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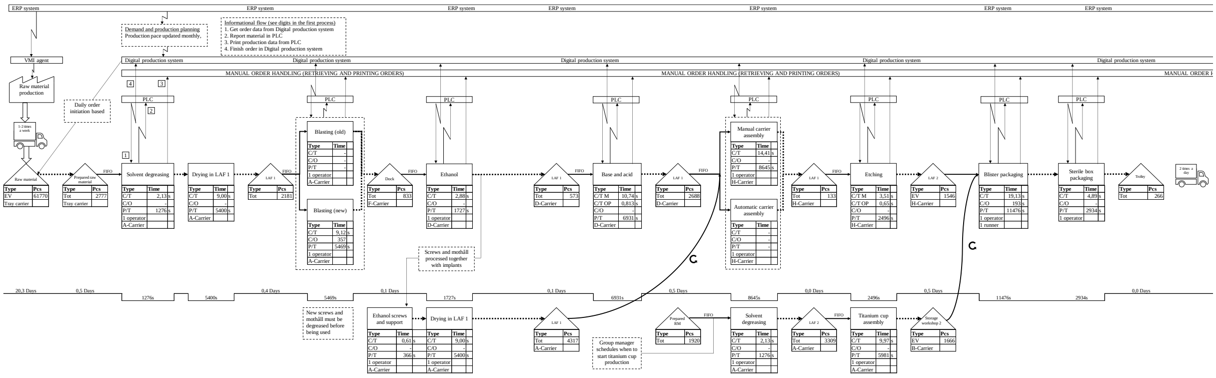

Combining VSM with Digital Data

Master's thesis in Production Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY

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MASTER THESIS 2020

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ABSTRACT

Productivity improvement is a must for survival in every competitive industry. Hence, to not lose competitiveness and profitability, companies must pay attention to this area. Luckily, there are numerous different ways of addressing it. If taking a production perspective, one way of dealing with the productivity is to reduce work in process (WIP) and shorten lead times. Historically, the tools and concepts of lean production have been frequently and successfully used in that context. In this report, the lean tool value stream mapping (VSM) is applied in a Swedish manufacturing company to give suggestion on how their production can be changed to improve their productivity. To mitigate some of the commonly stated drawbacks of a traditional VSM, the report investigates how the methodology can be combined with digital production data.

The study results in several improvement suggestions, possibly leading to improved productivity if being implemented. All improvement suggestions are comprised into an implementation plan, serving to guide the company if implementing suggested changes. Regarding the digital production data being utilised, it is concluded that it can help mitigate common VSM drawbacks, such as reducing the time spent on manual measurements, and making it less static and more easily updated. It is also shown that the ‘go and see’ approach in the VSM methodology can be a good complement when using digital data. To support productivity improvements in the future, an internal production assessment standard is developed to the company. Lastly, a roadmap towards digitalisation is created to encourage the studied company to be more digitalised.

Keywords: Production assessment; Productivity improvement; VSM; Digitalisation; Digital data; Lean; Bottleneck detection.

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Niclas Andersson & Jesper Rapp
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1 INTRODUCTION

In this introductory chapter, the background of the report is given, followed by its purpose, aim and research questions. Lastly, the limitations of the project are listed and explained.

1.1 Background

Improving productivity is a prerequisite for staying competitive in a setting of global competition (Huang et al., 2003; Syverson, 2011; Lugert, Batz, & Winkler, 2018). Put differently, productivity growth is a must for survival, creating an incentive for companies to pay considerable attention to this area. In a wider perspective, productivity improvements are important for the entire society since it determines the personal economy of people and affecting the wealth of nations (Brynjolfsson & Lorin, 1998).

Over the years, many companies have relied on ideas from the lean philosophy to support productivity improvements and overall organisational development (Womack, Jones, & Roos, 2007). The roots of lean stem from Toyota, where the methodology started to develop back in the 1950s (Womack, Jones, & Roos, 2007). Very shortly described, the idea of lean and its tools is to reduce waste and thus creating more output with less input by continuously improving the organisation (Womack, Jones, & Roos, 2007; Holweg, 2007). Since the 1950s, lean has transformed on an ongoing basis, and been successfully spread to other industries than the automotive (Holweg, 2007). From an academic standpoint, lean has been given a lot of attention since the term was popularised by Womack, Jones and Roos in 1990 (Holweg, 2007; Sinha & Matharu, 2019). By following prevailing trends, the lean philosophy has stayed modern and is still relevant to use.

Regarding the present research focus, it is pointing towards an increased utilisation of digital technology, making extraction of an extensive amount of real-time data possible. Such data could e.g. be utilised to improve operational efficiency, develop processes or to achieve an increased process understanding (O’donovan et al., 2015). In several studies, e.g. by Mrugalska and Wyrwicka (2017) and Kolberg and Zühlke (2015), the possibilities to incorporate digital solutions in traditional lean tools have been tested. For instance, Kolberg and Zühlke (2015) describes a successful case where a Kanban system has been built up with cameras and connectivity equipment, resulting in a responsive system where buffer sizes, and thus the work in process (WIP), could be reduced. As indicated by previous studies, it seems to be possible to develop traditional lean tools by utilising the benefits of digital data and technology, keeping the lean-era ongoing.

One lean tool, widely used in different industrial settings, is value stream mapping (VSM) (Lugert, Batz, & Winkler, 2018). In short, its main idea is to improve efficiency and productivity by creating an analysis of the prevailing production situation, and then design a future state to strive for (Rother & Shook, 2009). The assessment itself is reliant on manual measurements of the production system, and the importance of ‘go and see’ the factory with your own eyes is highly advocated as a key success factor when using the tool. This since problems often are hidden and difficult to discover when only looking at a production flow description together with a set of data. However, with digitalisation in mind, it could possibly be a missed opportunity to not utilise digital data.

This thesis is done in collaboration with a real-world Swedish company that previously have conducted VSM projects to address their productivity. However, they are not working with the tool at a reoccurring basis. Since productivity growth is an important factor for sustained competitiveness, it should be prioritised in order to not fall behind competitors. In an attempt of combining the benefits from a traditional VSM, with the possibilities of digitalisation and the utilisation of real-time data, this project intends to improve the productivity of the company being studied. Additionally, to secure future productivity growth, a standardised production assessment procedure that can be used by the company globally, is developed.

1.2 Purpose

The purpose of this master thesis is to improve the productivity in a real-world company.

1.3 Aim

There are several ways of improving the productivity in manufacturing companies. One way of doing it, is to reduce WIP and shorten lead times, which is the aim of this thesis. This will be done by assessing one of the production lines at the studied case company in Sweden.

1.4 Research questions

Below, the two research questions of the project are stated. The questions matured during the project and were created together with representatives from the studied company.

RQ1: How can VSM help the company increase their productivity?

RQ2: What can be achieved by combining VSM with digital data in production flow assessments?

1.5 Limitations

- The production assessment carried out in this project is limited to the production plant in Sweden. Hence, other internal production units, such as the manufacturing of raw material components, supplying the plant in Sweden is not considered. Thus, the value stream studied will be limited to the inbound delivery of material to the facility in Sweden, to the end products in the final warehouse.

- In the production, machines and other resources are shared among several different products or product families. This project, however, will only study one product family, which is chosen based on its importance for the company from a business perspective.

- To improve the credibility of the measurements more measures could have complemented the production assessments. However, the access to the production system were limited during the thesis due to unfortunate conditions. Moreover, the production plant consists of several chemical processes. These will not be investigated on a detailed chemical level since it requires a deeper focus towards surface refinement and chemical knowledge, which would change the direction of the thesis. Therefore, the analysis will consider these automated processes, but not further analysing how to optimise and trying to remove unnecessary waste activities of them.

- This thesis intends to give suggestions on how to improve the productivity in the production system. However, no changes will be implemented, and therefore there is no analysis of how the performance of the system is affected by the improvement suggestions given.

2 FRAME OF REFERENCE

In the first two sections of this chapter, two of the chosen methods used for the production assessment, VSM and theory of constraints (TOC), are described how they were used. This is followed by how implementations of these methods have been done previously, focusing on challenges and how to they have been overcome in order to successfully accomplish it. Moreover, how a manual VSM can be combined with digital data, adapting the tool into the era of digitalisation. This chapter are constructed in order to support the understanding of problems are solved in this thesis. Figure 2.1 describes how the different sections in the upcoming chapter is related to the previously stated research questions.

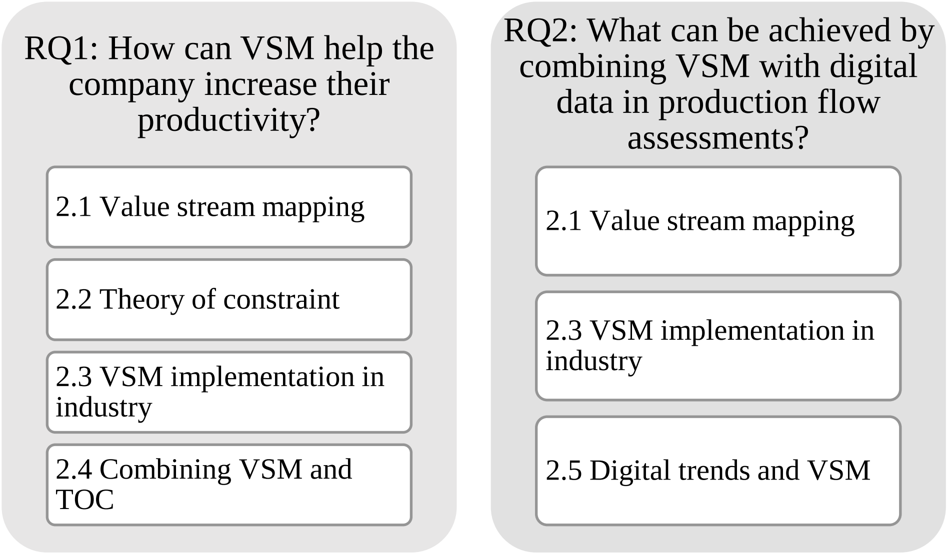


Figure 2.1 Frame of reference relation to research questions

2.1 Value stream mapping

Value stream mapping is a production assessment tool stemming from the lean philosophy (Sullivan, McDonald, & Van Aken, 2002; Lasa, Laburu, & de Castro Vila, 2008) During the years, it has been widely used in different industries, and helped company assess and develop their production systems (Lugert, Batz, & Winkler, 2018). In a handbook by Rother and Shook (2009), the tool is described and concretised into a four-step implementation guide, which are presented in the following sections.

2.1.1 Setting the context

The first step of the tool is an introductory one, describing what prerequisites that must be in place before starting to work more practically. First of all, Rother and Shook (2009) highlight the importance of having a person responsible for the value stream mapping. Since the value stream mapping often involves several different departments at the company, the responsible person plays a key role to coordinate the work effectively. Furthermore, in a complex production environment, e.g. consisting of parallel material flows, numerous different products or similar, a specific product or product family must be chosen for further investigation (Rother & Shook, 2009). If not doing this selection, the map could be too complicated and difficult to understand. Rother and Shook (2009) suggests that the selection should be based on products that are the most crucial ones for the customers. If choosing a product family, it is important that the products included follow a similar path in the production flow. Otherwise, the map easily gets incomprehensible, since it should cover both the physical flow of the product and the corresponding information that dictates the flow.

2.1.2 Drawing current state map

In essence, this second step is about assessing and mapping the present state of the production flow. Traditionally, and as suggested by Rother and Shook (2009), the mapping should cover the complete flow that takes place within the walls of the studied production plant. This includes the delivery of raw material from suppliers, to the delivery of finished products to either customer or final storage. The different mapping symbols and their meaning are the same as Lean Enterprise Institute (2020) use, shown in appendix A.

When drawing the current state map, Rother and Shook (2009) advocates the importance of actually walking in the production and personally seeing what is happening at the given moment. Understanding the complete flow is crucial. If only mapping or understanding a part of the flow, important details might be lost or misunderstood. In their opinion, it is dangerous to rely on data based on e.g. standardised times or similar. An instantaneous picture of the production can according to them never lie, and to capture data from the production system, the advice is to use a stopwatch and time every station. They further suggest a set of standardised icons to use when mapping the current state mop. Thanks to these icons, it is easy to go back and interpret an old VSM, regardless of who did it. In Table 2.1, the data needed to fulfil the current state map is presented and described. All times are measured in seconds, while batch size, WIP and inventory levels are measured in number of pieces.

Table 2.1 Data needed to complete the VSM (Rother & Shook, 2009)

Measure	**Description**
Batch size	Number of products manufactured in the same production order.
Changeover time	The time it takes to set up a machine when changing between two different products.
Cycle time	The time it takes for a process to complete a product, i.e. the time between two product completions.
Inventory level	Number of products and raw material components in finished goods stock.
Machine uptime	The relation between unscheduled breakdowns and scheduled machine utilisation.
Scrap rate	Percentage of discarded products due to e.g. defects.
Takt time	Describes how often the system must deliver a product to cope with customer demand.
WIP	Number of products in the system, i.e. in buffers and machines
Working time	How much time that is available for production, e.g. time per shift, where the breaks are subtracted.

