STRATEGIES FOR VALUE STREAM MAPPING AND PRODUCTION PLANNING – EXPERIENCES FROM LOW VOLUME PRODUCTION IN THE AEROSPACE INDUSTRY

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Abstract: This paper addresses the dilemma of designing and operating production systems with high resource efficiency and at the same time high flow efficiency in an environment with low volume mixed model production and large variations in the supply chain. The consequences of performing Value Stream Mapping (VSM), and using Lean, in such a variable environment have been analysed in this paper. The analysis is based on about ten years of experiences from conducting VSMs and performing production planning in this particular environment. One of the key issues is how to create a system that is flexible enough to manage variations and changes.

Keywords: Value Stream Mapping, Lean, Production System, Planning, Strategy.

1. INTRODUCTION

Value Stream Mapping (VSM) is a well established method to design production flows using a Lean Production approach (Rother and Shook, 1999). It is a systematic approach to implement the principles in the Lean methodology to create systems that can meet customer demands with short lead times and high efficiency (Womack et.al. 2003; Liker 2004). The typical applications and its large effects can be found in the automotive industry and other similar kinds of high volume customer products. In some industries, a variety of different components or products are made in the same plant, or value streams, and share a significant number of the production resources. This makes it more complex and complicated, but there are methods to apply lean principles in such mixed model production (Duggan 2012). The level of performance of such solutions is dependent on steady conditions with limited variability, which requires that both the external as well as the internal conditions have the required stability.

This is however not always the case. The attributes that characterizes the aircraft engine component industry inevitably results in a considerable amount of variations. Long supply lead times and tough quality requirements result in frequent quality deviations that need to be addressed. The advanced manufacturing processes have tight tolerance limits, which leads to a considerable amount of additional rework in the form of adjustments and repairs. Some of the production resources are utilized to a large extent, many times by more than one product, which leads to high utilization levels (~”bottle necks”). Other resources are used to a more limited extent, but may nevertheless contribute with specific tasks that are critical for the products. The routings are often very complex, and products may return to the same resource several times. Together, this leads to significant variations in flow routes, utilization levels and lead times – i.e. unstable conditions.

Furthermore, the demand is also subjected to short term variations, while the product portfolio constantly changes in the longer perspective. Changes to the production system and its resources are also required over time as new production technologies are introduced to meet new product demands, old equipments need to be upgraded or replaced. This equipment is often very expensive to acquire, but also very difficult to move after being installed in the shops. The situation is exacerbated by low production volumes and a product mix in the shops consequently changes much more often than the machines and the shops can be changed. Due to this, the resources cannot be fully dedicated to specific product flows, instead a number of resources need to be shared by several products. The production is therefore often set up in more of functional workshops rather than dedicated production lines.

As depicted in Figure 1, this leads to a deterioration of the designed flows, which will lose their beneficial flow properties and become more complex and increasingly inefficient – leading to lower service levels, longer lead times and more tied up capital.

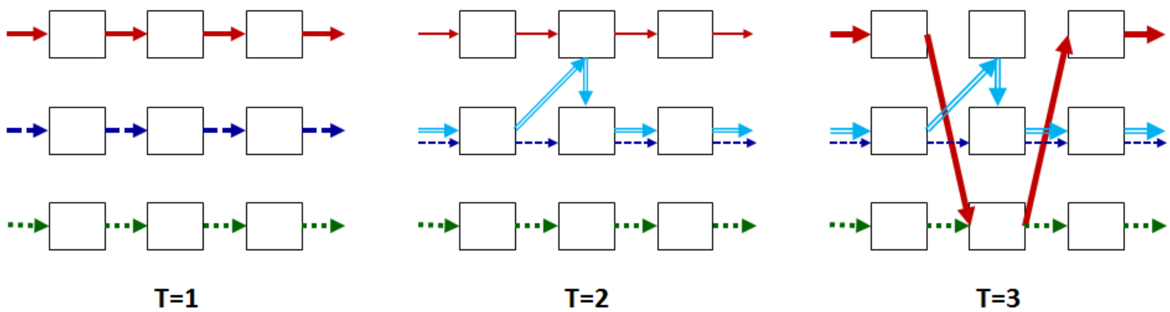

Fig. 1. Products, routings and utilization levels changes over time (T) as a consequence of changes in product portfolio and demand. Designed value flows therefore deteriorate gradually.

