futuristic way of doing things is called the future state map.

Before making the future state map, one needs to be familiar with the basic calculations for future state mapping. A common term used in VSM is takt time. To achieve level production throughout the factory the concept of takt Time is used [4, 15]. The average pace of sales of a product over a specific time is represented by takt time.

$$Takt\ Time = \frac{T_s}{N_p} \quad (1)$$

In equation 1, T_s is shift hours and N_p is the demand of the products per shift. Takt time provides a figure that gives a sense of the rate at which a process should be manufacturing products [7]. Another term used in VSM is the efficiency of the manufacturing process which is given by:

$$Efficiency = \frac{v_A}{L_T} \quad (2)$$

In equation 2, V_A is the Value Added Time and L_T is the lead time of the manufacturing process [7]. The discrepancy between the conventional VSM and a MTO are as follows:

1. The traditional VSM is developed considering the constant inventory and also the Work in Progress (WIP) is measured in number of parts under progress in a process. This approach is suitable for the companies with standard product type. While MTS companies often produce low priced products with a simple structure, MTO companies typically have multi-part products with complex structures. While in the MTO environment number of parts in the inventory are highly fluctuating and product type is more complex [12].
2. MTS companies arrange their workstations according to the flow of the material as the processes to be performed on the product are mostly the same. But in a MTO company the flow of material is complex as it is governed by customer specifications. In MTO Company the flow is job shop arrangement. This kind of arrangement makes it difficult to identify operations being applied on a product family in a VSM.

2.3. Commonality Analysis

A very large portion of research in commonality analysis focuses on the inventory levels, the total cost of the system. Commonality analysis is a technique of data analysis that uses multiple linear regression. Regression commonality analysis provides a level of interpretation of regression effects that cannot be revealed when only examining the regression structure coefficient and standardized regression coefficient (beta weights).

Jianxin and Mitchell [16], defined commonality analysis as a number of components that are unique within a system when compared to the total number of components. The benefits of commonality analysis have been widely recognized when it comes to reducing inventory levels, reducing planned loads, product standardization [17, 18]. In this paper, the author introduces how commonality analysis could be used in a VSM with the Bill of Materials (BOM). A BOM is a list of all the components or sub-assemblies of a product, the list is used in production planning and inventory control [19]. The data from BOM could be collected from an Enterprise Resource Planning software which would provide product routes.

3. Methodology

The following sub sections provides a step by step methodology to develop current state and future state value stream map which is used in followed

3.1. Developing Current State Value Stream Map

1. **Developing product families:** Since every order is different due to the bespoke nature of the order from the customer, a concept of reconfigurable manufacturing systems can be used where the products can be classified into product families based on their weight, shape, size, changeover time, material type, etc [5, 7, 20].

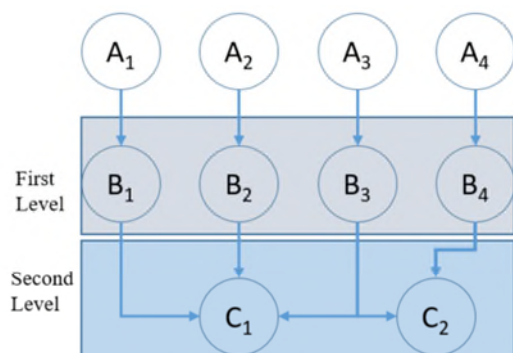


Figure 1. Structure of Bill of Materials. A: products, B: Molds, C: Shared Processes.

2. **Identifying common operations:** In this step, all the components from the BOM are laid out. Figure 1 shows a typical The most common process is identified using the commonality analysis [21]. Using commonality analysis over any other method would provide more precise data about routing of a product family as there could be shared sub processes or assemblies in a product family and also provides the most common operations that are being performed on that product family. The advantage of using this approach is that it provides the estimated lead time for each operation which could be later analyzed for continuous improvement purposes. There are various different algorithms available for this analysis. During this process Degree of Commonality Index (DCI) is calculated which provides a percentage of common or shared processes in the BOM [19].
3. **Creating the Current Value Stream Map:** The current value stream is created using the data gathered. As mentioned before, Figure 3 shows the current value stream map of the case company. The VSM points out all the bottleneck processes, inventories, cycle times, lead time, efficiency and information flow [7].

