

VALUE STREAM MAPPING (VSM) IN A MANUFACTURE-TO-ORDER SMALL AND MEDIUM ENTERPRISE

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ABSTRACT

This paper discusses the Lean methodology of Value Stream Mapping (VSM) in a manufacture-to-order (MTO) environment. Within a case study of a mold making company the method is applied and improved. The purpose of VSM is to initialise the Lean transformation and to understand the value streams of a company as a basis for further improvements.

The paper explores the current literature about VSM and also discusses the specific characteristics of a MTO environment and its limitations regarding the application of the current VSM methodology. Based on this an adapted VSM procedure with a special focus on MTO small and medium enterprises is presented. The first adapted VSM analysis provided valuable insights into the material flow for the management team. Therefore it was decided to use this method in a modified way as a “Value Stream Monitoring” tool which observes the impacts of all Lean implementation activities.

Keywords: Value Stream Mapping, Lean Production, SME

INTRODUCTION

In recent years, value stream mapping (VSM) has emerged as the preferred initial methodology to implement Lean Thinking, both inside factories and at the supply chain level (Womack, 2006), (Hines and Rich, 1997), (Hines et al., 1998). Rother and Shook used their knowledge of Toyota practices to create a simple way for managers to see the flow of value and presented the VSM method in the Lean Enterprise Institute (LEI) workbook “Learning to See” (Rother and Shook, 1998). As Lean manufacturing aims to achieve a steady flow of small batches of components or products moving through the company based on the systematic elimination of waste and systematic problem solving (Flinchbaugh), the organization of the shop floor and the allocation of resources to tasks can have a significant impact on job lead time.

Research Objectives

The main target of this paper is the application and adaptation of VSM for a manufacture-to-order small and medium enterprise (SME) in its early Lean implementation process. As the implementation of Lean methodologies in SMEs is still under-researched (Achanga, 2005),(Green, 2004), this paper

summarizes the experiences gathered within a case study having a special focus on the batch-of-one environment as a special case of the MTO production.

Research Methodology

The research methodology entailed the use of both published literature and cooperation with RPM International Tool and Die, a NZ tool manufacturing SME (<50 staff members) that has already been in the implementation of Lean methodologies for about 20 months.

The research methodology consisted of the following steps:

- Literature research in the correspondent field of research
- Observations of shop-floor activities to get a deeper understanding of the specific “manufacture-to-order” characteristics
- Informal talks with staff members and team leaders
- Mapping the current state of one project
- Presentation of results in management meetings and discussion of future steps
- Evaluation of implemented measures

LITERATURE REVIEW

Definition of Value Stream and Value Stream Mapping

“A value stream is all actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of customer, and (2) the design flow from concept to launch.” (Rother and Shook, 1998). Monden (Monden, 1993) introduced three categories classifying operations as non-value adding (NVA), necessary but non-value adding (NNVA) and value adding (VA).

Value stream maps which are drawn with a paper and pencil, are originally called "material and information flow maps" presented as one-page diagrams depicting the process used to make a product (Womack and Jones, 2003). Not only the material flows are mapped, but also information flows that control these material flows (Rother and Shook, 1998).

Value stream maps identify ways to get material and information to flow without interruption, improve productivity and competitiveness, and help people implement systems rather than isolated process improvements (Womack and Jones, 2003). Therefore value stream maps support people to see waste that exists in processes, where waste is defined as an activity (Womack and Jones, 2003) or behaviour (Emiliani, 1998) that adds cost but does not add value. By eliminating waste one can concentrate on the value creating activities that customers desire.