Regarding the takt time, it is calculated according to equation 2.1, where the available working time is equal to the time that is scheduled for production during a year (Rother & Shook, 2009). Customer demand represents the expected sales volume of the product or product family being studied.

$$Takt\ time = \frac{Available\ working\ time}{Customer\ demand} \qquad (2.1)$$

2.1.3 Drawing future state map

The drawing of the future state map is based on the same set of standardised icons as used for the current state map. In short, the future state should illustrate an ideal production flow that should be strived for. Rother and Shook (2009) suggest that the first future state drawn at a company new to VSMs, should not include extensive changes such as redesign of products or big investments in process technology. Instead, the focus should be on smaller changes, gradually improving the production flow using a limited amount of resources. However, in later VSM iterations, hopefully when most of the low-hanging fruits have been collected, the future states could be created more as a visionary model, allowing greater changes (Rother & Shook, 2009).

Before thinking about how to draw the future state, the current state map must firstly be thoroughly investigated. This could e.g. include identifying disturbances in the informational flow, or points where the physical flow is unbalanced. Additionally, the analysis could contain a determination of the bottleneck of the system, and whether it is shifting or not. To support this analysis, Rother and Shook (2009) have compiled eight questions, see Table 2.2 below. Simultaneously as answering the questions, corrections can be done in the current state map, forming the future state map bit by bit.

Table 2.2 The eight questions, by Rother and Shook (2009)

#	**Question**
1	What is the takt time of the system?
2	Should finished products be produced to a warehouse, or be directly delivered to customers?
3	Where in the flow is a continuous flow possible?
4	Where in the flow must a buffer pull system be used?
5	What point in the flow is the pacemaker of the system?
6	How will the production mix be levelled in at the pacemaker?
7	In what batch size should products be produced?
8	What process improvements are necessary to achieve, in order to reach the future state?

2.1.4 Implementation plan

This final step of the VSM procedure is about creating a plan for implementing the future state map in reality. Rother and Shook (2009) advocates the importance of having an involved management team when dealing with the value stream improvements. They argue that they are the ones having the holistic picture of the entire value stream, and thus the most appropriate to lead such initiatives. Developing the value stream should not be carried out in a single project, nor be seen as a randomly occurring event. Instead, it should be incorporated in the daily operations where Rother and Shook (2009) see an updated VSM as a good tool for reviewing daily operations and detecting deviations. Further, they state that no money, within in a budgeting process, should be approved without basing the decision on a value stream plan. In other words, the VSM and its implementation plan should work as a supportive tool to find which investments have the best impact.

To succeed with the implementation plan, Rother and Shook (2009) suggest that measurable goals, directed to certain parts of the value stream, should be defined. Such a goal could e.g. be to remove a buffer between two machines, or to reduce the changeover time with ten percent at a specific machine. The plan should preferably be created at a yearly basis in the form of a Gantt chart, clearly illustrating each action to be taken. After completing an action, it should be reviewed and checked whether it completes the stated goal or not (Rother & Shook, 2009).

2.2 Theory of constraint

Theory of constraint (TOC) is a methodology or thinking process to support production development. It was originally created by Eliyahu Goldratt in the 1980s (Rahman, 1998), who later has written several books on the topic, including e.g. *Theory of constraints* (Goldratt, 1990) and *The goal* (Goldratt & Cox, 2004). In short, the concept of the TOC can be described by two ideas. Firstly, every production system and supply chain have at least one constraint or bottleneck. If not, such a system would be able to obtain endless earnings. In other words, it is the constraint of the system that holds back its output. Secondly, and now rather intuitively, the only way of enhancing the overall performance of the system is by improving the constraint. Enhanced performance in the system must be related to goal fulfilment, meaning that a constraint should be improved such a way it supports the goal and the overall system (Goldratt, 1990). For instance, increased production volume does not by nature mean enhanced performance, unless it is not a part of the goal for the system.

The TOC methodology is an iterative process built up by five steps (Goldratt, 1990). In the first step, it is all about finding the constraint, or the bottleneck of the production system. As mentioned above, the constraint is recognised as the part of the system that is hindering or limiting its goal achievement (Goldratt, 1990). This could for instance be one specific workstation that cannot cope with the takt time required to cope with the customer demand, or a supplier that fails to deliver enough raw material. When the constraint of the system has been identified, the second step of the TOC is to explore how it can be utilised at max (Goldratt, 1990). Examples of actions in this step could be to assure continuous manning of the constraint or developing a more effective way of managing the constraint. The third step is somehow touching the second step of the TOC methodology and focuses on how non-constraint parts of the flow should be transformed to support the constraint (Goldratt, 1990). Practically, this entails making sure that it never gets either starved nor blocked due to up- or downstream non-constraint workstations.

If the constraint of the system is kept unchanged after completing the first three steps, the fourth step has it focal point on developing the constraint itself. Such development could e.g. regard some investments to support the constraint, or a continuously working with small improvements. The fourth step is not finalised until the constraint becomes a non-constraint. At that point, a new constraint will dictate the system, triggering the fifth step and another iteration of the methodology (Goldratt, 1990). In Table 2.3, the five steps of the TOC methodology are listed and shortly summarised.

Table 2.3 The five TOC steps (Goldratt, 1990)

Step	**What to do**
1	Identify the constraint of the system
2	Figure out how the constraint could be utilised at max
3	Subordinate other resources to serve the constraint
4	Improve the constraint
5	If, or when, the constraint has changed, go back to step 1

2.3 VSM implementations in industry

The requirements nowadays in competitive markets are stricter on being dynamic and flexible. VSM is a static tool however, analysing only a snapshot of the production system which makes it not competent handling rapid competitive environments, according to Huang et al. (2019). Therefore, the tool does not consider more complex parameters such as labour performance and cost, material flows and machine efficiencies (Huang et al., 2019). Moreover, a complex production system with several products are difficult to include in a single VSM (Lugert, Völker & Winkler, 2018; Huang et al., 2019). The creators are aware of this and even states that it is impossible to include every pathway of every part. Additionally, Lugert, Batz and Winkler (2018) states that it is difficult to manually update the conditions of a VSM regularly, considering the increasing complexity of manufacturing structures and value streams. Despite this, there are several successful VSM implementations documented in research papers.

Shou et al. (2017) made a review on publicised articles covering the use of VSM. They concluded that the main benefits obtained by implementing VSM within the manufacturing sector are improvements with inventory, lead time, cycle time and manpower. There are some factors that seems to be vital for a successful implementation of VSM in order to achieve benefits such as these. Some of the most critical success factors are theory refinement and integration, having an empowered inter-principle lean team, support from top management and lastly, training and education (Shou et al.,2017). Theory refinement and integration means that current VSM applications are incomplete, that is, that there exists a gap between the theory of VSM and its use in practice. For instance, a VSM are problematic to perform when several product flows exist. And also, VSM does not help in reaching the future state and therefore trial and error is used in order to achieve the future state, which consists of wasteful resources (Shou et al., 2017). Therefore, it is highlighted that the VSM theory must be updated and integrating related ideas in order to achieve the full potential of a VSM. However, even with the mentioned gap, VSM is profitably used in different sectors and manages to successfully optimise production systems (Lugert, Batz, & Winkler, 2018).

In a case study by Rohani and Zahraee (2015) where VSM were used in order to find waste in the production line of a company in the colour industry. The tool managed to help and lower the production lead time from 8.5 days to 6.0 days and almost decreased the value adding time by 50 per cent. This was partly done by merging four workstations into two. Thus, a more efficient process time, i.e. value adding time, was accomplished going from 68 to 37 min. Moreover, to reach the future state, the batch size was changed to only contain one product, which resulted in no inventory in between station, and therefore, lowering the production lead time (Rohani & Zahraee, 2015). Lastly, individual lean techniques such as, kanban, kaizen, 5s, were designed into the production system as well, in order to solve the problems that appeared in the current state map.

2.4 Combining VSM and TOC

VSM is a tool that allows companies completing structured production assessments and a way of pointing out the strategy for implementing some changes towards an improved future state (Pavnaskar, Gershenson, & Jambekar, 2003; Rother & Shook, 2009). However, as pinpointed by Librelato et al. (2014), the methodology does not suggest how to prioritise among different improvement alternatives. In a competitive industrial setting, where capital commonly is a scarce resource, the lack of prioritisation could lead to inefficient investments, potentially harming the long-term profitability and competitiveness. Librelato et al. (2014) further discuss that the VSM methodology do uncover problems in production systems, but that the methodology fails to guide users to the root cause of said problem.

To mitigate the perceived flaws of the VSM, Librelato et al. (2014) have performed a case study within the automotive industry, where they are combining a traditional VSM approach with the TOC methodology. By doing so, the idea is utilising the strength of the VSM to discover problems, and the TOC prioritise among these problems and finding root causes. At the same time, the first step of the original TOC process where the constraint of a system should be detected, gets supported by the VSM. Thus, and as mentioned by Librelato et al. (2014) the methods could theoretically complement each other in a good way. After implementing the combination, the article concludes that the combination seems promising, but also highlights the need of more studies, covering different industries, before stating anything definitive.

In an article by Garza-Reyes et al. (2019), a similar combination of VSM and TOC as used by Librelato et al. (2014) is tested. The article is a case study from an emergency medical service system, investigating how the combined methodology can be utilised when improving emergency transports. In the case study, Garza-Reyes et al. (2019) combines the two methodologies into a four-step iterative process. Firstly, they establish the context and gather knowledge about how the system is built up and how it works. Secondly, they create a current state map, where the system is visualised and described. Thirdly, the bottleneck of the system is identified by finding the resource with the highest cycle time. Note that these first three steps are similar to the ones suggested in a traditional VSM procedure, presented by Rother and Shook (2009). In the fourth and final step, which is iterative, the bottleneck is improved using the TOC approach, as suggested by Goldratt (1990). The fourth step also includes the formulation of an implementation plan, and the iteration of the improvement process is terminated either when no more improvements can be found, or when the capability or willingness to drive the project is missing.

As in the case study within the automotive industry, performed by Librelato et al. (2014), Garza-Reyes et al. (2019) concludes that the combination of the VSM and TOC yields a positive development and result. They further agree on, or confirms, that the VSM, at least in this case, is helpful when trying to uncover problems within the present system. Lastly, Garza-Reyes et al. (2019) also shares the opinion that more studies case studies in different areas are necessary to carry out before confirming the applicability of the method combination.

2.5 Digital trends and VSM

Mayr et al. (2018) highlight that industry 4.0, or digitalisation, can be a solution to overcoming the challenges and barriers that exist when implementing a lean initiative such as VSM. This statement is well-aligned with an empirical study regarding VSM and its suitability with industry 4.0 made by Lugert, Batz and Winkler (2018). This study concludes that lean approaches together with industry 4.0 does not contradict each other from neither a theoretical nor practical perspective.

Using a digital tool is superior in comparison to manual methods in order to be able to analyse more complex production flows, by using real-time data as input (Lugert, Völker, & Winkler, 2018). In the study by Lugert, Batz and Winkler (2018), respondents highlighted the possibility of integrating real-time data from MES and ERP systems of the production processes together with VSM. A large benefit when having real-time data displayed is the transparency that is obtained by it (Mayr et al., 2018). Furthermore, having constantly updated real-time digital data requires a diminished effort in comparison to constructing a brand new VSM in order to having up to date-data. This in turn enables the tool to give present and relevant information as support to decision makers with little issues of obtaining the data (Huang et al., 2019).

Adapting a VSM in order to follow the digital trend, it is needed to collect a large sample of data (Huang et al., 2019). Moreover, by having real time data, smaller waste-occurrences happening in the production flow can be mitigated in order to avoid or overcome a bottleneck. This will help in visualising actual times spent in buffers, in comparison with using the takt time to calculate amount of time spent in buffers. Measurements that are difficult to manually collect can easily be retrieved using digital data (Huang et al., 2019). For instance, this can include uptime of machines, number of breakdowns, labour time of individual operators at a station in comparison to actual machine processing time, and also, not following only one product or product family, but all products in the production flow. If successful in implementing real-time data in a VSM, the value stream can be dynamically displayed and improvements can be established, while at the same time continuously finding bottlenecks (Lugert, Batz, & Winkler, 2018).

The digitalisation trend has been ongoing for several years. However, since digitalisation includes new concepts and ways of working, companies are often struggling on doing the right things at the right time. Another complicating factor for utilising the benefits of digitalisation, is the rapid technological development. What was right to do yesterday, is not necessary the right thing to do today, putting many companies in a stalemate, fearing to make a move. Aa an answer to this, new frameworks, supporting the digitalisation transition have been created. For instance, Morteza (2018) does this in a six-step roadmap, explaining critical elements in succeeding with a digital transformation. Pessl, Sorko, and Mayer (2017) have created a similar guide, also divided into six implementation steps, focusing on how different divisions within companies should act differently. The applicability of such guiding frameworks is though questioned by e.g. Santos et al. (2017), calling them unclear and hard to follow due to the wide range of possible technological solutions available. Lastly, Morteza (2018) highlights the importance of tailoring guidelines for certain industries, or even individual companies. In the area of digitalisation transformation, the author argues that a general approach does not exist. To succeed with it, it is thus necessary to adapt the strategy used to the prevailing circumstances.

3 CASE COMPANY INTRODUCTION

In this section, the context of the company studied is set up, starting with a brief introduction to the company structure and business area. This is followed by more in-depth descriptions of the production flow, which here is divided into a physical flow and an informational flow.

3.1 General company introduction

The studied company in this project acts within the dental business and offers a wide range of products. They have production facilities worldwide, whereof this project deals with the one located in Sweden. This facility is supplied with raw material components manufactured by another plant within the company. Briefly described, the main tasks for the Swedish facility is to refine the surface finish of the products, and to pack them into containers that can secure the required sterility of them. Finished goods are shipped to a foreign central warehouse at a daily basis.