The situation is apparently not ideal for traditional lean manufacturing where achieving short lead times by creating a flow based systems is the primary goal. An alternative solution is to use designated schedules for each resource, an approach that often are used in functional workshops. (Jonsson and Mattsson 2009; Setia et al. 2008; Krajewski et al. 2007). The aim should be to move the performance of the operations towards the ultimate goal where both the resource efficiency and the flow efficiency is high. These quantities have a strong link to financial measures related to fixed costs, investments and variable costs. This is however not an easy task as those measures, in a discrete production system, usually are in conflict (Modig et.al. 2012).

The challenge at the company where this study is made, is thus to find the good and sustainable balance between resource and flow efficiency in a situation with mixed production, low volumes and long cycle times. The purpose of this paper is to study the operations from a holistic perspective, and over a long period of time, to find out which are the key issues with significant impact on the production efficiency.

Value Stream Mapping has (among other initiatives) been used to make improvements. The purpose and goals behind using VSM is to reduce tied up capital buy putting more focus on flow efficiency, whereas much of the priorities in production planning and preparations so far are focused on capacity planning and resource utilization. In this paper, the effects of this development is described and analyzed with a holistic perspective and some conclusions and recommendations are given for how to achieve better conditions and solutions.

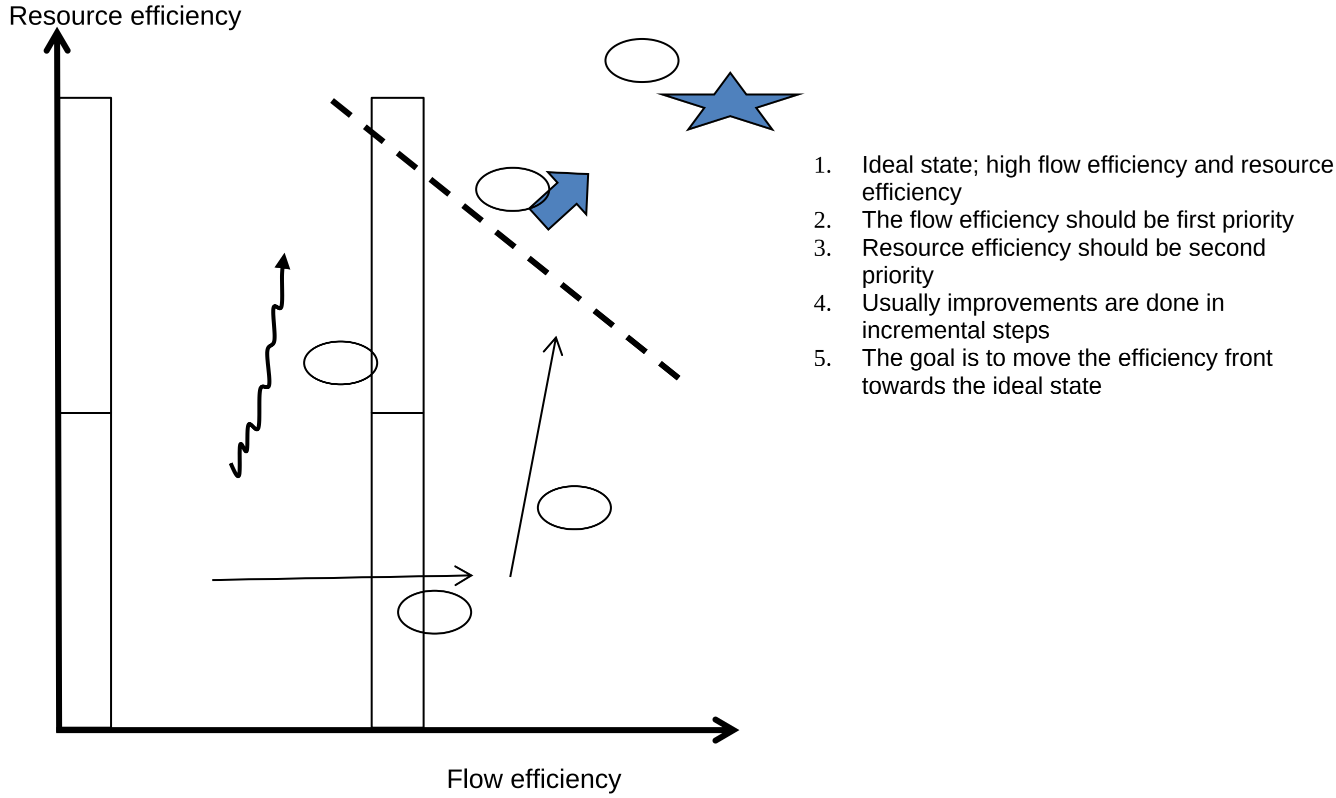

Fig. 2. Improvements to the flow efficiency (2) need to be done before resource efficiency can be addressed (3). The ultimate goal is to step by step (4) push the efficiency front (5) to the upper right corner (1). (Based on Modig et.al. 2012).

2. METHOD DESCRIPTION AND CASE STUDIES

The information and data collected to make these studies is obtained from different types of sources.

- To study the effect on production flow efficiency the production leadtime was selected as the key indicator. This data is collected from the ERP system and measurs the actual lead time from start to finish. The average production rate (Takt) is also illustrated in the diagram.
- The equipment utilisation is calculated in the ERP system during production planning and also followed up as reported actual production hours. This is in this case considered to be equal to a resource efficiency metrics.
- At a few occasions, VSM analyses have been conducted to define the current state and to develop a future state by suggesting a number of planned improvements. The primary focus has been to reduce lead time and tied up capital, thus identifying opportunities for improved planning and control, buffer sizes and reduction of quality issues, operation time or location, reasons for downtime, etc to reduce WIP. The typical results often shows a potential to reduce the production lead time / WIP with 20% - 50%, if all suggested improvements are implemented.
- During the same period of time, there have been some changes to the industrial structure regarding layout changes and/our production allocations, new machinery and equipment. These changes will, among other things, have an effect on the production lead time.