Background of Value Stream Mapping

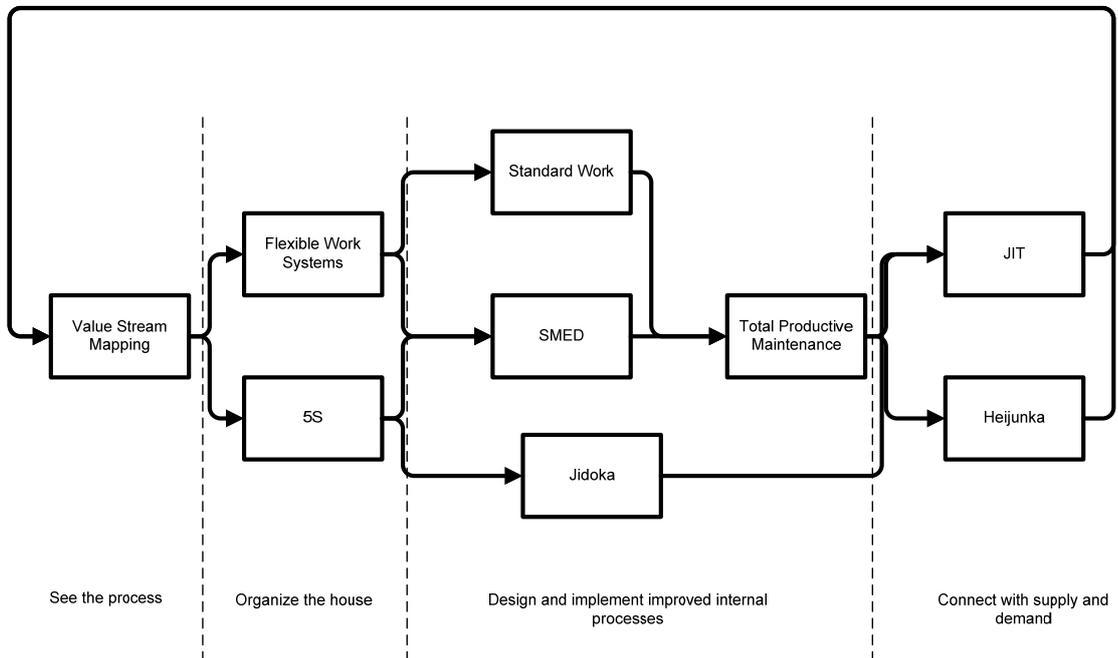


Figure 1: Typical process for Lean implementation (Rivera and Frank Chen, 2007)

Womack and Jones suggest in their Lean action plan (Womack and Jones, 2003) after firstly establishing a correspondent change agent, secondly embracing an initial theoretical understanding of the Lean principles and thirdly after finding a lever by seizing the crisis, to start directly with identifying the current value streams and mapping by product family. Rivera (Rivera and Frank Chen, 2007) presents VSM as the initial tool (see Figure 1) to start a Lean implementation which complies with the Lean implementation procedure presented by Womack and Jones (Womack and Jones, 2003). It needs to be mentioned that there is a slight inconsistency regarding the use of the terminologies presented in Figure 1. VSM, 5S, Standard Work and SMED must be seen as tools respectively as methods, whereas the expression Total Productive Maintenance (TPM) embraces a strategy that supports the purpose of equipment improvement to maximize its efficiency and product quality (Willmott and McCarthy, 2001) which consequently implies the above mentioned tools and methods. In this context Ahuja (Ahuja and Khamba, 2007) mentions for example the introduction of 5S within a TPM implementation program.

VSM supports the understanding of the value stream as a whole and reveals opportunities for improvement and the priority as well as the first destination of further measures, e.g. the implementation of 5S methodologies.

Emiliani (Emiliani, 2004) adapted VSM for determining the beliefs, behaviours, and competencies possessed by business leaders. This adapted VSM tool can be used as a diagnostic tool to identify leadership problems and pathways for improving leadership effectiveness.

Procedure of VSM

The first step before starting the mapping is to identify the product families. Womack defines a product family as a “group of similar items that proceed through the same basic steps and equipment within the organization” (Womack, 2006). As a second step Womack emphasizes to determine the current problem(s) with the value stream, e.g. within an A3 analysis. An A3 analysis is a standardised report form used by Toyota to systematically document problems and their solutions on one page of an A3 sheet. Afterwards the development of the current state map is ideally conducted by a multidisciplinary team where participants should be from the whole value stream. Special attention must be paid whether every process step is:

- Valuable (out of the perspective of the customer)
- Capable (process capability)
- Available (utilization of equipment)
- Adequate (machine capacity)
- Flexible

The final step of mapping the current state is measuring the throughput time of the value stream.

Finally the future state map can be created focusing mainly on the following improvement areas (Womack, 2006):

Value: Every step must be analysed whether it really adds value to the product or service.

Create continuous flow: By connecting manufacturing processes (whenever possible) throughput time can be dramatically reduced which reduces consequently costs.

Levelling the output of the value stream: Womack suggests to identify one spot along the value stream, the so-called pacemaker step where customer orders are transformed into production instructions. It is essential to create a standard inventory at this point to “operate in a level, smoothed manner, using first-in/first-out (FIFO) scheduling downstream from the pace-maker and pull signals upstream.” (Womack, 2006)

Liker (Liker and Meier, 2006) emphasizes that the real benefit of value stream mapping lies in creating a true ‘system’ based on the flow of materials and information across the entire value stream instead of isolated point kaizen.

Braglia (Braglia et al., 2006) developed a new value stream mapping approach for complex production systems. He developed the following “Improved Value Stream Mapping” (IVSM) procedure, which addresses the problem of complex production processes characterized by multiple flows that merge:

- select a product family;
- identify machine sharing;
- identify the main value stream;
- map the critical path;
- identify and analyse wastes;
- map the future state for the critical/sub-critical path;
- identify the new critical path and iterate the process.

Bozzone (Bozzone, 2002) emphasizes the reduction of lead time for job shops as the equivalent of the reduction of inventory in a mass-production environment. He concludes that one of the main strategies during a Lean implementation of a MTO company should be the reduction of lead time. Goldratt (Goldratt, 1997) describes the analogies between the lead time of projects and the inventory of a mass-production. The production of complex products having a batch size of one can be conducted in a Project Management approach.