Since the company acts in the dental business, and their products are used in dental applications, there are high requirements on the cleanliness of the final products. Thus, almost the entire production is carried out in a cleanroom environment with a low level of pollution in order to avoid contamination of the products.

3.2 Physical production flow

The Swedish production facility consist of two separated production flows, each producing different brands. This project is limited to only consider one of these flows, which is the one further described below. At the studied production flow, two different brands are manufactured. The different brands however hold similar products, and the processing times in the workstations are the same, regardless of product or brand. Until the packaging stations, the brands follow the same flow, resulting in several workstations being shared resources. Throughout the flow, the products which have a size ranging between 5-20 mm, are transported with the help of different carriers to avoid contamination from operators. The common batch size is within the span of 100 to 600 pieces.

All workstations in the production flow are described below. The focus of the following sections is to describe how much attention operators must give to the stations to keep them up and running, and how different batch sizes affect the process times of the stations. As previously mentioned, almost the entire production flow is kept inside a cleanroom environment. The exception for this is the blasting process and workstations downstream of the blister packaging.

In addition to the main production flow, where the final products are being processed, there are two supportive side flows. The dynamics of the flow, including the side flows, is illustrated in Figure 3.1, where it is important to note that the main flow will be halted if the side flow activities are not completed when needed. For instance, the carrier assembly cannot start before the screws and supports are prepared. The same goes for the blister packaging process, which is reliant on the completion of the titanium cup process. Since both the titanium cups and the screws and supports are linked to specific production orders, they are not made in bulk and put in stock. In order to avoid unnecessary stoppages, there is thus a need of synchronising the main flow with the side flows.

Another element that affect the flow is the carriers that are used to transport products within and between processes. There are several different carriers used throughout the flow, all with a tailored design to fit the need at certain stations. Since some of the carriers are made out of an expensive material, there are a limited number of them, creating a situation where they have to be used wisely to reduce the risk of shortage. If there is a lack of a certain carrier for a production order to be processed, it must wait until the right carrier is available. How the different carriers are integrated in the flow is depicted in Appendix B.

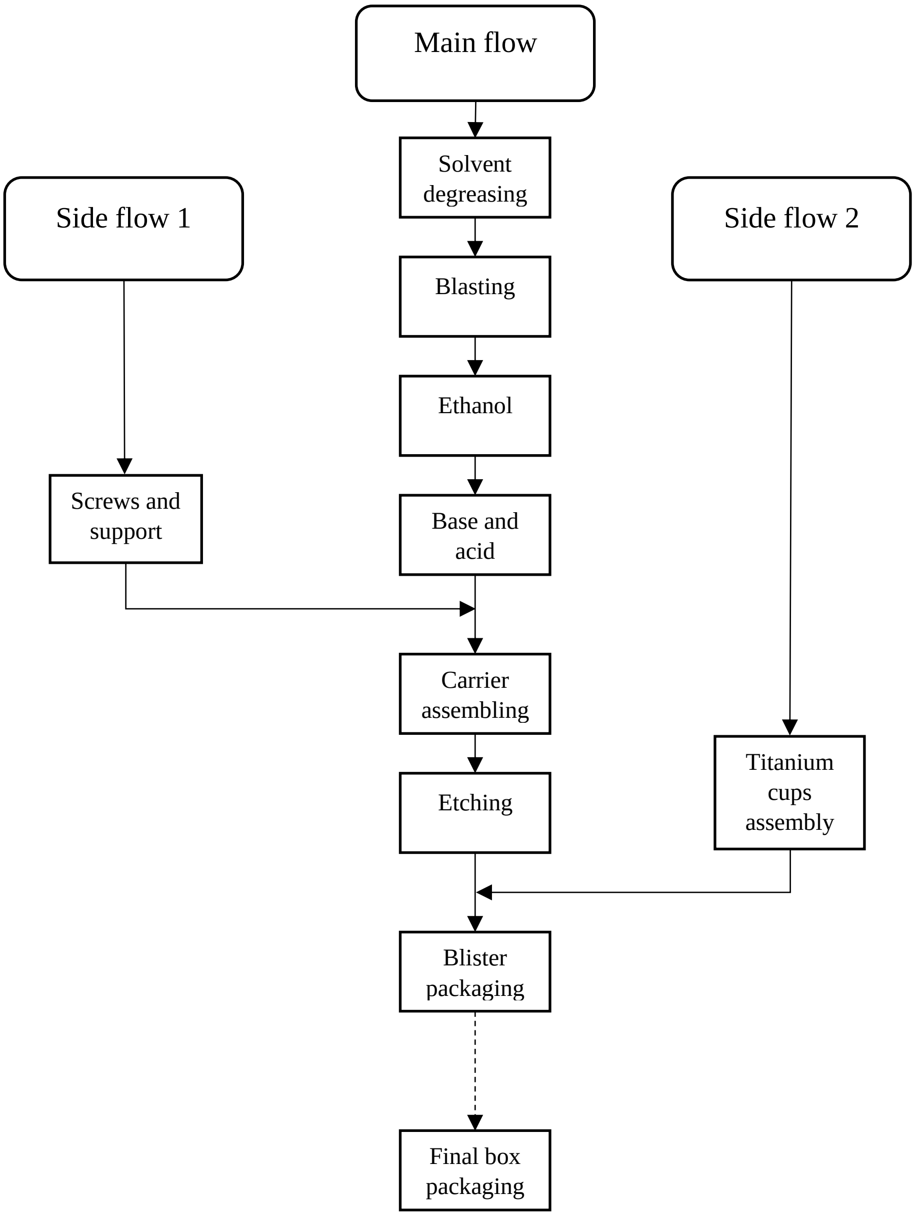


Figure 3.1 Main and side flow dynamics

3.2.1 Solvent degreasing

The first station of the production, solvent degreasing, is a chemical cleaning process which includes two steps in order to secure the high requirements of the cleanliness of the products. One operator at a time works at the station with the responsibility to gather material, change chemicals between the two cleaning steps, and lastly to deliver the cleaned products to the downstream buffer. If necessary, it can be possible for two operators to work in parallel with different production orders at this station.

It is important that the operator is present in the end of each cleaning step as the products might be damaged if being processed too long. However, the process itself is automated and the operator can perform external tasks during the cycle time, such as preparing for the following cleaning step. Since the cleaning steps have predetermined cycle times, the total process time is not dependent on the batch size. The solvent degreasing is a shared resource for the two brands in the flow. Additionally, titanium cups used later in the process are also cleaned following the same procedure.

3.2.2 Blasting

To give the products the right surface, they are blasted using a metal powder. Before the products can be blasted, they must be completely dry after the previous cleaning process. This drying process takes place in a fume hood, which also works as the product buffer between the workstations. Since metal powder is involved, potentially causing contamination, the blasting process is kept in a separate room, away from the cleanroom environment. Products are exchanged between the cleanroom and the blasting room via a two-door lock, where operators in the cleanroom leave products to be blasted, and later fetch blasted products.

The operator working at the blasting station must constantly be present to feed the machine to keep the process up and running. As the machine is fed product by product, a larger batch size means a longer process time. To ensure the quality of the products, they are visually checked by the operator, while a counter keeps track of the number of products produced. If the operator deems the blasting of a product to be poor, it can be blasted again. As in the solvent degreasing process, the blaster is a shared resource. Finished orders are placed in the two-door lock, where they are kept in buffer until being further processed in the ethanol station.

There are two parallel blasting machines in the production flow. They both share the same operator attention characteristics but differ in productivity. The machines can be run simultaneously if being manned by two operators.

3.2.3 Ethanol

From the blasting process, excessive metal powder sticks to the products and must be removed. This removal process is similar to the initial cleaning process, and thus has the same batch dependency and operator attention characteristics, which also means that the resource is shared by the two brands in the flow. Finished orders are placed on metal carriers that are designed to fit in the downstream base and acid machine. Basically, this carrier is a flat tray, where the products can be evenly spread out. Orders with a batch size of 600 pieces, which is the largest size being released in the flow, can all fit on one carrier.

In addition to the products that have been blasted, the side flow consisting of screws and supports, are also processed at this workstation. These components are later used at the carrier assembly station. Before being used, screws and supports must be dried in a fume hood, which again, also works as a buffer.

3.2.4 Base and acid

This is another chemical process used to obtain the right surface finish to the products. It is built up by five baths, altering between chemicals and water rinsing. After the baths, the products are dried in a built-in dryer. The process is highly automated, and the only attention needed from the operator is when starting and finishing orders. When starting an order, operators feed the machine with the metal carriers introduced in the upstream process. As the order is finished, the machine signals the operator, who can deal with other tasks during the cycle time of this workstation.

The different baths take the same time to finish regardless of the batch size. This is also true for the final drying process, but where larger batch sizes could take slightly longer time to dry. At maximum, the machine can deal with four carriers at the same time, being processed in different steps within the machine.

3.2.5 Carrier assembling

In contrast to the base and acid machine, the carrier assembly station is a manual process. The station can be seen as a preparation step for the downstream etching process, where the inner side of the products must be protected from chemicals. To do this, products are assembled to a new carrier, using the screws and supports, previously mentioned in the ethanol process. This type of carrier can hold 300 pieces at maximum, meaning that orders with a larger batch size than this must be divided on more than one carrier. Since the products are assembled one by one, the total process time is longer for larger batch sizes. Before the products are fastened to the carrier, the operator visually checks their quality. At the station, there can be one to three operators working simultaneously.

3.2.6 Etching

A process with the same characteristics as the base and acid process. It is highly automated, and the operator can perform other tasks as the process is started. The etching process consists of three baths, shifting between water rinsing and chemicals. If neglecting that large batch sizes can take slightly longer time to dry in the final step of this process, the process time is independent of the batch size. However, as batch sizes larger than 300 pieces are divided onto two carriers, and a bath only can process one carrier the time, this must be considered when deciding the process time. The process time could be said having a stepwise dependency to the batch size.

3.2.7 Blister packaging

This process can be divided in two steps. Firstly, the products are disassembled from the carriers by a robot, and automatically put inside a plastic tube that has been prepared at a side flow station. Secondly, the tubes together with the products, are put inside a plastic blister and sealed with a cover to keep the products safe from contamination. The first process is automated, and the operator only need to load the machine with the carrier with products. In contrast, the second operation requires complete attention from the operator, who manually put the plastic tubes with the products inside the blister before they get sealed by the machine. For the two different brands, this workstation is a divergent point, and only the brand being analysed is processed in this machine.

During the start-up of this process, the operator can be supported by an additional operator to assist with eventual changeover due to the fact that changing between different covers is time-consuming. Since the products are packed in blisters one by one, the process time gets longer with increased batch size. The blister packaging process is the last process within the cleanroom environment. In direct connection to the station, there is a hatch through where products can be transferred to the downstream process with lower cleanliness requirements, as the product now is sealed. Occasionally the operator manually transfers a box of finished products through the hatch which sets the downstream operator into work.

3.2.8 Sterile box packaging

After receiving the plastic box with blistered products, the operator at this station put the products on plastic trays in a carton box to later be sent to the external sterilisation process. The operator at this completely manual station is always present and pack the products in the pace they are delivered from the upstream machine.

In addition to the packing process, the operator working here is also responsible for checking the quality of the blister packages. In case of unacceptable quality, the products are sent back to go through the blister packaging process again. To support the more time-consuming blister packaging process, the operator here is also responsible for finishing that process in the ERP-system.

3.2.9 External sterilisation

Products packed in sterile boxes are sent to an external sterilisation process twice a day, once in the morning and once in the afternoon. The external steriliser is part of the same company group, located in the building next to the production facility, enabling close collaboration. It is however necessary to use a truck to transport the products between the facilities. Every morning, products sent to the sterilisation process the previous day are returned. Thus, the lead time of this external process, including waiting time before the products are sent, is close to a day. In addition to the products being studied at this production flow, the external actor is also responsible for sterilising other products from the company. However, their capacity is rather high and there is a low chance of overloading the system.

3.2.10 Final box packaging

When products are returned from the sterilisation process, they are put in a buffer before the final box packaging process, where products are put in the box that is later delivered to customers. The machine is rather automated, folding boxes and putting the blister packages inside. Lastly, the boxes are grouped ten by ten and moved into a larger shipping box. Since the products are packed one by one, the cycle time is dependent on the batch. In case of poor quality, such as unreadable prints or badly folded boxes, products can be re-worked by running them one more time.

The operator at this station is responsible for feeding the machine with products and boxes, where the products are gathered from the upstream buffer. Regarding the boxes, they are printed in a printer, specially designed for box printing. During the cycle time, the operator has time to print boxes and prepare material for the upcoming order. As this machine manages several different product types, it is a shared resource.

3.2.11 Documentation control

In this final step, an operator makes sure that the documentation and details for the order is according to standards. For instance, the operator checks that the order is signed as it should and goes through the products that have been scrapped along the production flow. The operator must pay the same attention to an order, regardless of the batch size. If everything is fine, the products are placed in a buffer, waiting for a shipment to the abroad final storage. The physical production order, i.e. the complete documentation and details regarding the certain batch being produced, are sent for further inspection at the quality department.

All products being manufactured within the plant passes this station, and it can thus be seen as a final convergent point of the different flows.