The research in this paper is based on the initial obeservation that the results from VSM provide a good opportunity for making fairly large improvements in a rather short time frame (not all suggested improvements can be done quickly or turn out to be feasible). However, when following up on the actual production lead times, they are not always changing (improving) as expected. Sometimes they even change in the wrong direction, which became particularly apparent when a new VSM is carried out a few years later.

The case studies in this paper are based on data collected from two component shop areas:

1) Product A is a casing machined from a forged ring. The typical process for such components include 4-5 maching operations (turning, milling, drilling, ...) followed by deburing, cleaning, inspection, Non

Destructive Testing (NDT) and final assembly of some small parts onto the component. The inspection and NDT is done in resources shared with other value streams. The component has been produced for more than 15 years and has a well defined and stable process. Production volume is about 400 parts per year, which in aerospace is a relatively high volume. The product is one of two similar ones that has almost the same operation routing and share the same resources.

2) Product B is a fabricated component, i.e. a number of machined parts from forgings and sheet metal are welded together to an assembly. This component is machined to its final dimensions and a number of small parts are assembled. The component has been produced for more than 15 years and has a well defined and stable process. Production volume is about 400 parts per year, which in aerospace is a relatively high volume. The product is one of two similar ones that have almost the same operation routing. Many of the frequent operations is also performed in resources shared with other products, e.g. cleaning, inspection and NDT. Thus, this is a mixed product flow and more than 50% of the operations are in shared resources operated by other value flows.

In chapter 3, the results from studies of two value streams will be presented. The data and information for each is presented in a diagram to give an overveiw of what happend and/or has been changed during the time frame of the studies. In chapter 4 the results are analysed and discussed to give explanations to the reasons behind the different effects. In chapter 5 conclusions are drawn and an approach for how to avoid the degradation of the flow efficiency is suggested in order to improve the sustainability of the outcomes for future VSM:s.

3. RESULTS

The results from the case studies are summarized in figure 3 - 5 below. The time frame for the study is 2006 – 2013. For each of the case studies the information in the diagrams is explained to provide a clear view of the development. Please note that due to confidentiality reasons the actual data cannot be provided. The following data are presented:

- Production flow lead time (FLT)
- Production rate / Takt (finished orders/week)
- Points in time for when a VSM has been conducted and the estimated potential effect
- Points in time for different changes in the value stream and conditions influencing the lead time

The case studies are analyzed in the discussion to provide a more complete and holistic context of the different influencing factors. The results are then assessed and conclusions are drawn.