Alves (Alves et al., 2005) et al. investigate the use of VSM for manufacture-to-order products in a job shop environment. They conclude that VSM for a job shop environment has to be flexible to deal with

its dynamic nature. Within a case study, specifically the fabrication of Heating Ventilating and Air Conditioning, the authors present a VSM for the fabrication of sheet metal ducts.

CASE STUDY AND APPLICATION

Characteristics of a manufacture-to-order environment

For a better understanding of the specific characteristics of a MTO environment, the following differences to a mass-production company could be identified by the authors:

Changing customer takt (dependent on required shipment date)

As a rule, every product is unique or at least identical products are manufactured rarely. Therefore also the requirements of the customer vary from product to product, including the required shipment date. That is why a levelled customer takt and in consequence the FIFO principle in comparison with the mass-production is very difficult to realise. Besides cycle times are often not known at the beginning of a project because of the uniqueness of the correspondent components. Therefore it is quite difficult to implement pull principles and tools (e.g. KANBAN) between the different production stages.

No clear material flow

Every product can consist of a different number of components and also the components themselves are different with regards to the necessary manufacturing processes and manufacturing cycle time.

Slightly different definition of Work in Process (WIP)

Several authors stress that decreasing the level of inventory is a crucial principle of Lean thinking (Liker and Meier, 2006),(Womack and Jones, 2003). Because every product is manufactured according to an order of a customer, there is no inventory in terms of finished products. Furthermore, because of the uniqueness of the products and their components, raw material is mostly purchased project-oriented. Hence, the existing level of raw material inventory can also be neglected in this case study. Though, taking semi-finished parts between manufacturing processes into account, a slightly different definition of WIP in a manufacture-to-order company is necessary.

Different loads on processes, no clear pitches (work units)

As already mentioned above the work loads of the processes vary because of the changing cycle times which are also difficult to forecast. These accuracies of forecasting and the wide standard deviation of the process duration (e.g. in our case study the cycle time at the CNC machines can be between several minutes and up to 40 hours) also exacerbate any standardization efforts towards clear pitches.

Dynamic scheduling / many changes

According to the already mentioned characteristics, scheduling is dynamic involving many changes during a project's progress hindering a proper balance of the workflow through the production.

Quantification in a manufacture-to-order environment

To illustrate the specific characteristics of a manufacture-to-order environment the example of the production of an injection molding die is presented in the following. The production of injection or press tools can be seen as a special case of the manufacture-to-order environment.

Usually an injection molding die consists of standard vendor parts (e.g. screws, where no further treatment is required), semi-finished parts (e.g. guide pins, ejector pins that need to be fitted to the

required size) and unique components (e.g. those defining the cavity). Latter components can usually pass several manufacturing steps:

- rough cutting of raw material
- heat treatment
- wire-cutting and/or CNC machining of the cavity details
- grinding
- sparking
- polishing

These manufacturing processes can be generalized with the index

$i := 1; 2; 3; 4; \dots$ number of the manufacturing process with $m :=$ number of processes

The different components are defined in this example as:

$j := 1; 2; 3; 4; \dots$ number of the component with $n :=$ number of components

According to this definition the component $j=1$ can pass through the manufacturing processes $i=1, 3, 4, 6$ (see Figure 2). The manufacturing processes $i=2$ and $i=5$ (e.g. heat treatment and sparking) are not necessary. Figure 3 illustrates that several components ($j=1, \dots, 6$) need different cycle times in the process $i=1$ (e.g. rough cutting the raw material).

The necessary manufacturing time for the component j at the process i can be summarised as:

$$T_{ij} = t_{S,ij} + t_{P,ij} + t_{Q,ij} \quad \text{with}$$

S: Setup time

P: Processing time (actual value adding time)

Q: Queuing time (time between two processes minus the setup time)

The total necessary manufacturing time for the component j for all processes can be summarised as:

$$\sum_{i=1}^m T_{ij} = T_{Tj} \quad (\text{Index T means Total})$$

The component being on the “critical path” and constrains the total manufacturing time of the whole die can be characterized with:

$$\max\{T_{Tj}\} = T_{Tj,\max} \quad \text{with } j=1; 2; 3; 4; \dots; m \text{ and } m := \text{number of parts}$$