3.2.12 Side flow 1: Screw and support

As mentioned earlier, the screws and supports are used to keep the products in the right position at the carriers. These components can be used several times, and if used earlier, they are processed in the ethanol process, as also described above. New screws and supports, that have not been used in the flow before, must be cleaned properly, using the same steps as in the solvent degreasing process. When the components are processed, they require full attention from the operator, and the process time is independent on the batch size.

3.2.13 Side flow 2: Titanium cup assembly

This side flow process is a manual assembly station, where operators prepare the plastic tubes that are used in the blister packaging process. The operator put titanium cups, that previously have been cleaned in the solvent degreasing process, inside the plastic tubes. Later, when products are placed in this subassembly, they are kept safe from contamination. If necessary, several operators can work at this station simultaneously.

3.3 Informational production flow

The following sections describe how the informational flow is built up to steer and support the physical flow. Initially, the planning procedures for the raw material components and production orders are described. This is followed by an explanation of the informational flow at the shop-floor level. The main task of the planning department is to decide what to produce, while the shop-floor information help operators to execute their actions when working in the production flow.

3.3.1 Raw material component planning

As previously mentioned, the raw material components are supplied by another production plant within the company. Since this production has long setup times, their production batches are normally larger than the ones used in the Swedish plant. The planning department of these components are physically decoupled from the Swedish plant and are instead tied together via the ERP-system, where production orders are placed based on predicted demand, current stock levels and products in ongoing production. Delivery of the components takes place 1-2 times per week. When arriving, the raw material components are put in a buffer that is located within the cleanroom environment.

3.3.2 Production order planning

Before the raw material can be further processed, a production order must be started. Production orders are started daily, based on certain criteria. These criteria are based on factors such as stock level of finished goods, actual and predicted demand, and products within the production flow. If the right raw material components are in stock, production orders for products with the highest priority are started. Otherwise, products with the highest priority that have components in stock are started.

The decision to start a new production order is made by a production coordinator that works close to the flow. If a certain product for some reason needs to be processed extra quickly, the coordinator can prioritise it, and thus override the first-in-first-out principle that otherwise is followed throughout the flow.

3.3.3 Shop-floor informational flow

For the operators, the shop-floor informational flow follows a similar pattern for all workstations. The flow is a combination of a digital and a manual flow, where the operator handles both a physical paper copy of the production order and communicates with the digital production system. Before performing the tasks at the certain workstation, the operator firstly chooses the right order to process according to the first-in-first-out principle. This is done by checking with the digital production system, where the orders are correctly sorted. Thereafter, the products and material needed are gathered together with the paper copy of the production order, that is located alongside the corresponding products throughout the flow.

After registering material and products in the PLC at the workstation, the actual process can be started. When later completing the order, the operator must finish the order in the ERP-system and print a paper copy of a machine run report, that is used for traceability and quality control. The machine run report is put in a folder together with the production order, and as the flow proceeds, the folder gets filled with the reports from every workstation. As a last step, the folder is placed in an order shelf, close to the buffer where the products are kept.

4 METHODOLOGY

In this chapter, the used methodology is described, including how the four steps of the VSM were performed, how the manual and digital data collection was performed and what was done to uphold the reliability and validity of said data. This is followed by a description of how a roadmap to develop towards digitalisation was created. Lastly, how the design of an internal production assessment standard was created, combining VSM with the utilisation of digital data, is explained. Figure 4.1 illustrates the different components in the used methodology and how they were composed in order to fulfil the aim. The frame of reference, presented in chapter 2, works as the basis for the entire methodology. As can also be seen in Figure 4.1, there was an iterative process between the VSM and the data collection. This to both assure the data validity and reliability, as well as re-taking inadequate measures.

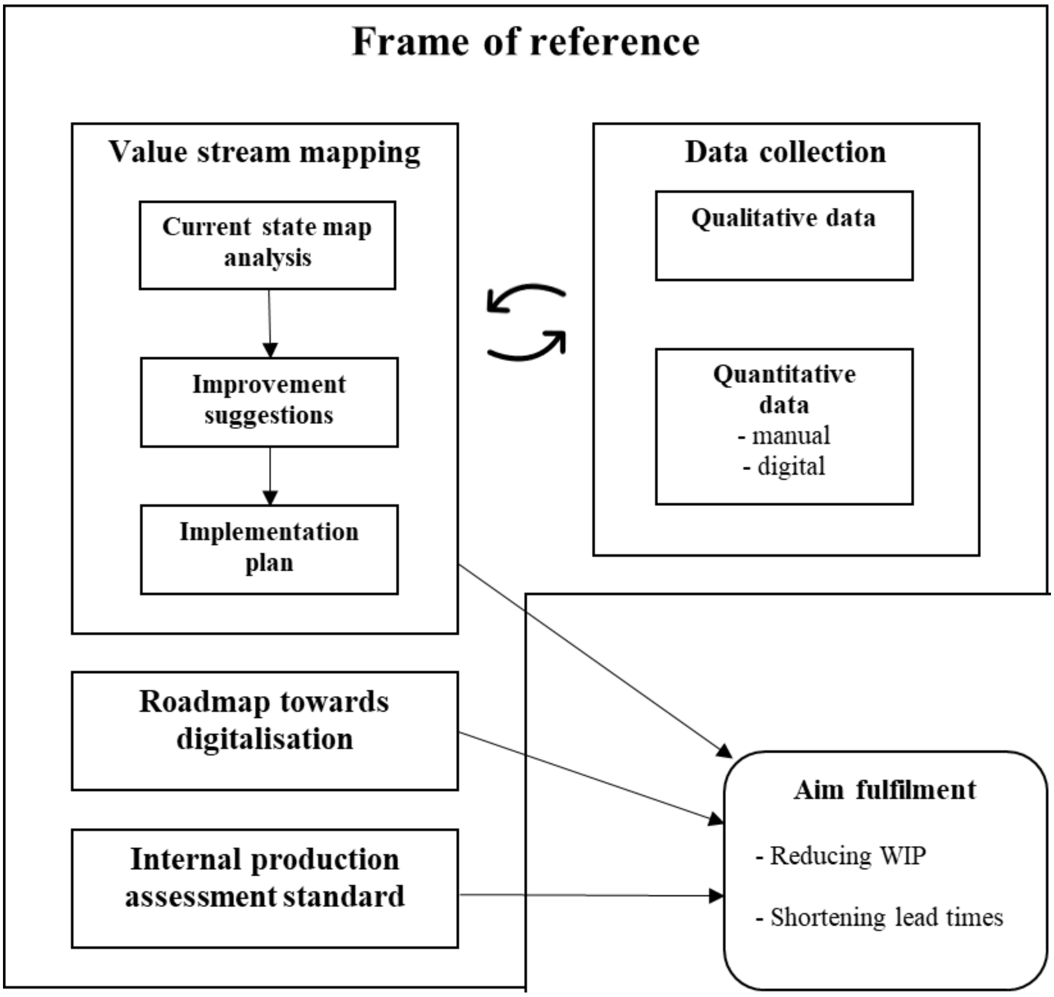


Figure 4.1 Methodology structure

4.1 Value stream mapping

When performing the value stream mapping consisting of the four steps suggested by Rother and Shook (2009), the two first and the fourth were closely followed. At some instances, these steps required important assumptions and decisions to be made in order to move forward. Additionally, the analysis of the current state map, which is guided by the eight questions (Rother & Shook, 2009), was complemented with the theory of constraints philosophy (Goldratt & Cox, 2004; Rahman, 1998). The third step, drawing the future state map was executed in a different way than suggested by Rother and Shook (2009). Regarding the fourth and final step, implementation plan, an extended approach compared to the one suggested by Rother and Shook (2009) was chosen. How this and other modifications to the traditional VSM approach was executed, as well how the important decisions, assumptions, and the combination of the eight questions and the TOC was carried out, is explained in the following paragraphs.

4.1.1 Choosing product family to investigate

Since the production flow at the studied company is complex, including both parallel flows and a wide range of products, one product family was chosen to be studied for the value stream mapping. This to avoid making the map too crowded and difficult to follow, as suggested by Rother and Shook (2009). Through discussions with people at the company, the product family most crucial for the revenue was chosen. This product family was also considered being the critical one for the customers, further confirming the choice.

4.1.2 Determining takt time

How to calculate the takt time was presented in equation 2.1. The equation itself is straightforward, however determining the varying customer demand is not. There are numerous ways and models that can be used to predict future demand and is a complete research topic on its own. To facilitate the demand prediction, it was simply set to the average of the actual sales volume the past year. The downside with this approach is that it does not consider any trend or seasonal demand peaks. However, it at least gives an indication on what volumes the production system must be able to cope with in the nearest future. The numerator in equation 2.1, available working time, was deduced from the work schedule in the production, with consideration to breaks, reoccurring meetings and multiple shifts.

4.1.3 Combining VSM and TOC

Both Librelato et al. (2014) and Garza-Reyes et al. (2019) identify a combination of VSM and TOC as promising as the methods work as complements to each other. In this study, a similar combination of approaches that was successfully tested by Garza-Reyes et al. (2019) was implemented. It is however notable that this project more closely follows the traditional VSM steps suggested by Rother and Shook (2009), while Garza-Reyes et al. (2019) are using an adjusted version that is tailored for their process.

Practically, the combination of the methodologies meant that issues in the production system were discovered with the help of the current state map together with the eight questions, created in line with the VSM approach. Subsequently, the TOC methodology was applied to critical workstations. Criticality of workstations were based on their cycle time workload in relation to the calculated takt time. Thus, stations with cycle times close to the takt time were investigated further, using the four last steps of the TOC methodology.

4.1.4 Future state and improvement suggestions

Instead of drawing the future step map as suggested by Rother and Shook (2009), only concrete improvement suggestions were listed. This was done since companies new to VSM, like the one being studied, should focus on finding improvements easy to implement, not needing any major investments (Rother & Shook, 2009). Without doing any major changes, the future state map simply would have been similar to the current state map and was thus not drawn.

A benefit from having this alternate approach, not drawing an ideal future state map, was that no assumptions regarding how much cycle times or level of WIP potentially can be improved were needed. Thus, simple guesses and prediction regarding the future, possibly spreading false expectations to the company could be avoided.

4.1.5 Implementation plan

The implementation plan was designed similarly to the one proposed by Rother and Shook (2009), focusing on how to achieve and implement the suggested improvements. Since the improvement suggestions already were clearly listed, and not built into a future state map, the creation of the implementation plan was straightforward. The improvement suggestions together with the plan itself, were formed successively during the work with the VSM. Waste activities and other inefficiencies that were found were the base for the improvement suggestions made. These were then incorporated to the implementation plan, complemented with planned start date and what effect the proposed improvement can have when implemented. Moreover, if a change had too little information, then it is stated that more research should be done before implementing this change.

4.2 Data collection

To successfully create a VSM, there is a need of gathering different kinds of data. For instance, to be able to draw the current state map, it is necessary to be familiar with the production flow of both the physical products and the information required for execution. This type of data is of a qualitative nature (Patel & Davidson, 2011), and how it will be gathered is presented in the consecutive section.

In addition to the qualitative data, the VSM itself requires data on e.g. cycle and set-up times of certain machines and the size of buffers in a specific point of time. Such data is of quantitative nature (Patel & Davidson, 2011), and can be obtained by making measures in the real production, e.g. by clocking cycle times and counting number of products in a buffer. How the qualitative data is collected is described in section 4.2.2.

4.2.1 Qualitative data

Before taking measures and analysing the production flow in detail, a basic and practical understanding was obtained regarding how the production flow and its informational flow work. This by walking the complete production flow about to be studied as recommended by Rother and Shook (2009). The first production tour was guided by a production manager, sharing information about the purpose of every workstation, and describing how the informational flow is built up. To get a deepened understanding of how the operator works at every station, and how the products are processed more in detail, a second production tour guided by a shift manager was completed. After these tours, enough basic knowledge was gathered to continue the production assessment without structured guidance, meaning no person was set aside to support with guiding.

As the project proceeded, and when the basic data described above was gathered, the demand on more complex and detailed, many times abstract or subjective information increased. This type of information could e.g. concern how a certain machine is fed with material or how the information flows between two adjacent workstations. It could also consider subjective factors such as how the production flow is perceived by the operators et cetera. To pick up that kind of information, workstations were observed while processing several different production orders. The operators working at the stations being observed also worked as a source of knowledge and inspiration, asking them questions about the flow and if having any improvement suggestions. Together, this qualitative data regarding the production flow helped to later realise what measures to take in order to represent the actual production flow in a realistic way. As an initial contact and relationship already established with the operators, it was easier when later explaining the purpose of the time measurements to be taken at the different workstations.

In addition, information from old VSMs, previously done by the company, was analysed and used as a starting point when drawing the current state map. Further, repeated dialogues were held with employees from different departments, assisting with specific information regarding their working area. For instance, the planning department was consulted for questions regarding material and production planning, while the engineering and quality departments were contacted with questions concerning their areas of specialty. Thanks to a high availability and acceptance from the different departments being contacted, the communication has been informal and unstructured. The data being gathered was continuously noted, summarised and written down in a digital document sorted by date. This structure allowed a good overview and a possibility to go back to old data already gathered.

4.2.2 Quantitative data

The quantitative data gathered is here divided into two parts, manual measurements and digital data. This is done since the methods used to gather the data is different, even though the form of the data is similar. Together, the data work as the input for the present state map and later analyses. The different types of quantitative data that was gathered are listed in Table 2.1 in chapter 2.