Figure 3 demonstrates how the production flow lead time is illustrated for a period of 8 years. The fluctuations are considerable and there are several reasons for this. The factors relevant for these case studies are described in figures 4 and 5 below. One is the variable demand from the customers, but also an effect of the production planning as it attempts to adapt the production volumes to compensate for planned production shut downs. The sharp high peaks (long lead times) are associated with planned or unplanned stops due to activities as machine installations, maintenance, breakdowns, or problems with deliveries from suppliers. In this case the production rate is high enough to result in a relatively rapid effect. The sharp low peaks are associated with planned production stops and is to a large extent an effect from production over time to catch up back orders. The ERP system measures the lead time based solely on the planned production times.

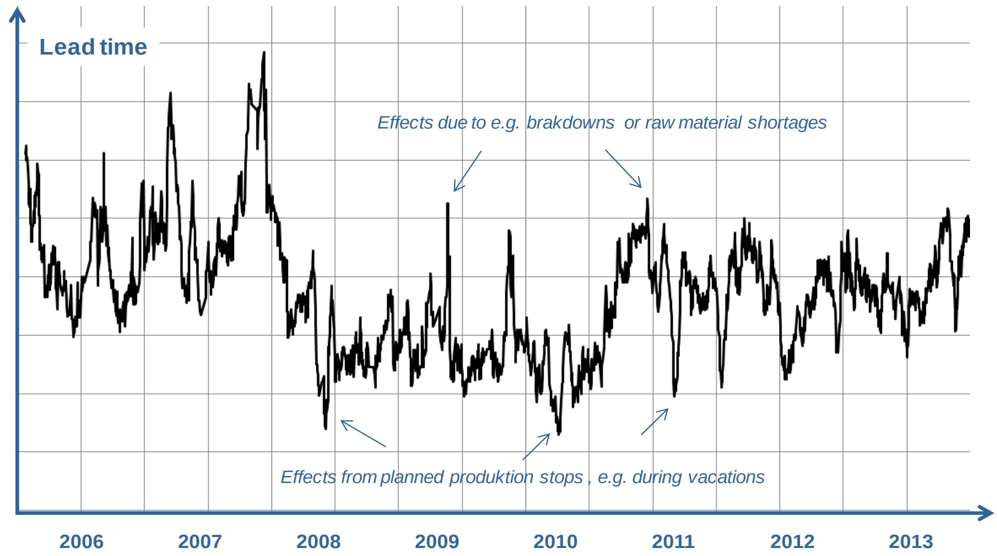

Fig. 3. Example of production flow lead time for product B.

In figure 4, the data and results from collected information for Product A is shown and summarized below.

- The production flow lead time is illustrated, using a 3 months moving average to better see the effect from changes to the value stream. There is also trend lines for different sections which indicates that there have been some large changes at different times.
- The production rate (takt) has increased in total about 40 % during the time period 2009 -2013. The trend line is shown in the diagram. The actual takt during each month can vary due to varying demand and other variations in the value stream.