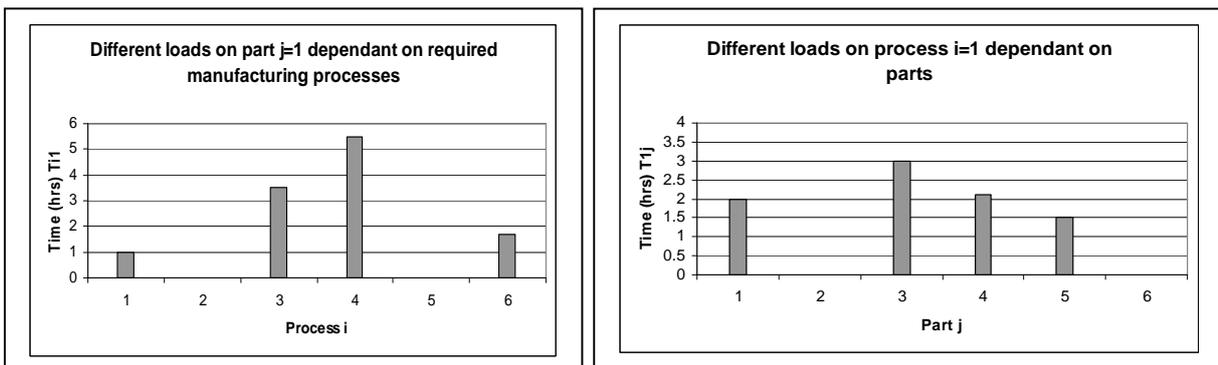


Figure 2: Process time of several processes for part $j=1$, Figure 3: Process time of several parts in the process $i=1$ e.g. rough cutting

These characteristics were determined during observations of the shop-floor activities, a detailed process analysis, and interviews and informal discussions with the management team of the industrial partner.

Additional constraints affecting not only manufacture-to-order companies but also SMEs in a wider sense are (in comparison with a larger company):

- less resources
- several functions are held by one person
- no investments in complex ERP systems

Adaptation of VSM methodology to the manufacture-to-order requirements

Because of the explained differences of a batch-of-one respectively manufacture-to-order environment to mass-production, the VSM methodology needs to be adapted.

In case of a complex product consisting of several subassemblies and components, it proved to be reasonable only to map the components on the critical path. Those components can also be called bottleneck components as they constrain the overall lead time of the project. It needs to be mentioned the difference between bottleneck components and bottleneck resources which constrain the throughput of a company (Goldratt, 2004). In the case study, several components that were supposed to have the longest processing time were mapped, because processing time could only be estimated at the beginning of the mapping process. As a manufacture-to-order product is most probably produced only once in exactly this configuration, the VSM focuses on one project and the observation follows the material flow of the components on the critical path downstream rather than from ramp to ramp upstream.

It is differentiated between three types of time [minutes]:

- cycle time (P): the time where value is added to the component e.g. the cutting time.
- changeover, respectively set-up time (S): the time that is needed from the processing end of the preceding component until value adding time begins (e.g. loading the CNC machine, setup of the component).
- waiting time between processes (Q): the time where neither value is added to a component nor a setup process takes place for that component. In the case study the waiting time was only captured from 7:30am to 4:30pm from Monday to Friday.

The total manufacturing time is defined as the sum of these three categories.

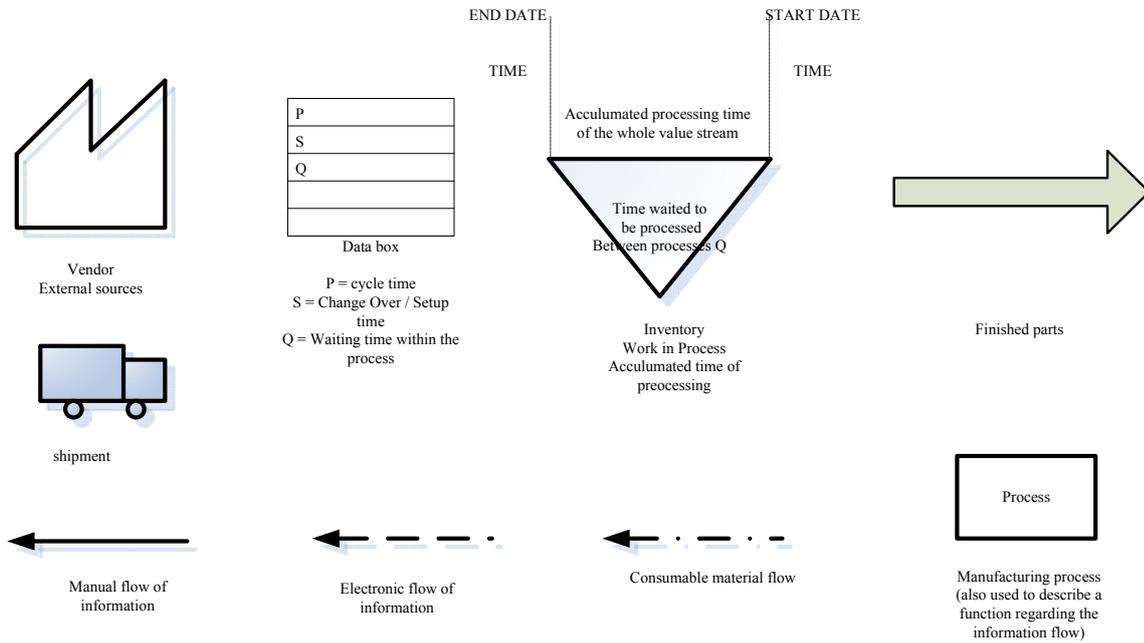


Figure 4: Used symbols for VSM

The VSM symbols of Rother and Shook (Rother and Shook, 1998) (see Figure 4) are mainly used. As in a MTO environment there is generally no inventory between the processes, the symbol of a triangle is used to document the waiting time between two processes. Additionally to monitor the WIP at every process step, the accumulated processing time of the observed component is written on the top or the bottom of the triangle. Potential rework is treated as waiting time during a mapping process and the calculation of the performance indicators V and I (described below) because it does not add any value to the product.