4.2.2.1 Manual measurements

The manually gathered measures were captured by using traditional stopwatches. In order to notice all the details, every workstation was measured separately by two measurers simultaneously. To obtain some stability in the measurements, two to five complete production orders, or batches, were studied at every station. The reason for not doing the same amount of measures at the stations is the big spread in total process time for different workstations. Since the production studied takes place in a cleanroom environment, it was not allowed to use contaminated equipment, such as ordinary laptops or similar. Thus, approved pen and papers was used to store the data when taking the measures. After exiting the cleanroom, the data was transcribed and digitalised for further analysis.

As mentioned by Zandin (2001), it should be expected that operators do not work at their average pace when being observed and measured. In other words, it is probable that the operator being studied will perform a task either slower or faster than during normal circumstances. To mitigate this effect, Zandin (2001) stresses the importance of establishing an acceptance among the workforce being studied. Thus, before the first measurements were initiated, the production managers briefed the operators about the upcoming measurements. Right before the measurements took place, the operators were given a more in-depth description of why they should be carried out and were requested to work at an ordinary pace.

4.2.2.2 Digital data

The digital data retrieved was extracted from the production system used in the company. Some data were gathered to complement the manual measurements, and some with the purpose of testing the validity and reliability of said measurements. For instance, within a limited timeframe, it could be difficult to manually measure reliable scrap rates and inventory levels. By instead utilising digital data, it was possible to determine such measures based on data from several years of production.

In Table 4.1 below, the different types of digital data gathered are listed. The last column of the table shows whether the data could be compared with the manually measured data or not. Note that *Real throughput time* is included here, but not in Table 2.1. From a VSM perspective, the throughput time is calculated from other measures, while the digital data can show throughput times from actual production orders that have been processed in the production system. Before being used, the digital data was sorted, and poor data was removed to not mislead the analysis. Sources of poor data points were e.g. small test batches and cycle time measurements not stopping during breaks, resulting in unrealistically long cycle times per piece at the different workstations.

Table 4.1 Digital data specifications

Measure	**Unit**	**Comparable with manual measures**
Batch size	[s]	Yes
Cycle time	[s]	Yes
Past demand (for takt time calculation)	[pcs]	Alternative calculation/assumption possible
Inventory level	[pcs]	Not completely (foreign warehouses)
Real throughput time	[s]	No
Scrap rate	Percentage	No (samples possible)
WIP	[pcs]	Yes

4.2.3 Data validity and reliability

During the collection of qualitative data, it was important to make sure that the information gathered was reliable and valid. By having a structured interview with questions made in advance, the prerequisite of obtaining a good reliability is achieved according to Patel and Davidson (2011). However, different interviewers can interpret an answer differently. Thus, both authors made separate notes and, in the end, examined the result. This was done to achieve an inter-rated reliability, i.e. used the data that both authors agreed was stated in order to increase the credibility of the data used, by reducing the risk of individual interpretation (Patel & Davidson, 2011). Moreover, the validity of the information was checked by three different aspects. Firstly, several operators were contacted in order to check the validity of the information. This to have a comparison between answers in order for repeated patterns to appear. The information was then cross-examined between different operators, since operators can have their own interpretations and experiences that might deviate from the truth. Secondly, the author themselves used their own knowledge of the production system in order to validate the information retrieved. Thirdly, and lastly, the answers themselves was later checked with experts of the production system, to get their input on the collected data.

A similar approach was made during the collection of quantitative data. Both authors did individual measurements which also meant that different measuring devices were used to avoid any bias or mistakes (Patel & Davidson, 2011). Moreover, several operators were studied, more than once, in order to find reliable measurements in order to obtain a realistic representation of the production flow. Regarding the validity of the quantitative data, the measured values must correspond to its intended use (Patel & Davidson, 2011). For instance, when cycle times were measured, the stations were studied in advance to make sure that only the cycle time, and not parts of the setup time were included in the measurements. Moreover, with rotations of production workers during two different shifts, workers have different expertise and speed of the operations. In other words, different setup times is achieved depending on which operator being studied. Therefore, three different validation methods were used to obtain valid measurements. The first method, the authors themselves could critically review the obtained measurements due to having studied the production system in person. However, smaller errors could be difficult to detect using this approach because of little experience of the production system. The second method was therefore to let experts of the production system validate the data. The third method was to validate both the manual and digital data by having them compared against each other.

4.3 Development of a roadmap towards digitalisation

A roadmap towards digitalisation was constructed for the company to reach a more digitalised state, functioning as a guide on how to make more and better use of digital data. This strategy was designed with the studied company in mind but is deemed to be applicable on similar manufacturing companies, due to its generality. The different components of the roadmap were based on the frame of references.

Moreover, experiences from collaborating with the studied company was also a source of information towards designing the roadmap, regarding both the manual measures and when worked with digital data of the. On the other hand, a similar roadmap or guidelines on how to implement a more digitalised approach was not studied.

4.4 Development of internal production assessment standard

The idea of developing a standardised production assessment method, was to make it possible for the company studied to perform similar production assessments in the future and at other global sites as well. In other words, the overall purpose was to give the company a chance to keep on working with productivity improvements on a regular basis. Having a standard on how to perform a complex task is seen as a fundamental strategy in order to improve efficiency and quality (Wears, 2015). Furthermore, to successfully implement a VSM at a company, it is beneficial to tailor the procedure to that specific company (Kurdve, Zackrisson, & Harlin, 2014). Consequently, assumptions and calculations made using the VSM tool and digital data was documented and implemented in the standard.

Belkin (1984) mentions that in order to design successful work instructions, it is vital to understand the challenge and problem of the future users at the company. Therefore, an important step towards constructing the instructions was to make a production assessment, in order to manage and solve upcoming challenges during the assessment process. In the end, these solutions were included in the production assessment standard to guide future users. Moreover, utilising information from both production workers and engineers that have great experience from the production system (Belkin, 1984). This was an ongoing process, communicating with future users in order to revise and improve the work instructions.

5 RESULT

This chapter starts with a stakeholder analysis, revealing how the research questions were constructed. Then, the VSM is shown, starting with the current state map which is complemented with a bottleneck analysis using the collected manual measurements. Moreover, a comparison between the screened digital data and the manual data to validate both sets of data, which leads to using a combination of them. This is followed by the last step of the VSM in this thesis, an improvement plan to reach a future desired state. Here is also a roadmap introduced of how to reach a higher level of digitalisation. Lastly, this project results in an internal standard for the studied company to use for future similar production assessments.

All numbers and values presented in this chapter are not real production values and have been reconstructed to keep the company demand on secrecy. The relation between the real values is however kept, not affecting the reasoning behind the results.

5.1 Stakeholder analysis

In the beginning of this thesis, the collaboration with the company initially was to examine and evaluate two different production flows. This was discussed back and forth in order to decide how the research questions were to be constructed, regarding how the analysis of the flows should be done. In the end of these discussion, the choice fell on mapping both current production flows, using the lean tool VSM, and continuing to find potential productivity improvements. However, since the production facility was closed during the project, there was only enough time to study one of the flows within the production. As a consequence, the focus shifted towards a deeper analysis of the one flow being studied, including digital data, in order to complement the manual data already captured. Thus, the research questions were changed accordingly, including one question examining how a combination of manual and digital data can be used for production assessment.

5.2 Current state map

In the current state map, see Appendix C, the cycle time of all stations are based on a batch size of 600 pieces. As previously described however, the batch sizes are in the real production flow altering between 100 and 600 pieces, where a batch size of 600 pieces is commonly used. This simplification, basing all workstations on a fixed batch size, is made to have the same prerequisites for all workstations in order to be able to fairly compare them.

There are two stations, the old blaster and automated carrier assembly, without any data in the current state map. These two machines are supplementary machines and are not used to the same extent as the other machines. The old blaster is producing three different brands, while the new blaster is focused solely on the brand the analysis is made upon. Furthermore, the automated carrier assembly is a new machine that has not yet been fully implemented in the production flow. Having said that, one operator at the manual carrier assembly station can manage the takt time, which also is the case for one operator at the new blaster. In other words, the supplementary machines must not run in parallel to cope with the takt time.

Regarding the data from the external sterilisation process, it has not been manually measured like the other stations. Instead, its cycle time is based on information shared by the external process owner. Interesting to note is the short process time at 1128 seconds in relation to the average lead time of the process at 1.2 days. The obvious reason for this is that the products are only delivered back to the company once a day, although the sterilisation process itself theoretically could deliver products at a higher rate. If more frequently delivering back products to the main flow, the lead time impact of the sterilisation process could be reduced.

Since it occurs sporadic quality controls on the products throughout the production flow, it can be difficult to pinpoint which station causing the scrap. This because a faulty product can pass through the flow and not be scrapped until a later stage. For instance, failures caused in the blasting process might not be detected until products reach some of the latter downstream processes. Having this in mind, it is difficult to decide the scrap rate for every individual workstation. Thus, there is a scrap rate of 0.85 per cent in the current state map, representing the entire production flow. Data on scrap rates on workstation level would have been beneficial and favourable, but the total scrap at least gives a good indication or sense of the overall impact of scrap. Also note that both the blasting and blister packaging station allow reworking of products, leading to reduced scrap but at the same time longer processing times.

The outputs, stated in the down right corner of the current state map, see Appendix C, is calculated according to equations 5.1-5.3. Production lead time, see Equation 5.1, is an estimate of the time it takes for an order to go through the entire production flow, including waiting time in buffers and final warehouse storage (Rother & Shook, 2009). Since the calculation includes waiting time in the final storage, products that are sold immediately or at least sold faster than average, will falsely be burdened with additional time. If interested in a purer production lead time, the time spent in the final warehouse can simply be subtracted from the production lead time. This will give an indication on how many days it takes from production start, till the products can be sold and shipped to end customer. However, if doing this, it is still important to remember that the final storage possibly is an inherent inefficiency that at least causes capital being tied up (Rother & Shook, 2009).

Total process time, seen in equation 5.2, is a measure of how long time a batch spends being processed at all workstations. In other words, it depicts how fast a batch theoretically could be processed if neglecting physical movements and waiting times in buffers and storages. The measure is an important building block when determining how much of the time spent in the production system that is value adding.

Calculating value adding time is difficult due to the fact that defining value adding time can be tricky. However, in this project, value adding time is chosen to be the total process time for all stations, i.e. the result of equation 5.2. This entails that order handling, movement and cleaning of the products are all classified as value adding time, which can be argued whether it increases value for the customer or if it rather is a necessary waste or activity that must be performed. That said, value adding time in equation 5.3 gives an idea of how much of the time in the flow that that stations actually are processing the products, without considering what actions actually is value adding time.

$$Production\ lead\ time\ (PLT) = \sum(WIP) * Takt\ time \qquad (5.1)$$

$$Total\ process\ time\ (TPT) = \sum(Cycle\ time_n * batch\ size) \qquad (5.2)$$

$$Value\ adding\ time = \frac{TPT}{PLT} \qquad (5.3)$$

As can be seen in Table 5.1, the calculated production lead time is 69.9 days, while the total processing time is 0.87 days. Together, this means that 1.24 per cent of the production lead time is value adding. Intuitively, this can seem as a low number, but it is reasonable to have a value adding percentage around 1-5 per cent (Haschemia & Roesslerûa, 2017). Also note that these calculations are made for the plant in Sweden while the raw material components are manufactured abroad before arriving to Sweden, making this only a part of the complete manufacturing lead time of the products.

Table 5.1 Outputs from the current state map

	Current state map (Lot size: 600 pcs)	**Equation**
Production lead time [days]	69,9	5.1
Total process time [s]	74795	5.2
Total process time [days]	0,87	5.2
Value adding time [%]	1,24%	5.3

When further analysing the production lead time, it is from Table 5.1 obvious that the total processing time has a little effect on it. Instead, the bigger part of the production lead time is spent in buffers and inventories, waiting to be processed or delivered to customers. Inventories here include the raw material storage and the final goods storage. Table 5.2 shows how the lead time is allocated over the production flow. Together, the time spent in the inventories stands for approximately 90 per cent of the total production lead time. Note however that products are available for sale already after 36.7 days, corresponding to total production lead time minus the time spent in finished goods stock. If the finished goods stock is filled with obsolete products, this measure could be a more accurate measure of the total production lead time. Again, the effect finished goods stock could have on tied up capital should however not be neglected.

Table 5.2 Influence of buffers and inventories on production lead time

	Percentage of total production lead time	**In days**
Raw material stock	41,0%	28,6
Buffers	11,6%	8,1
Finished goods stock	47,4%	33,1
	100,0%	69,9

5.3 Current state map analysis

In this section, the current state map is analysed using two different approaches. Firstly, following the VSM methodology, the eight questions are reflected upon and the value stream itself is designed. Secondly, a more classical bottleneck detection is constructed, using TOC to find and mitigate bottlenecks. This section ends with a validation of the data used in the VSM by comparing it to digital collected data over the span of a year, to make sure that the manual measurements are credible.

5.3.1 Eight questions of VSM

Below, the eight questions suggested by Rother and Shook (2009) are answered. Some of the questions have already been touched upon, but they still serve the purpose of guiding the analysis of the current state map.

Q1: What is the takt time of the system?

The takt time of the studied product family is 40 seconds, which is calculated using equation 2.1. However, if a station and its upstream buffer are shared resources, the takt time is a combined value of all different products types produced in that station. This results in a takt time of 21 seconds and occurs when said stations and buffers consist of multiple brands or product types. Note that a shorter takt time is more demanding from a production system perspective, meaning that the system must manage to deliver a finished product more often.