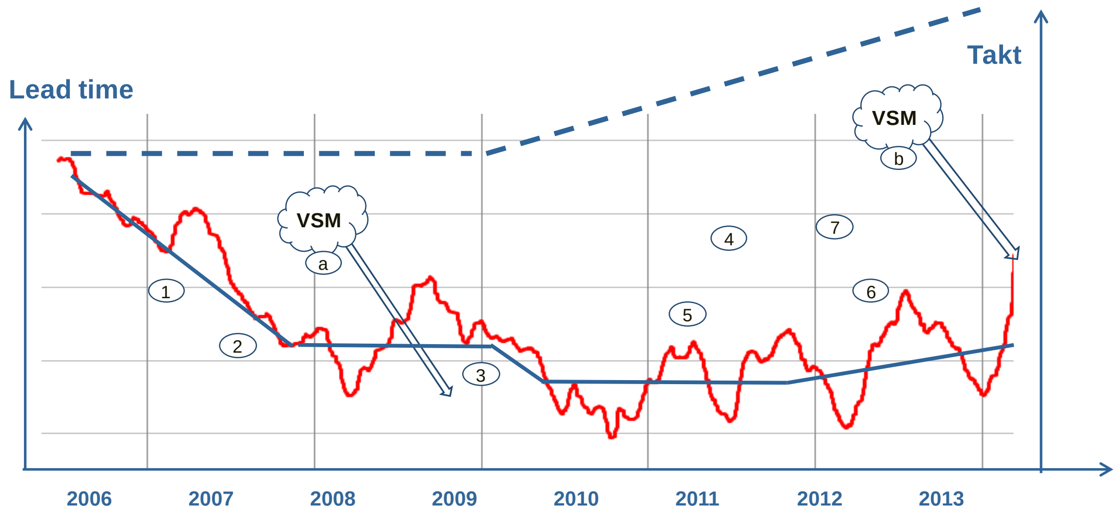

Fig. 4. Data and information from case study 1 (Product A), a machined casing. Solid line is for the lead time and the dashed line is the takt.

The results from the VSMs are summarized as follows:

a) VSM 2008: The identified potential lead time improvement was 42% and the total operation time could be reduced by 12 %. The lead time improvement could be achieved by smaller changes to the operation routing and to use well defined buffer and flow sequences, the latter by introducing stricter production planning and control to maintain the decided takt time. One major issue was a bottle neck equipment that also had rather low technical availability.

b) VSM 2013: The identified potential lead time improvement was 45% and the total operation time could be reduced by another 12 %. The current state VSM analysis showed that the actual total lead time was considerably higher than in 2008. The major effect was related to layout changes, routings and raw material storages. (The gap between the VSM and ERP lead time is further commented in the "General comments to the case studies" in Chapter 4). The plan to achieve this included improvements and re-balancing of cycle time between some of the machines, and stricter production planning and control to maintain the takt time. Physical material movements between work centres were to be made directly by the operators, instead of using fork lift transports. The WIP and buffer sizes were also revised.

Product A - Changes in the value stream:

1) 2007 – 2008: Some layout changes within a limited area that had some small effects on the overall "spaghetti flow".
   i. A couple of machining centres were moved.
   ii. The work centre for inspection was moved and combined with assembly.
   iii. There were some problems with a machine that was subjected to breakdowns. These problems have been reduced by improvements and preventive maintenance.
2) 2007/2008: Forgings from a new supplier caused disturbances due to variations in material hardness.
3) 2008-2009: Reductions of tied up capital was focused. WIP/Buffers and lead times between operations were reduced.
4) 2009-2013: Slow increase in production rate with all time high in 2013 had some negative effect on lead times.
5) 2011: Fukushima earth quake/tsunami caused different problems regarding material supplies. The effect lasted for several months.
6) 2012: Severe supplier quality problems caused effects in production
7) Operation times have gradually been lowered, which has reduced bottle neck problems and probably had a positive effect on the value flow. Planning and control to balance cycle times and efforts to keep the takt times has had effects.

In figure 5, the data and results from collected information for Product B is shown and summarized below.

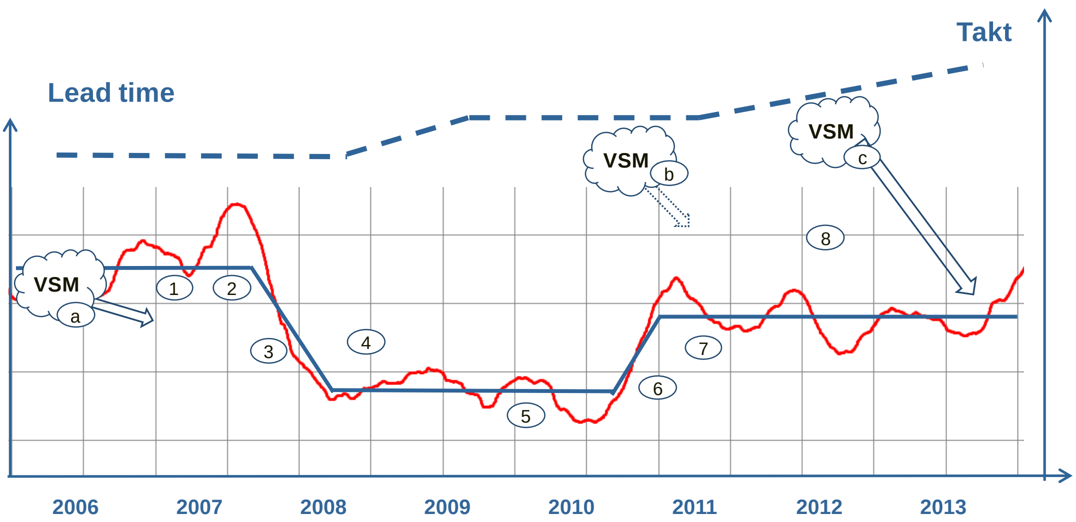

Fig. 5. Data and information from case study 2 (Product B) a fabricated structural casing. Solid line is for the lead time and the dashed line is the takt.