Davis and Heineke (Davis and Heineke, 2005) define “Process Velocity” (V) as total throughput time divided by value added time. Regarding only those components with the longest processing time, this ratio can be adapted to the manufacture-to-order environment as follows:

$$V = \frac{T_{Tj}}{\max \left\{ \sum_{i=1}^m t_{P,ij} \right\}}$$

Another ratio respectively indicator, the Relative Flow Velocity (I), was used in the case study to emphasize the improvement potential concerning the overall lead time, if the waiting time can be reduced, and is expressed as:

$$I = \frac{\sum_{i=1}^m t_{Q,ij}}{\sum_{i=1}^m (t_{P,ij} + t_{S,ij})}$$

This indicator proved to be comprehensive during discussions and is to be used for all major projects. It clearly shows the ratio of the waiting time Q to the manufacturing time (processing time t_p + setup time

t_s). This indicator clarifies the degree of synchronisation of the process chain. The ideal value is $I=0$, which means, there is no waiting time between the manufacturing processes of an observed component, i.e. the component flows through the whole value stream without any interruptions. Further improvements can be achieved by reducing the setup time t_s which leads to a reduction of the index I as well. This index used in early stages of a Lean implementation also encourages to consider the improvement of the whole value stream instead of local efficiency improvements.

The following procedure was developed in the case study based on the VSM procedures presented by Rother (Rother and Shook, 1998) and Braglia (Braglia et al., 2006):

1. Select a value stream and a project
2. Identify the components on the critical path
3. Identify the merge activities (if applicable)
4. Map the components on the critical path
5. Identify and analyse wastes
6. Detect the root causes for the wastes
7. Set target scores for “Process Velocity” (V) and/or “Relative Flow Velocity” (I)
8. Develop countermeasures to reduce waste (future state map) and achieve the target scores
9. Iterate the process (ideally with similar projects)

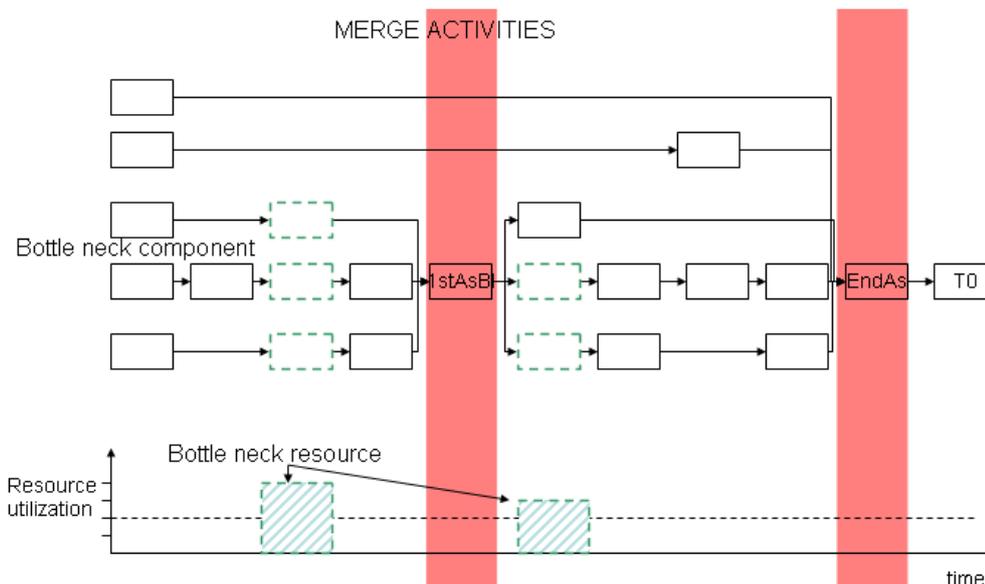


Figure 5: Schema of merge activities

Figure 5 schematically shows the merge activities (highlighted by the grey beams, 1stAsB: first assembly; EndAS: End assembly, T0: First trial of tool) during the production of a plastic injection mold. Merge activities are processes where at least two components are needed at the same time (e.g. adjustment). After a merge activity components can either be processed separately again or in a subassembly. Each row symbolises one component except where a merge activity takes place. Every box represents one process step. Additionally the dashed boxes demonstrate a process with shared resources (e.g. CNC machine), which can lead to bottlenecks in the capacity. The diagram at the bottom of Figure 5 schematically points this out by showing the utilization of one resource (in this

example one CNC machine) which is needed twice for at least two components at once. This constraint must be taken into account during scheduling so that merging activities are not delayed. Countermeasures can be for example either to manufacture one of the components externally or to start one of the components earlier. The horizontal dashed line represents the maximal possible capacity utilisation of this resource. It must be emphasized that the component(s) on the critical path can change from one merge activity to the other. It is important to identify those merge activities at the beginning of the project, because they should be the pacemaker respectively control points of the project schedules. If there is waiting time of the component(s) on the critical path before a merge activity, the reasons for that must be analysed. Possible reasons can be in this example:

- other components need a longer processing time
- the waiting time of other components was extensively longer
- long or even delayed delivery of vendor parts
- rework on other components

Analysis of current state map

In the following the adapted VSM approach is presented within the case study.

1. Select a value stream and a project

The first step is the identification of the existing value streams and its product families. The following main value streams could be identified:

- Designing and manufacturing new injection tools
- Designing and manufacturing new press tools
- Service of plastic tools
- Service of press tools
- Random CNC jobs

As the main turnover of the company is achieved by the production of injection tools, the value stream of manufacturing a new plastic tool is selected for the first VSM. The main manufacturing processes and the scope of the first analysis (see the frame) are shown in Figure 6. Heat treatment is the only process that is done externally in the case study. Additionally the chosen project is in a certain price range. The cavity inserts are considered to be on the critical path. Therefore all components defining the cavity were mapped.

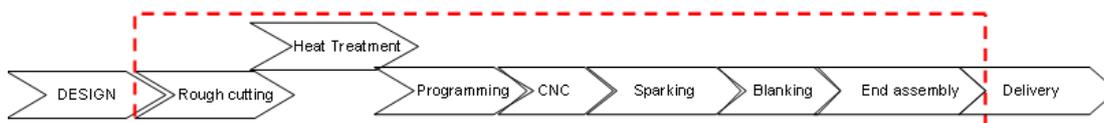


Figure 6: Scope (dashed line) of the Value Stream Map

2. Identify the components on the critical path

As a tool can consist of several hundreds of parts, it is essential to monitor those components defining the critical path. These components determine the required minimum lead time of the whole project. As a rule, the components defining the cavity require the most manufacturing time. Therefore and because of the fact that the critical path can change, e.g. in the case of rework, several components that are part of the cavity are mapped.

3. Identify the merge activities

The merge activities in the case study are at the end of the production (blanking and end assembly). Therefore there was no switch of components on the critical path.

4. Map the components on the critical path

Figure 7 shows the VSM of the component on the critical path. The manual information flow is coordinated by the production manager and the team leader. One manufacturing step was done externally (heat treatment). Processing time (t_p), setup time (t_s) and queuing time within the process (t_q) are written in the data box. Although the process of machining electrodes does not belong to the value stream it is added to the map, because the process ‘sparking’ cannot start without electrodes.