Q2: Should finished products be produced to a warehouse, or be directly delivered to customers?

The company produces multiple variants of each product. Moreover, the production lead time is long and therefore the production system is not that flexible in producing a certain product variant on demand. Thus, delivering to customer directly would mean a long time until the customer receives the order. With that said, continuing to produce to warehouse is deemed as a more reasonable option. However, further in the future, this could be questioned again since producing on demand often is preferable from several perspectives (Rother & Shook, 2009).

Q3: Where in the flow is a continuous flow possible?

The production consists of several workstations that are batch independent. That is, they have the same process time regardless of how many products within the batch. This makes a continuous flow less suited, as the current machines and stations will demand a big change in order to accomplish a continuous flow. However, continuous flow could be implemented in the end of the production flow, between blister packaging and sterile box packaging. However, with a big difference in cycle time, it would be unbalanced with a lot of idle time at the blister packaging station. For it to work, the stations would have to be rebalanced, e.g. divide work tasks between the two operators better. Since these workstations are separated by the cleanroom boundary, this could however be complicated and inconvenient.

Q4: Where in the flow must a supermarket pull system be used?

In the main flow, there is no need for a supermarket pull system to keep up the flow. Instead, products are pushed through the system after the start of a production order. To start an order, it is however necessary that raw material is available in the storage at the beginning of the flow. This storage is though not used a pulling point since the replenishment is independent on the rate of its withdrawal. As previously described, the raw material is instead replenished based on customer demand prediction in relation to the present inventory level of finished goods. Regarding the side flows, the replenishment of their components is reliant on a supermarket pull system, using Kanban cards.

Q5: What point in the flow is the pacemaker of the system?

A pacemaker is the process or information that dictates the pace of the production flow, meaning it is halted if the pacemaker does not signal the production to continue (Rother & Shook, 2009). The studied flow is dictated by the release of production orders, which is done on a daily basis. After being released, orders are pushed through the production flow and every workstation.

Q6: How will the production mix be levelled at the pacemaker?

Since the pace is dictated by the release of production orders, which in turn is based on prioritisation rules and available raw material, there are no natural levelling in the system. Since parts of the system gets overloaded if only producing one of the different brands, the person responsible for order release must however pay attention to the production mix. For instance, the limited number of carriers could be limiting factor if not considering the production mix in the flow.

Q7: In what batch size should products be produced?

Currently, the batch sizes range from 100 to 600 pieces. Keeping in mind that it exists a relatively low number of carriers and that a carrier can hold 300 or 600 pieces, depending on what type of carrier. Moreover, striving towards a one-piece flow is not optimal in this production flow, since the cycle time of certain machines are the same independent of batch size. This means that the cycle time per piece is lowered with larger batches. Thus, in order to utilize the carriers and simultaneously keep the cycle time per piece at a low level, 300 pieces is deemed to be the smallest possible batch size, if having it fixed.

Q8: What process improvements are necessary to achieve, in order to reach the future state?

See section 5.6.

5.3.2 Bottleneck analysis

The current state map and its manually- measured cycle times, seen in Appendix C, is here used to analyse which station that is the bottleneck of the production flow. Blister packaging is the workstation with the longest cycle time, intuitively making it the bottleneck of the system. However, in a complex production system like this, where several resources are shared among several products and brands, the longest cycle time might not always reflect the true bottleneck. Because of resources being shared, the availability of each station, or rather how occupied stations are, must also be considered. For instance, a workstation with a short cycle time, producing big volumes, are busier than a station with the same short cycle time, producing fewer products.

To cope with the shared resources and give a realistic image of the reality, the cycle times of the workstations have been weighted in relation to their production volume. If two or more different products are produced in the same machine, the cycle time of that machine increase with the same ratio as the total production volume ratio of all products produced in that machine. For instance, consider a station producing two products. The considered product has 40 per cent of the total output in the machine and the other product has 60 per cent, while the cycle time for both products are 10 seconds. Then the considered one would have a weighted cycle time of 25 seconds, see equation 5.4. Once again, this is done in order to adjust for the availability of the machine.

$$10s * \left(\frac{0.4+0.6}{0.4}\right) = 25s \qquad (5.4)$$

By comparing weighted cycle times with each other, instead of plain cycle times, it is possible to identify the bottleneck of the complete production system, and not only the bottleneck for the certain product. Figure 5.1 shows a comparison of the measured and the weighted cycle times. The figure also shows how the cycle times relates to the calculated takt time. Further, the blister packaging process, that previously was identified as the possible bottleneck station, has the same cycle time, weighted or not. This since only one type of product is produced in that station, which is not the fact for e.g. the base and acid station or the final box packaging, where several different product types are manufactured, resulting in an increased cycle time when weighted.

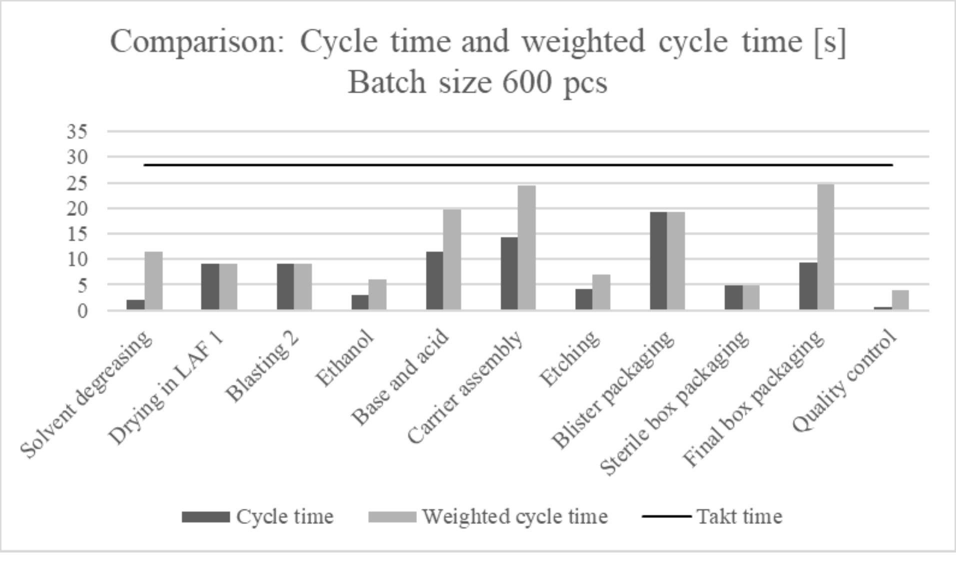


Figure 5.1 Weighted cycle times showing the impact of stations producing several products.

Considering the measure of weighted cycle times, the bottleneck of the system seems to be a close call between the station carrier assembly and final box packaging, as can be seen by looking at the lighter bars in Figure 5.1. However, before stating anything definitive, some details must be considered. Firstly, the cycle time of the manual carrier assembling is based on only one operator performing the operation. However, there can be three people working there simultaneously, making it possible to reduce the cycle time by increasing the number of operators. Moreover, the new automated carrier assembly, not yet producing at full pace, can work with some orders in parallel. When the machine is fully implemented, it will be able to relieve the pressure on the manual carrier assembly further. Secondly, the weighted cycle time does not consider the sequencing of production orders. If the system for instance is loaded with one type of product, the bottleneck might shift between the stations with highest weighted cycle times. A last important note from Figure 5.1 is the fact that all stations, even when considering weighted cycle times, manage to cope with the takt time, illustrated with the black horizontal line, meaning the present demand can be met in the way the production system is managed today, if producing to a fixed batch size of 600 pieces.

The analysis initiated above, is based on a fixed batch size of 600 pieces. However, and as previously written, the batch size in the real production flow varies between 100 and 600 pieces. Since some cycle times are dependent on the batch size and some are not, an analysis with a fixed batch does not tell everything about the dynamics in the real flow. In Figure 5.2, a comparison is made between having a batch size of 300 and 600 pieces, where all cycle times are weighted. Sizes of these are the most common batch sizes used, due to the fact that carriers either have 300 or 600 pieces as maximum capacity. Importantly, more time is spent on order handling and movements between workstations when decreasing the batch size, because a greater number of orders, with a smaller batch size, will be processed. As can be seen in Figure 5.2, the cycle time for each station increases with a batch size of 300 pieces but still remains within the takt time, except for the base and acid station. Having said that, base and acid together with etching are automated machines that are up and running during breaks and meetings. Hence, resulting in more available working time compared to the manual stations, meaning their real capacity is higher than indicated in Figure 5.2. However, in the case of base and acid, which cycle time exceeds the takt time by approximately 15 seconds, this cannot fully be offset by the increased available working time.

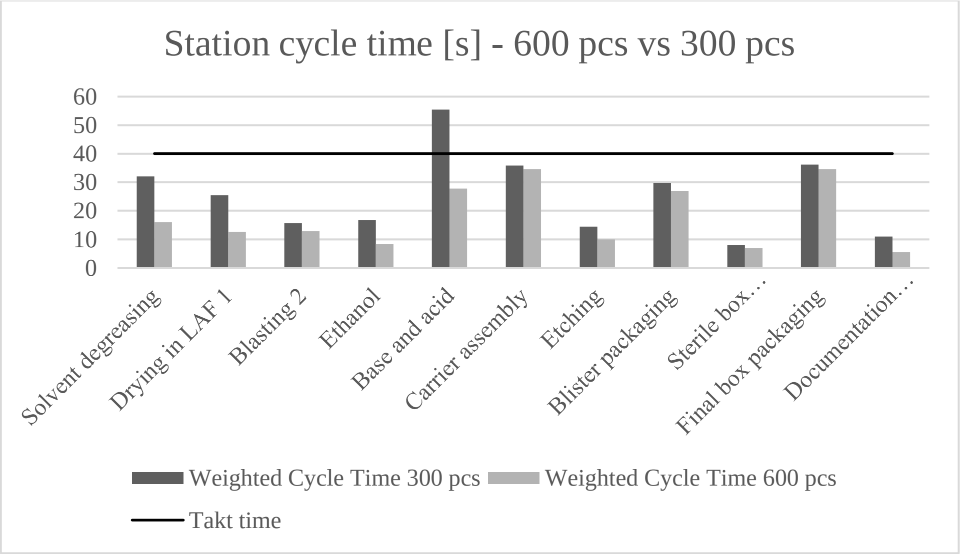


Figure 5.2 The size of cycle times depending on batch size, in relation to the takt time

An interesting and important note from Figure 5.2 is the uneven lengths of the cycle times, making the production flow unbalanced. Some of the cycle times are far from the takt time, while others are close. This is truth both for batches of 600 pieces and 300 pieces. There are several downsides of having an unbalanced production system. To mention some, it is difficult to man it in an efficient way and possibly causing uneven workload to operators, resulting in worn operators. Another consequence is that WIP often must be at a high level keep the flow up and running. A way of balancing the flow could be to merge some of the workstations with low cycle times into one station, still making it possible to cope with the takt time. Another more easily implemented change, could in this case be to reduce the batch size to 300 pieces. This since the cycle times for bathes of 300 pieces are closer to the takt time than batches of 600 pieces, as shown in Figure 5.2.

If again considering Figure 5.2, it is tempting to call the base and acid station the cycle time bottleneck of the system if producing in batches of 300. Further, it could be alluring to deem it impossible to produce with a fixed batch size of 300 pieces. However, since the base and acid measures in Figure 5.2 are not based on an optimal feeding principle from a productivity perspective, the machine has more potential. Recall that the machine can manage to handle up to four carriers at the time, while the numbers in Figure 5.2 are based on processing one carrier at the time. By feeding the machine with more than one carrier at the time, its cycle could thus be reduced.

How the cycle of the base and acid process is affected by its feeding is illustrated in Figure 5.3. As can be seen, the weighted cycle time of 55.5 seconds is true if only one carrier with a batch size of 300 pieces is fed to the station at a time. However, this is not the case if constantly feeding the machine with carriers. By having two carriers in the station simultaneously, the cycle time is 38.9 seconds, which is below the calculated takt time. If feeding the machine by three or maximum four carriers, the cycle time is further reduced, possibly creating a margin on managing the takt time. By keeping the machine fully fed, it will manage to deliver a per piece rate at 30.5 seconds for batches of 600 pieces, and 15.3 seconds for batches of 300 pieces. This could be said being the maximum output of the machine, depending on the choice of batch size. The most important conclusion from Figure 5.2 is however that the production system could theoretically cope with the takt time when producing in batches of 300 pieces.