Product B – Results from VSM:s

a) VSM 2006: The identified potential lead time improvement was 27% and the total operation time could be reduced by 1 %. This could be achieved by minor changes to the operation routing. The major change was to reduce the buffers in production and to achieve a stable steady state in order to plan and control sequence and takt time. That would also include some operations performed in shared resources.
b) VSM 2011: This VSM did not deliver a future state with data such as quantified predictions of effects, but only an action plan for improvement. Compared to the data in 2006, the current state map revealed that operation time had increased 20% and the lead time had increased as much as 70%. The primary focus was to improve production levelling, planning and control. This was done by eliminating disturbances and other sources of variation to increase stability and predictability. The estimated improvements are in line with other VSMs.
c) VSM 2012: At this stage the current state mapping showed that total operation time was reduced by 6% compared to 2011, but the lead time was slightly higher. The identified potential lead time reductions were 47% and the operation time could be reduced by 4 %. The results and plan for improvements included both changes to the production routing by combining operations and to reduce the use of

shared resources (to reduce transportation and queue lead time), but also to employ a systematic approach for operator supported planning and control – in order to manage production orders in sequence and within takt time. An increased use of manual transports between work centres was also a part of the solution.

Product B - Changes in the value stream:

1) 2007/2008: New machines and changed layout/routing for machining of two sub-components resulting in some more transportation. Some effects during tryouts and ramp up in new equipment.
2) 2007/2008: New machines and small layout change for final machining of the product. Some effects during tryouts and ramp up in new equipment.
3) 2008/2009: Reductions of tied up capital was focused. WIP/Buffers and lead times between operations were reduced.
4) 2008: The storage was moved to another location. The queuing times in the storage are not included in the FLT followed up in the ERP system (20-30 days). That is the reason why the lead time measured by the later VSM is much longer than ERP data.
5) Normal / Steady state production after all issues with new machines etc. were resolved.
6) A couple of operations were moved to another workshop / shop area. One effect was the need for an increased amount of transports and increased lead time.
7) Some cleaning/washing operations were moved to another workshop using a large shared resource. This resulted in a significant increase in the amount of transports and related lead time.
8) Increase in production rate had some effect on lead times. The increase could more or less be handled within the original resources.

4. DISCUSSION

The results show that for the Product A case study, the value stream has had the chance to work with continuous improvements without the influence of any major or dramatic changes, and achieved sustainable results.

- There have been a few large changes to the production routing and layout.
- The continious improvements has had a possitive effect on operation time and lead time.
- The takt has increased during the last few years, about 45 %, which explains some of the increasing lead time the last years when the resource utilisation has reached levels that effect the lead times. No investments in new equipment has been made and most of the extra production hours needed has come from improvemnts or increased utilisation. However, for one machine the capacity limit has been reached and a few parts per week has been machined in another work centre.
- The production rate for the other product in the same value stream has decreased from 2 to approx 1 per week. This has also freed up some of the machining resources and made the scheduling easier.

In the Product B case study, the individual decisions may have been made in a seemingly correct way but often been influenced by the situation in adjacent flows to solve “local” problems. Without proper regard to the overall situation in the long term, such decisions often have a significant impact that can affect the whole plant. It is apparently very hard to foresee these effects without a clear strategy for the production system.

- There have been major changes in layout and the equipments for manufacturing of the sub-components and the final fabricated component. This does not only concern the machining (value add) but also processes for cleaning and inspection and/or NDT. These changes have had a impact on operation time and particiluary a large impact on the lead time.
- Investments in new equipment were made as some machines were old and did not fulfill the requirements on capability and availability, but also to increase the capacity.
- Some of the new machines that were installed during 2007 – 2009 caused some serious disruptions due to installation and other preparations, but the most serious problem was that the machines did not work as intended from the start.
- The takt has in creased during the last few years, about 40%, which explains some of the increased lead time due to higher utilisation. At the same time the production rate for the other product in the same valuestream has decreased from 2 to less than 1 per week. This has also freed up some of the machining resources and made scheduling easier.
- The use of shared resources has increased and some of those work centres have also been moved to new locations which has resulted in considerable more transports. It is not only the transport time that is important but it also results in much waiting, delays, etc. that have a large impact on the lead time. There was also investment done in some of those resources to increase the total capacity.