3.2 Future State Value Stream Map

Revealing the inefficiencies that are hidden in a value stream is the reason for developing a VSM. Once all the hidden inefficiencies are identified, a future state map showing the directions on how to improve the system can be presented. The following methodology could be used in order to develop the future state VSM.

1. **Calculating takt time:** Since the concept of pure takt time is not to be considered in MTO as it has a highly diverse product range and could be low volume as well hence an average takt time is more appropriate [22]. Thus average takt time is calculated [23].
2. **Creating a continuous flow between the processes:** Multiple factors could affect the continuous flow of a product on the shop floor such as unbalanced cycle times of each process, shared resources and the skills of

the operator. During this step, continuous flow is achieved wherever possible.

3. **Creating a pull-based system:** As described by Rother and Shook [7], creating a pull rather than a push system is highly recommended.
4. **Defining pacemaker process:** The pacemaker process is responsible for controlling the pace of the upstream by pulling the parts through. It also controls the process downstream by regulating the release of work or products to maintain First in First out (FIFO) processing flow to the customer.
5. **Levelling the production mix and volume:** There are various benefits of leveling the production mix. As suggested by Alves [8] and Rother and Shook [7], a variety of products are distributed evenly over a time period. Batching products during a production process might increase the lead time and could also increase the inventory between the processes. According to Fabian Bohnen [24], leveling the production would eliminate the three main factors i.e. waste, overburden and unevenness which are responsible for the loss of productivity. In MTO environment this could often be achieved by good forecast.
If the bottleneck process and pacemaker operation are two different processes then the capacity constraints must be taken into consideration while planning to level the volume upstream. Release of pre-defined work at a certain point in time i.e. pitch could be used to release work to the pacemaker process in order to control the pace of the work. Also, labor could be added to level the takt time with cycle time.
In high demand and low variety, supermarket scenarios could be also used to level the production volume.

4. Case Study

4.1. Current State Value Stream Map

This case study illustrates the use of VSM for the MTO environment. The company in the case study produces cast stone and has its manufacturing base in the UK. It manufactures