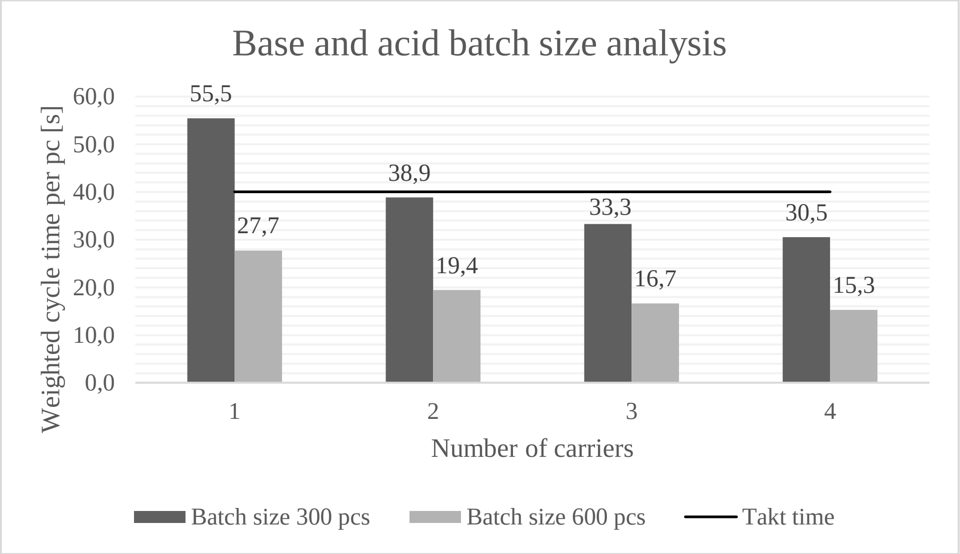


Figure 5.3 Illustration of how the feeding frequency and batch size affect the cycle time of the base and acid station

Following the same reasoning, similar conclusions can be drawn for the etching machine. This can be seen in Figure 5.4, where the cycle time decreases with number of carriers processed in the station at once. However, in the case of the etching station, the cycle time is already lower than the takt time of 40 seconds when feeding the machine with one carrier at the time, and therefore not an equally big issue as the base and acid machine. Processing one carrier at a time in the etching machine results in a cycle time of 14,5 seconds which is considerably lower than the takt time. Important to note for both the etching and the base and acid machine, is that it does not require more time to having them constantly fed. However, it does require some timing and extra attention from the operators.

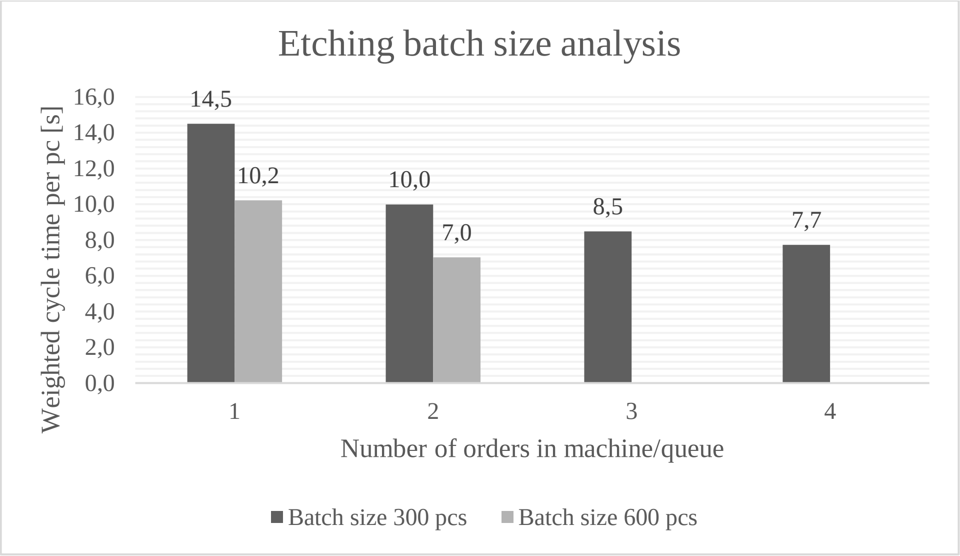


Figure 5.4 Illustration of how the feeding frequency and batch size affect the cycle time of the etching station

As a final remark for the bottleneck analysis, the most critical stations for the system, if producing in batches of 300 pieces, are the blister packaging station and the final box packaging station, see Figure 5.2. Have in mind that the base and acid machine must be fed according to Figure 5.3. Regarding the solvent degreasing station, it is highly reliable and also possible to perform at different places in the production flow, making it an unlikely bottleneck, even though its weighted cycle time is close to the takt time. The carrier assembling station is also reliable and can be run in parallel if necessary. Therefore, none of the stations are currently considered as takt time bottlenecks, meaning that the system can cope with the expected customer demand. Depending on the level of rework and breakdowns, it is likely that the cycle time bottleneck of the system shifts between the blister packaging station and the final box packaging station, when considering all products produced in the final box packaging.

5.4 Digital data

This section is divided into two subsections, where the first one describes how the data is sorted to only show good data, meaning that assumptions and choices made up until this stage are explained. The second subsection illustrates the digital data used. Moreover, the digital data is compared to the manual measured data, in order to see if the same result is achieved from the different analyses.

5.4.1 Screening of digital data

In the production system, data is automatically gathered and saved from the PLCs of the machines within the production flow. The data utilised for this report is the start and end time of production orders at the different stations. In other words, the time from when an operator starts the order until he or she finishes the order in the computer system. Data from the last 12 months has been used to reflect the performance of the production system the last year. Unfortunately, there are stations, including carrier assembling and documentation control that do not log digital data, leaving these stations outside this analysis. Neither the sterile box packaging is logged, but its cycle is within the cycle time of the blister packaging station. This since the operator at the sterile box packaging station terminates both of mentioned stations at the same time. To better display the reality of the production system, some of the data points were removed or adjusted. For instance, the times of breaks, meetings and weekends have been removed, in order to catch the real process time better. If not doing this, stations requiring constant operator attention, such as the carrier assembly or the blasting process, would have been falsely long. If there for instance are orders started without being completed before the weekend, their process times are running until they are finished the upcoming week. Thus, elapsed time during weekends was removed. Regarding the stations etching and base and acid, breaks and meetings were not removed since these machines are up and running during these times. However, eventual time elapsed during weekends of said machines was removed.

The time from start to finish of an order at a station can vary depending on how much work is done in advance before the orders are actually started in the PLC by the operator. Since the digital start and end of processes are made manually by operators, who might follow different routines, the digitally gathered times could possibly be inaccurate. However, such preparation time, that could vary among operators, is short compared to the whole station cycle time. The fact that data are gathered for an entire production year, creating a stable average built up by several different operators, it is not deemed to be a problem. If comparing the level of detail of the digital data, with the VSM measures, the VSM distinguishes between changeover time and cycle time, which the digitally gathered data does not. The digital data only depict the time taken from an operator to start and finish an order, without dividing anything further into specific operations. In other words, the level of detail is higher in the manually gathered VSM data.

Even if adjusting the data according to above, there are measurements within the collected digital data sample that are poor and therefore should be excluded from the collection. This is done using the interquartile range (IQR), excluding poor data points from the population. The lower and upper limit within the approved scope are calculated according to equation 5.5-5.6. With the use of IQR, the poor data points of each station were removed.

$$IQR_{Upper\ limit} = Quartile_3 + 1.5 * IQR \qquad (5.5)$$

$$IQR_{Lower\ limit} = Quartile_1 - 1.5 * IQR \qquad (5.6)$$

Before removing the poor data, the number of data points for the workstations ranged between 490 for the old blasting machine and 1955 for the solvent degreasing process. The difference in number of data points depends on how frequently the machines are used. In the case of blasting for instance, there are two machines available, explaining why the old blaster has the least number of data points. The percentage of poor data points removed for every workstation can be seen in Table 5.3, which ranges between 6 to 16 per cent.

Table 5.3 Percentage of removed data points of total digital data set

	Solvent degreasing	**Blasting new**	**Blasting old**	**Ethanol**	**Base and acid**	**Etching**	**Blister packaging**	**Box packaging**
Poor data points removed	13,71%	7,65%	10,41%	14,38%	12,24%	15,24%	6,14%	7,59%

There are several potential reasons for why poor data points are present in the collected raw data. For instance, it could be due to small test orders with an unusually small batch size going through the flow. This would result in an unfair cycle time per piece in machines that are independent of batch size, in comparison with orders of normal orders of 300 or 600 pieces. Another source of error was orders that were started and then instantly ended, resulting in a cycle time of 0 seconds per piece. These types of orders were then correctly run at a later stage, thus indicating that an operator started the wrong order by mistake, for instance. If not excluding such orders, digital data representation of the cycle times would have been unrealistically short. Moreover, a poor data measure can appear due to a high number of breakdowns during an order in a machine or because of training of a new operator.

5.4.2 Utilising digital data

As previously mentioned, the digital data used is based on the last 12 months of production, creating a large sample in relation to the one gathered manually for the VSM. This means that the digital data include expected as well as unexpected disruptions in the production flow. Such disruptions are difficult, and to some extent also undesirable, to catch and account for when manually gathering data, since it heavily affects the result due to only having a few measurements. Further, the digital data smoothens unusually slow or fast operators, and thus gives a stable average for cycle times. In Figure 5.5, the stability of cycles times of the stations logging digital data, are illustrated using box plots. The box plots are built up by the screened data, where poor data points have been removed, according to the previous section. Important to note is that the cycle times in the box plots is not weighted, making it inappropriate to compare it with the takt time and to draw any bottleneck conclusions from them.

From the box plots in Figure 5.5, it seems like the two blasting stations, the base and acid, and the blister packaging station, are less stable processes than the other four. A common factor for the blasters and the blister packaging stations is that these are batch dependent, and that the operator working at the station affect its pace. Thus, at least some of the variation can be explained by the speed of individual operators. Another explanation, also common for the three mentioned stations, is that products can be processed more than once in case of inadequate quality. Thus, batches that require much rework will get a higher cycle time. The wider spread for the old blaster in relation to the new, is deemed to be a result of technology improvements that is utilised in the newer machine. Regarding the base and acid station, it could be expected that its box plot characteristics should be similar to the etching machine, since these machines are of the same type. However, and as elaborated in section 5.3.2, the output from the base and acid process is dependent on how frequently the machine is fed with material. Thus, when the machine is fully loaded during a certain time, the cycle time will be lower compared to a less loaded machine. In other words, if always feeding the machine with the same frequency, the spread shown in the box plot would have been more limited. Applying the same logic for the etching station, this station seems to be fed with even frequency, making the box plot more compressed.

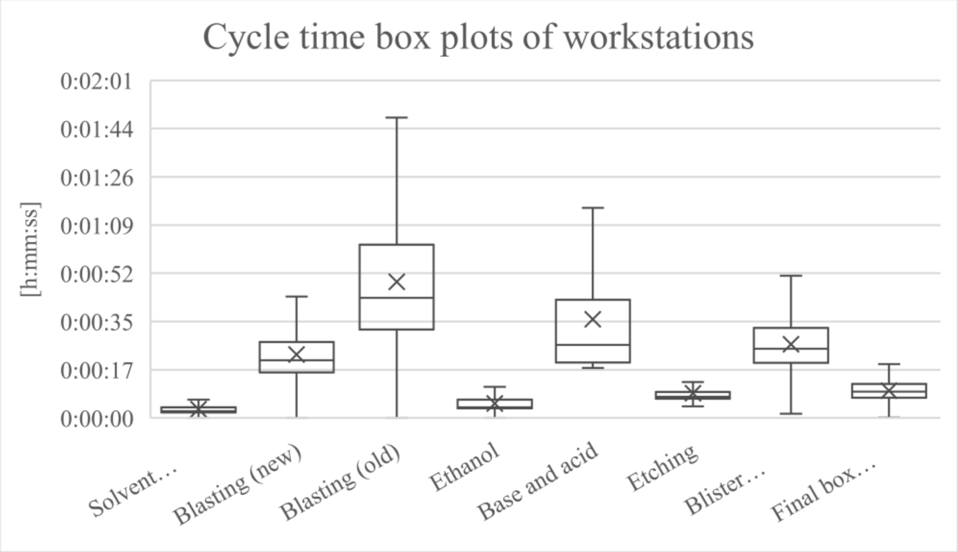


Figure 5.5 Box plots showing the stability of the cycle time of workstations

Regarding workstations solvent degreasing and ethanol, it is expected that they show a similar box plot pattern in Figure 5.5, since they share both the same operator characteristics and batch dependency. The reason for their low spread, is deemed to be due to the chemical bathes involved in these stations. If not following the times for a certain bath, complete batches must be scrapped. Further, the risk of stoppages or unexpected failures are low at these stations, stabilising the cycle time even more. When the final box packaging was studied in reality, it was shown that this machine does not have an equally high reliability. The machine could stop several times when studying one batch. This could possibly explain the wider spread in comparison to the recently mentioned chemical processes. Another explanation for the wider spread can be the relatively time-consuming changeover that e.g. includes printing new boxes.

In Table 5.4, the mean and median cycle times, used to create the box plots, are listed. To get an understanding of the production flow, these different measures could complement each other. For instance, the median cycle time value can possibly be a reasonable measure for what cycle time to expect during normal circumstances, namely when no breakdowns or other unexpected occurrence takes place. How the mean cycle time deviate from the median, might reveal something about how often, or how long stations are struggling, since the mean is raised by batches taking longer time to complete. Identifying stations with noticeable spread between mean and median cycle time, such as the old blaster and the base and acid machine, could thus be a way of finding stations that are instable or having trouble with much breakdowns. However, as in the case of the base and machine, where the feeding frequency is a factor to consider, the spread must not certainly indicate a problem.