- There is also a system effect from how the lead time is measured. Some of the storage time for machined parts (lead time) is not measured in the ERP system flow lead time. That part of the lead time has been included in the VSM however.

General comments to the case studies:

- The difference in lead time between the VSM and ERP data is because part of the time in inventory is not included in the ERP. The delivery of material may also be different in both amount and frequency.
- There has also been some changes to the definition and measurement method in the ERP system (factory calendar from 7 days/week to 6 days/week) which indicates that the lead time has become shorter but without any real effect.
- The paper has showed the results from two case studies (Product A and B), but there are several more ones which follows the same pattern, with the same kind of performance and development.
- It is also important to consider the very complex situation with a number of products and value streams that shares the resources. In total, 70-80 products are manufactured and about 25 of these constitutes 80% of the total value. Therefore, it is a risk that even relatively few separate decisions may have a large influence on the overall system. The same logic apply to production planning and control, i.e when locally sound decisions may influence the overall production in a negative way. A single event, or other change to the value flow, is therefore hard to detect and will consequently remain ”hidden”.

The results shows that the VSMs, and their future state plans, have a great potential and contribute to large improvements in the short term perspective, given that stable conditions can be maintained. It is equally important to study the results and data in a holistic and long term perspective to better understand how the system behaves under different circumstances and analyse the effects from planned decisions or alternative solutions for improving the industrial structure and the supply chain. In the longer term perspective, external factors as changes in product range and customer demands results in subsequent changes of resource allocations (i.e. of products to resources), production technology and workshop structure. The designed value flows becomes significantly altered by this, which have a very big impact on the production performance.

The above described conditions are not normally associated with the preconditions for Lean, quite the opposite. They are also difficult to take into account during the VSM work, which makes it challenging to design and plan for future value streams – especially as the future situation and goal is difficult to predict. The approach is presently to make the best of the situation, and try to solve the issues within the scope of the tactial and operational production planning (Olhager, J. and Selldin 2007; Thomé, et. al. 2012) – but the prospects to succeed are not the best. For the long term strategic planning the aspects of flexibility in the production resources capacity and localisation is possibly an enabler for more of lean implementation (Chryssolouris 1996; Abele et al 2006; Georgouliasa et al 2009; Munther 1984).

5. CONCLUSIONS

We have in this paper summarized the results from studies of two products and their value streams. We can conclude that they have developed in quite different ways after that the VSM:s were conducted. The long term improvement has been significantly higher in the more stable value flow. The conclusions are that external factors are difficult to influence, so the situation must be managed with a combination of adapted VSMs in combination with strategic logistic analysis (such as discrete event simulation) and industrial planning. Each and every decision may have been made in a seemingly correct way. They have often been influenced by the situation in adjacent flows to solve “local” problems, without proper regard to the overall situation in the long term, The often have a significant impact that can affect the whole plant. It is apparently very hard to foresee these effects without a clear strategy for the production system. A long term strategy regarding the development of the production system as an industrial backbone is essential to provide the required stability for the gradual development of the production system. Without this strategy, every change is a potential threat towards the efficiency in the revised value flows as well as negative effects on other value streams.

Tactical production planning has been identified as a supplementary success factor, i.e. to allocate production tasks to specified resources in a way that ensures efficient production flows in the long run, while maintaining high capacity utilization, seen from a factory perspective. Dynamic operational production planning and scheduling for limited, but critical, parts of the production shops is another identified success factor in this type of environment. Different ways to increase the flexibility of the production resources is also needed, not only regarding process capability, but also mobility – i.e. to be able to move selected resources to the places where they are needed. The purpose is to find solutions to create systems that are reconfigurable, with the goal to achieve and maintain high flow efficiency and resource utilization.

Future work will focus on how to manage variations, in the design of the production system to improve the value stream as well as in the Lean implementation work, but also in the use of methods for logistic analysis, strategy and production planning.

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