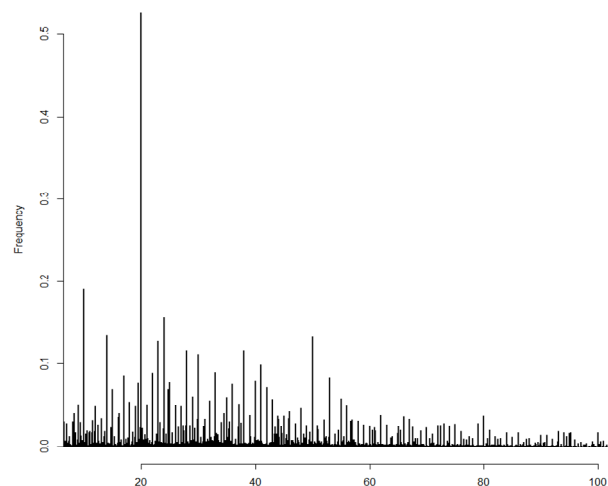


Figure 2 Sales data analysis from past 5 years

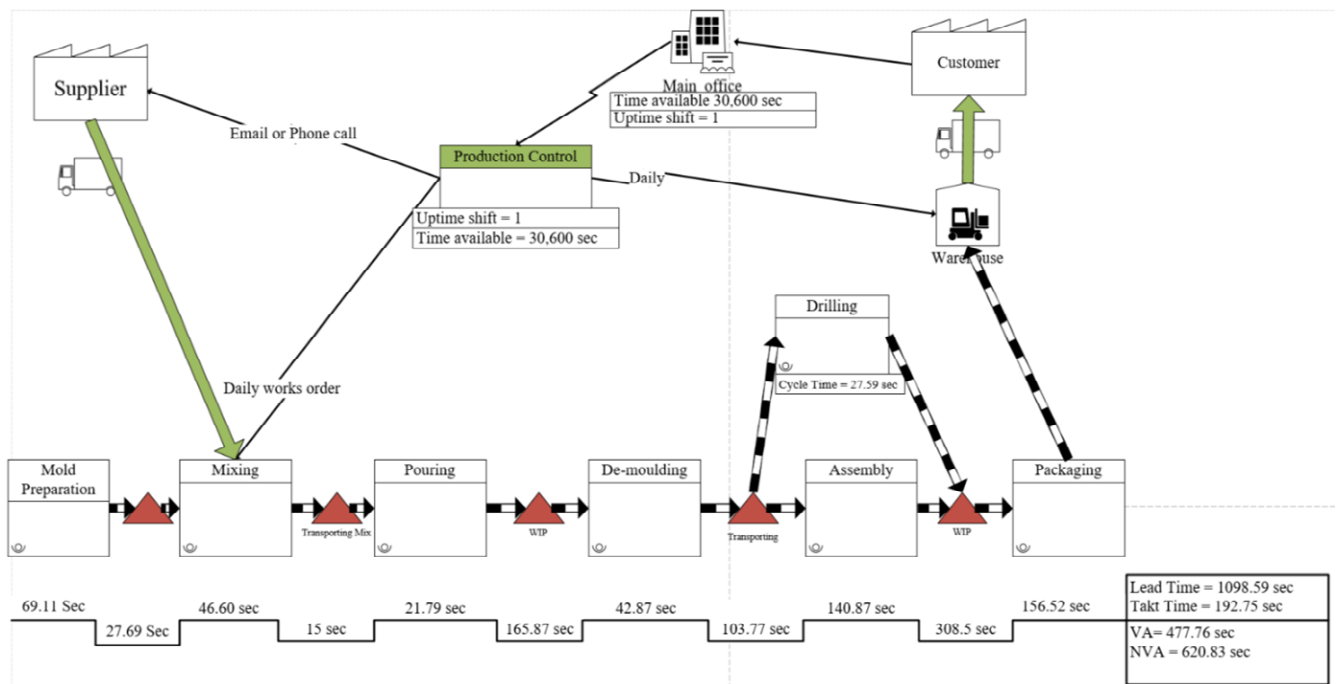


Figure 3. Current State Value Stream Map

architectural bespoke cast stone products. The VSM was developed on the basis of the real data collected from this cast stone company. One of the specifications of the cast stone is the weight. Firstly, products are divided into product family. In order to develop product families, products were classified on the basis of their weight in this case. Sales data from past 5 years was analyzed. The product family which was produced mostly was chosen for the VSM. Figure 2 shows that cast stone weighing 20 Kgs was produced more than any other type of stone. However as highlighted before, in MTO each order is different which could go through various different processes during manufacturing. For example, some products in the 20 Kgs product family might need an assembly but majority of them will not be needing an assembly.

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The value stream starts on the upper right corner when a customer contacts the head office with their requirements. After a customer places an order with the main office, it is sent across to production control. On the basis of the orders coming to the factory, production control orders raw materials from the suppliers. Production control then generates an electronic works orders. Works orders are sent to the shop floor which dictates the production for that day. The company runs one daily shift 8.5hrs and it is a batch-based production system. All the processes shown in VSM are explained below: All the products are manufactured in a batch production.

1. **Mold preparation:** During this process molds are cleaned and a release agent is applied to the molds.
2. **Mixing:** The production starts from the mixing process where a mix of concrete and additives is made.
3. **Pouring:** The wet concrete mix is poured into the molds.
4. **Demolding:** The casted stone is taken out of the mold
5. **Assembly:** During this process, multiple parts that are within the stone are put together.
6. **Packaging:** All the cast stone is packed during this process on a pallet against the customer order number.

The following observations from the current VSM could be made:

1. The waiting time before De-moulding process is high.
2. The packaging process take the longest of all i.e. 156.52 sec.