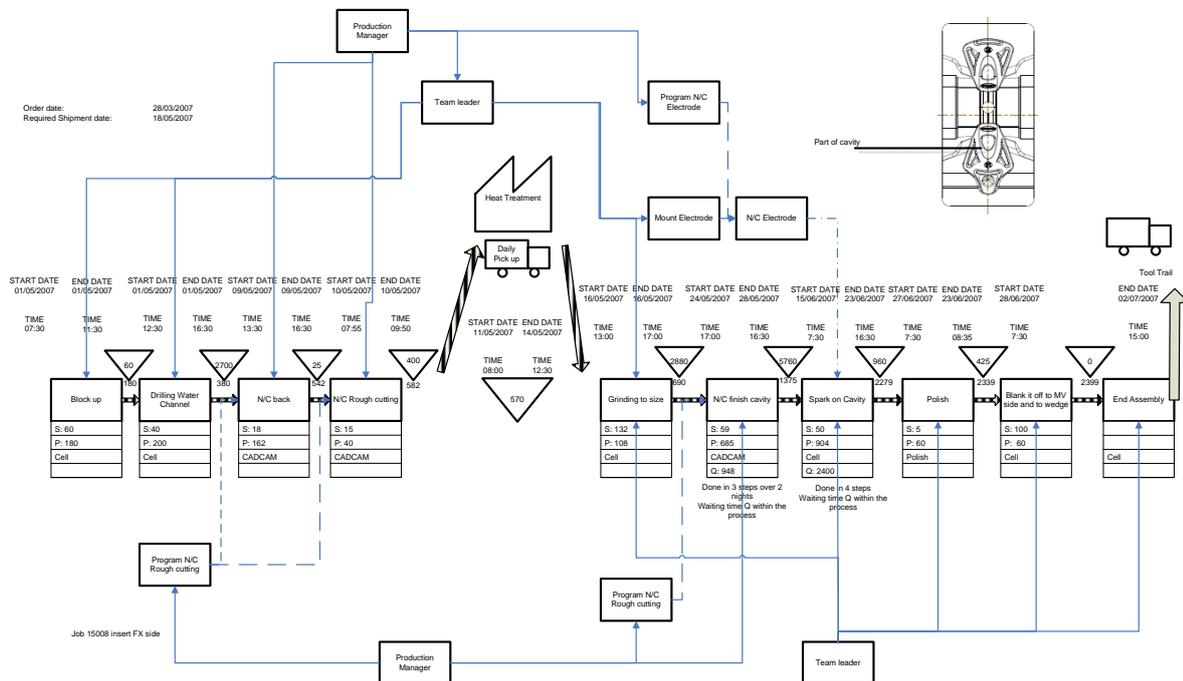


Figure 7: Current Value Stream Map of an insert

5. Identify and analyse waste

Table 1 contains an analysis of the waiting time and the calculation of the indicator ‘Relative Flow Velocity’ I were conducted to identify the main waste.

Table 1: Results of first VSM (times in minutes)

Processing time Σt_p	2399
Setup time Σt_s	479
Waiting time Σt_q	17128
Relative flow velocity I	6.0
Process velocity V	8.3

The following observations could be made:

- The waiting time of components on the critical path is significantly higher ($I=6.0$) than the actual process time. There is a restricted flow of “bottleneck” components.

- The waiting time before the CNC machines takes 33% of the total manufacturing time. CNC machines seem to be the bottleneck capacity, which could be confirmed in the subsequent value stream analysis.
- The waiting time before the sparking process is high.

6. Detect the root causes for the waste

After the first VSM, the results were discussed during a management meeting. All agreed that possible reasons for the long waiting time in front of the CNC machines are a lack of systematic decision criteria to prioritise workload of the bottleneck resources and to level out capacity fluctuations as well as physical capacity constraints. One reason for this is the limited transparency of the job durations which weren't estimated and considered within the scheduling system.

The waiting time before the sparking process is high because the electrodes weren't machined simultaneously. Electrodes also need to be processed by the bottleneck resource 'CNC machine'.

7. Set target scores for "Process Velocity" and/or Relative Flow Velocity (I)

In the case study the first target score for the Relative Flow Velocity (I) is set at I=2 (see Figure 8) and was continuously monitored over the following value stream analysis.

8. Develop countermeasures to reduce waste (future state map) and achieve the target scores

New projects must be scheduled based on the TOC approach (Goldratt, 1997) to manage especially the bottleneck resources. As the CNC machines are the bottleneck resource, the developed scheduling system uses the CNC machines as the pacesetters. The developed scheduling system must include decision criteria regarding the urgency and importance of the tasks and the CNC schedule must be visualised on planning boards. A weekly planning meeting must take place to evaluate the foreseeable utilisation (e.g. 2-4 weeks) of the bottleneck resource. Therefore estimates for the job duration on the CNC machines are necessary. These estimated durations must be compared afterwards with the consumed time.

This guarantees timely preventative actions to level out the workload (e.g. the use of external CNC resources). The team leaders coordinate the work within the cell according to the CNC schedules.

The work procedure and the job instructions between CNC operator and CNC programmer need to be improved and standardised.

Besides this, further improvements regarding setup reductions are required.

9. Iterate the process (ideally with similar projects)

A similar tool was monitored to evaluate the effects of the first countermeasures (see Figure 8), which are still in progress.