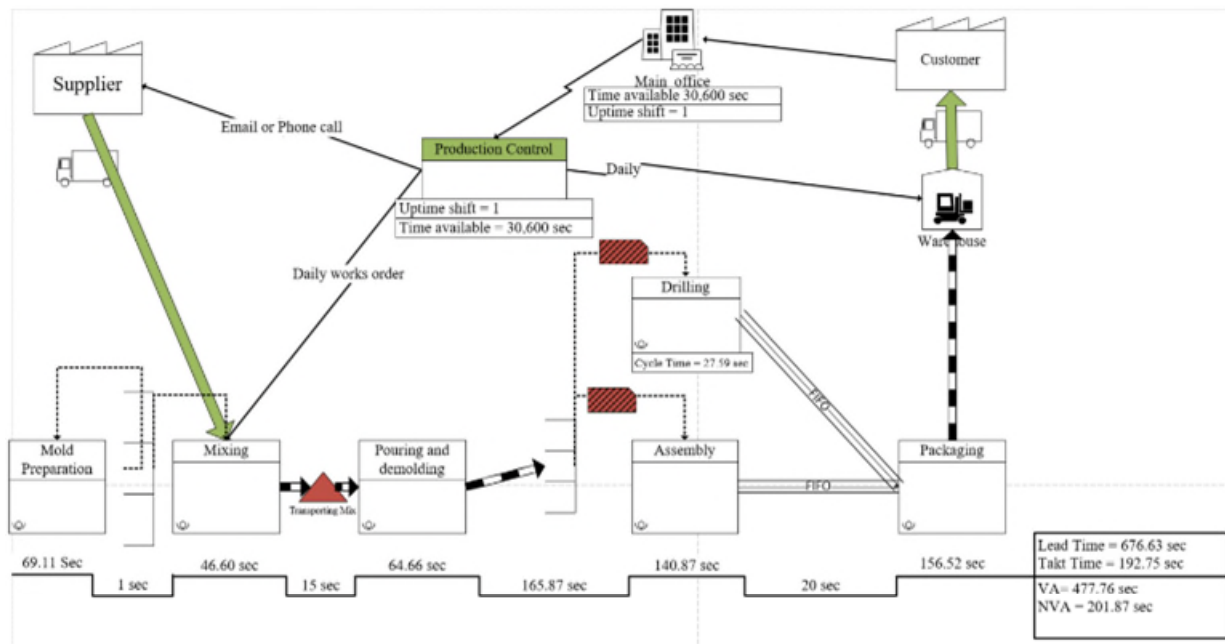


Figure 4. Future State Value Stream Map

3. The efficiency of the manufacturing process as per the current state VSM is 43.48% using equation 2.

Following the classical method of creating a VSM [7], the cycle time in the VSM is recorded in seconds. The current lead time is 1001.19 sec and the Takt time is 226.95 sec. In the current VSM, demolding is the pacemaker process in the value stream map as it controls the pace upstream. Some of the operations have been altered due to confidentiality.

4.2. Future State Value Stream

All the process shown in the current VSM (Figure 3) are well under the average takt time. As shown in Figure 5, the average takt time is 192.75 seconds which has been calculated using equation 1 by taking an average of the customer demand. As per the graph shown in figure 5, all the process are well under the takt time.

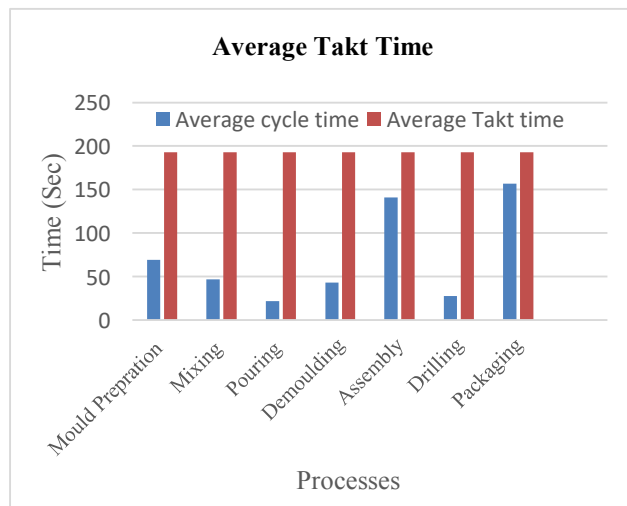


Figure 5. Average Takt time

The production type in this case is a batch production system. As described in the methodology one-piece should be achieved wherever possible. Supermarket system can be used after the mixing process to create a pull system. Using a withdrawal Kanban could also reduce the cycle time of a process. Future state VSM is shown in the figure 4. A Kanban is being used in the future VSM for signaling the operation to be performed on the product.

The future VSM shows a reduction in the Lead time from 1098.59 sec to 676.63 sec. Furthermore, the future state VSM also shows an increased efficiency from 43.48% to 70.60%.

5. Conclusion and future work

This paper presents a systematic approach to develop a Value Stream Map in a Make-To-Order environment. The approach presented in the paper has added one more step to the traditional methodology to develop future value stream which helps in better analysis of data. The commonality analysis uses preliminary data from the commonality analysis. Commonality analysis produces DCI which is used for mapping the value stream using the traditional approach. The commonality analysis provides data regarding all the shared operations which can be put into the Value Stream Map. The paper also reviews recent literature on how to create a lean future state map.

Finally, it should be noted that commonality analysis has been shown to be satisfactory and a thorough commonality analysis could be carried out as future work.

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