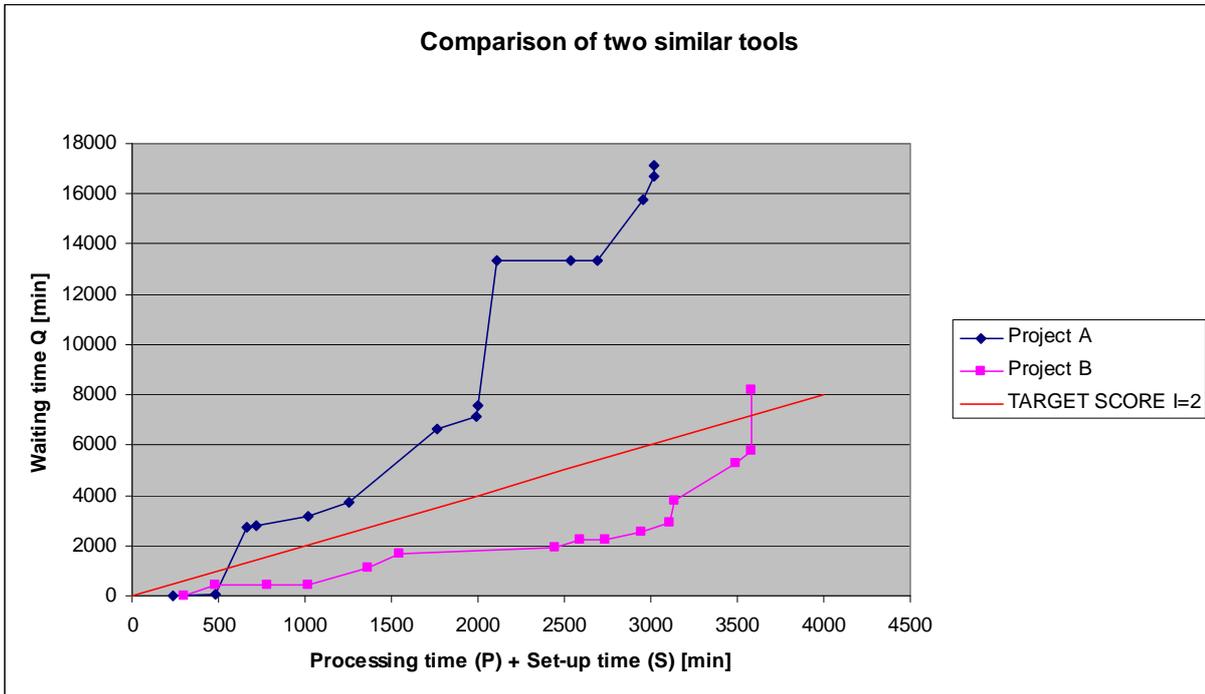


Figure 8: Monitoring the relative process velocity

Figure 8 shows the waiting time and the manufacturing time (processing time + setup time) of the first VSM project respectively its component on the critical path (project A, marked with rhombus). The gradient of the graph is equal to the indicator 'Relative Flow Velocity' I . Additionally a second VSM project (project B, marked with squares) is shown that was done after the first improvements evolved out of the first VSM project. Because of the fact that the projects are very similar (similar tool, there are only small deviations in the shape of the cavity, which do not influence the sequence of manufacturing processes and only have a slight impact on the processing time), this gives a great opportunity to measure the effects of the first implemented improvements and the risen awareness of waiting time as waste by all staff members. It can be highlighted that the indicator I significantly improved from $I=6.0$ (project A) to $I=2.3$ (project B) after the first implementation of measures. This reduction of waiting time directly contributes to the improvement of the overall lead time of the project.

DISCUSSION

VSM in a batch-of-one environment can only be done project by project. However for MTO products that have a modular structure and less unique components, the process of Braglia (Braglia et al., 2006) is more appropriate.

The main gain of VSM in an early Lean implementation state is the analysis of the waiting time. It is recommended to map several projects of different scopes to get a better understanding whether the complexity of a product and the necessary manufacturing processes influence the flow of components through the workshop.

Although every project is unique, the analysis of several projects and the comparison of their current state maps showed general opportunities for improvement (e.g. a more detailed planning and scheduling process). Value Stream Maps offered a good basis to start discussion to raise awareness about muda (waste) within management meetings and within the manufacturing teams which led to

small group activities (5S and SMED activities at the bottlenecks). There are difficulties to quantify the effectiveness of the countermeasures because of the uniqueness of each project. In the case study there was the opportunity of a similar project shortly after the implementation of the improvements after the first VSM which fortunately offered a reasonable evaluation of the effectiveness of the first countermeasures.

It proved to be helpful to continuously monitor further projects with a graph as shown in Figure 8. Consequently the initial process of Value Stream Mapping changed to a continuous Value Stream Monitoring approach based on the indicator 'Relative Flow Velocity' I. The components on the critical path of ideally every project are monitored through the manufacturing processes and the correspondent waiting, process and setup times are observed. This daily monitoring process gives the management team the opportunity to keep an overview of the progress of projects and of the 'flow' of material. Additionally during the daily process of observation, the reasons for waiting time can be discussed with team members and countermeasures (e.g. changing the queuing sequence or reallocating resources) can be introduced much earlier.

As the observation time is dependant on the project duration, the higher time effort compared to the VSM in a mass production environment (VSM can be done within a few days (Rother and Shook, 1998)) must be mentioned. This inevitably led to a time lag between analysis and final discussion with the management team. The potential time lag can be avoided, if intermediate results during the observation period are immediately discussed and analysed by the affected staff members.

CONCLUSIONS

An adapted VSM approach for a batch-of-one environment which is a special case of a manufacture-to-order system is presented and experiences of a case study are discussed. Within the case study the adaptation of the tool VSM turned out to be necessary for a manufacture-to-order company. The literature review revealed that there has been done research ((Alves et al., 2005), (Braglia et al., 2006)) for complex products and manufacture-to-order products in a job shop environment. This paper presents a further case study with a focus on the special case of a batch-of-one product.

A detailed VSM procedure was developed and its usability has been tested within the case study. Additionally an ongoing monitoring process beyond the conventionally conducted VSM using presented KPIs of the VSM turned out to be valuable. The comparison of two projects before and after the first VSM shows the potential benefits in lead time reduction and justifies the invested effort in this methodology in early stages of a Lean implementation.

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