Table 5.4 Mean and median cycle times from digitally gathered data

	Solvent degreasing	**Blasting (new)**	**Blasting (old)**	**Ethanol**	**Base and acid**	**Etching**	**Blister packaging**	**Final box packaging**
Mean	0:00:03	0:00:23	0:00:49	0:00:05	0:00:35	0:00:09	0:00:26	0:00:10
Median	0:00:02	0:00:21	0:00:43	0:00:04	0:00:26	0:00:08	0:00:25	0:00:09

Visualised in Figure 5.6, the chemical processes in the flow is further analysed by dividing their cycle times into times spent on chemical recipe, as well as other necessary actions to keep the process up and running. The recipes are fixed process times, predetermined to follow the chemical process needed to improve the surface, or prepare the surface before the next process. Thus, the times denoted in the recipes can be interpreted as the value adding time in the process, making it possible to identify where there is waste elimination potential. Since the recipes includes washing and drying of the products, it could however be questioned if all the entire recipe time can be classified as value adding time. Other necessary actions include, for instance, order handling, moving material or waiting for an operator to make an action. Worth mentioning is that order handling involves both time at the computer, together with printing out order papers, and manually complementing the information needed. Thus, the order handling is somewhat doubled in time due to having both manual and digital order handling. For the automated machines, base and acid as well as etching, the necessary actions or waste category also includes robotic movements and time spent in queue within the machines.

As can be seen in Figure 5.6, the recipe stands for the majority of the time chemical stations spends on an entire order. Regarding the etching process, it appears two times in the figure due to its stepwise batch size dependency, where an additional carrier is necessary for orders larger than 300 pieces. Consequently, the time spent on material handling is increased, and a queueing time arises for the second carrier. However, it is important to keep in mind that smaller batches equal more production orders, resulting in more time spent on order handling. Figure 5.6 also shows that base and acid process has a similar relation as the etching process. This is rather expected since the machines are functioning and managed in the same way. Surprisingly, the solvent degreasing station and the ethanol station, that also share the same characteristics, do follow this pattern. A possible reason for this, is that the ethanol process includes more chemical baths than the solvent degreasing. During these baths, the operator has the chance to manage some, or possibly all, of the necessary actions needed to complete an order.

As a final remark to Figure 5.6, based on the digital data available, it is only possible to complete this analysis for the chemical processes that follows a predefined recipe. The other, more manual stations cannot be treated in the same way without making more detailed manual measurements and studies.

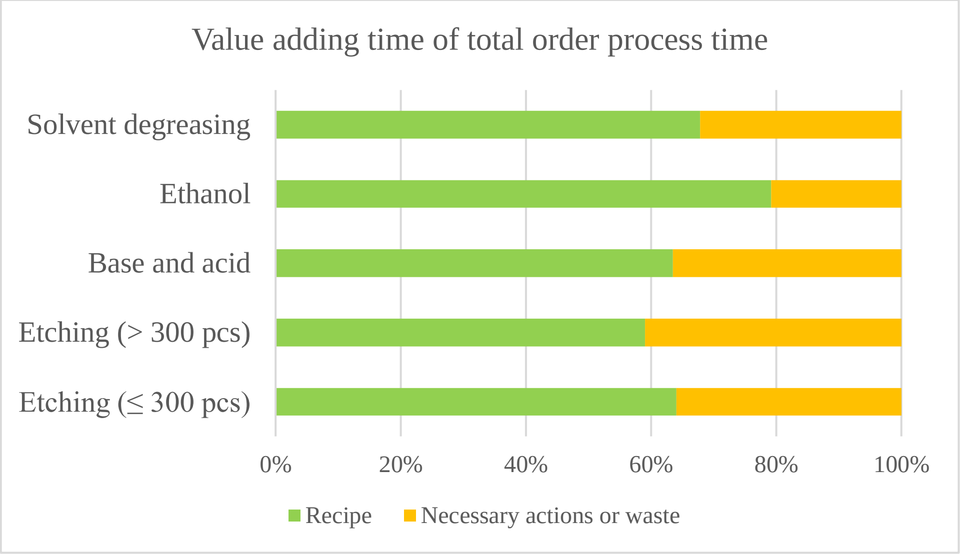


Figure 5.6 Time allocation of orders in chemical processes

Until now, the digital data used for the analyses, has been the screened one, where e.g. time spent on breaks and reoccurring meetings was considered and removed. This to represent the real production flow in a more realistic way, and to discover pieces of the flow that can be improved. With this internal efficiency focus, it could however be easy to forget the customer, which is probably more interested in knowing when ordered products can be delivered, regardless of how many breaks or meetings that are taken. As an answer to this, Figure 5.7 was created, where complete production orders are followed from the moment they are created in the solvent degreasing process, until they are finished at the final box packaging station. By following orders from start to finish, it is also possible to see how long time they on average spend in the buffers between the different processing stations. The darker staples in Figure 5.7 illustrates the individual contribution to the cumulative throughput time from the buffers and workstations. When summing up the time orders on average is active, the real throughput time is approximately 9 days, corresponding to the time a production order on average spends in the production flow. Note that the carrier assembly station is not isolated from its two adjacent buffers since there is a lack of digital data for that station. Instead, that time is interpreted as the elapsed time between the ending time of the base and acid process, and the starting of the etching process. The same goes for the external sterilisation process.

Besides from the external sterilisation process including its buffers before and after, it is mostly the buffers who increases the real throughput time. This is also the case in the VSM with measurements taken manually. However, in this case it is the actual time spent in the production system, while the VSM uses takt time to calculate how much time the products on average are spending in buffers within the system. Moreover, VSM consider workdays, i.e. excluding breaks, meetings and non-work hours. Thus, not thinking of lead time in terms of how many calendar days the production of an order takes.

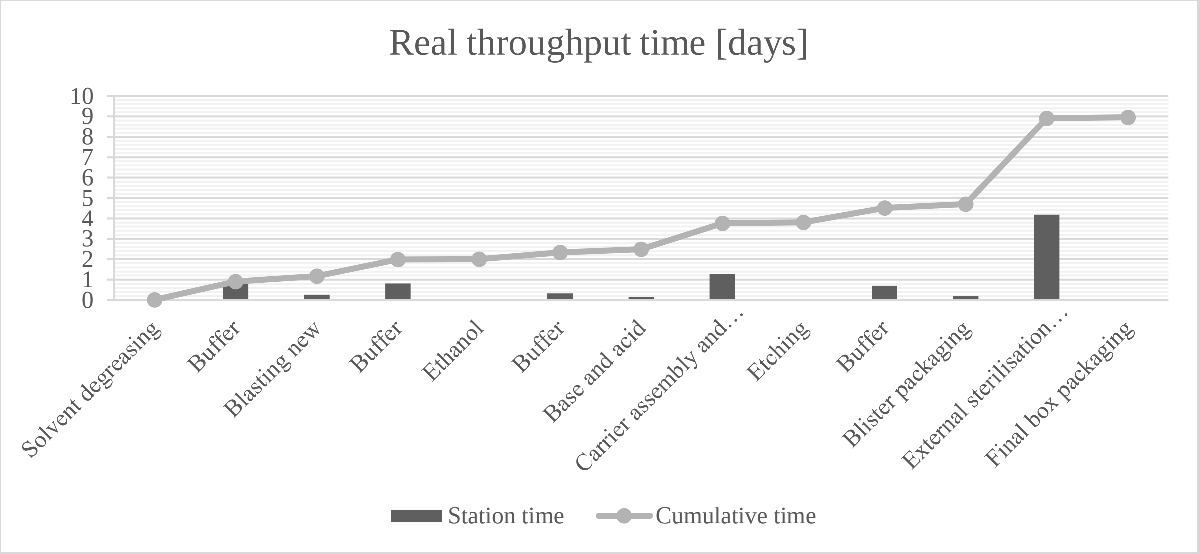


Figure 5.7 Real throughput time for complete orders

5.5 Combining VSM with digital data

In the previous sections, both manually gathered data, used in the traditional VSM, and digitally gathered data has been processed and analysed. As briefly touched upon, the different methods of data gathering have their own benefits and drawbacks. Looking at manual data collection, it is a time-consuming process and it takes a long time to take only a few measurements of the stations in the production system. Not only does the measurements themselves take a long time to perform, it is also vital to understand the process in order to know how and what details to include in the measuring at a workstation.

Regarding the digitally gathered data, it is quickly acquired, though it often needs some type of screening before being used. Another obvious benefit is the amount of data that can be extracted, possibly covering several years of production, making it possible to identify trends and development patterns. Nevertheless, with digital data there is a risk of utilising data without the exact understanding what is represents, highlighting the importance of having knowledge about how the digital measuring is constructed and what it actually measures. This should not be the case of an VSM, since the owners of it have performed the measures themselves and thus having the knowledge of the flow. The term ‘go and see’ is frequently used within lean production, advocating the importance of visiting the factory to see the production flow with your own eyes, in order to truly understand how it works. It is seen as an opportunity to take notice of problems and other occurrences that might lead to improvements, which digital data is incapable of pick up on.

In Table 5.5, there is a comparison between the manually measured cycle times and the digitally gathered data for cycle time average and mean. Note that the digitally gathered data is the same as previously presented and described in Table 5.4. Interestingly, the final box packaging is the only station with lower cycle time in the digital data, than the manually measured cycle time. This can be explained by during the manual measurements of said machine, there occurred more breakdowns than usual, according to the operator being measured. As also can be seen, base and acid together with the new blaster stands out by having a large difference in cycle time depending on being measured manually or digitally. Regarding the base and acid machine, a probable reason for this is, and as previously explained, its cycle time is dependent on how it is fed. Thus, it is not inconvenient that the manual and digital measures differ. For the new blaster, however, it is not as straightforward as to why it differs with 8-10 seconds. One thing for instance that increases the cycle time, is the rotation of operators during an order. An explanation to this is that the start for each operator includes a start-up period before actually starting to work. This includes some cleaning of the station and him or herself, changing setting of the work bench, getting up to speed with the order, et cetera. Another part of the spread can be the speed of the individual operators, meaning the operators being manually measured were faster than average.

Table 5.5 Comparison of cycle times between VSM and digitally gathered data

Stations	**VSM**	**Digital mean**	**Digital median**
Solvent degreasing	0:00:03	0:00:03	0:00:02
Blasting (new)	0:00:13	0:00:23	0:00:21
Blasting (old)	-	0:00:49	0:00:43
Ethanol	0:00:04	0:00:05	0:00:04
Base and acid	0:00:17	0:00:35	0:00:26
Etching	0:00:06	0:00:09	0:00:08
Blister packaging	0:00:27	0:00:26	0:00:25
Final box packaging	0:00:13	0:00:10	0:00:09

The comparison in Table 5.5 can be interesting from several different perspectives. By having similar values between the different data illustrated in Table 5.5, the credibility of both the VSM and digital data can be increased. Further, having been in the factory and manually measured the different station do help in validating both the manual and digital collected data, since a sense of understanding of the processes and its cycle time is achieved. Worth mentioning, Table 5.5 does not consider weighted cycle time, i.e. the measurements do not consider that other product types are produced in the same station. This means that the cycle time for each station except for the blister packaging would have increased if weighted cycle times instead were used.

Lastly, and the most important takeaway from Table 5.5, the consistency in the values, together with the possibility to explain the deviations, tells it is feasible to replace manual measurements with digital data. Before doing so, a good understanding of the entire production flow, backed up with some manual measurements is a must to not be fooled by ambiguous digital data. As soon as the digital data is trusted, it should be used to save time on from manual measurements, and to get stable measures that eliminates factors such as operator skill or unexpected breakdowns.

5.6 Future state

This section starts with improvement suggestions gained from the VSM and its visits in production, from interviewing and discussing with people of more experience and better knowledge of the production system and from the digital data. Continuing with transforming these suggestions into an implementation plan, and lastly, the section ends with a roadmap with a focus on how to utilise the beneficial aspects of both VSM and digital collected data.

5.6.1 Improvement suggestions

In this section, all the proposed changes to improve the production flow are described in individual subsections.

5.6.1.1 Reducing batch size

During the past production year, the average batch size for the product type studied was approximately 415 pieces. By reducing the batch size being used, the WIP of the production system can be reduced (Monden & Ohno, 2011). Since the buffers, and thus the WIP, have been shown as one of the main contributors to the total production lead time, reducing batch sizes should be considered. As previously shown in section 5.3.2, a batch size of 300 pieces is manageable for the production system, and is also a good fit with the size of the carriers being used. In Figure 5.2, it was also demonstrated that a batch size of 300 pieces makes the production flow smoother and better aligned with the calculated takt time.

If started with reducing batch sizes, a second step could be to try always keep them equally big, instead of having different batch sizes ranging from 100 to 600 pieces. Since a one-piece-flow is not feasible to achieve in the production flow, a fixed batch size could be a way of utilising some of the benefits of it. For instance, the planning of the production will be simplified, and it will be easier to standardise the operations in the flow. Standardised operations will make it easier to monitor the flow and detect deviations. Lastly however, it is important to note that the reduced batch sizes will increase the number of production orders, resulting in an increased order handling time and setup time.

5.6.1.2 Merging workstations

Regarding the sterile box packaging station, the operator working there is often idle, waiting for products to be packed. The idleness stems from the upstream blister packaging station, that has a considerably longer cycle time. If the person working at the blister packaging station can, instead of the operator at the sterile box packaging station, be responsible for approving the blister packages, there is no need for the sterile box operator to constantly be present. This will reduce the workload of the sterile box packaging station further, making it possible to completely freeing up the operator working there by assigning the remaining tasks to the operator working at the final box packaging station.

Since the final box packaging is highly automated, this change should be feasible. Important to note with this change, since final box packaging already is a critical station from a bottleneck perspective, the operator must prioritise this station, which does little to affect the sterile box packaging. Sterile box packaging is sending a delivery to the external sterilisation process twice a day and during the rest of the time placing products in a buffer waiting for said delivery. From a flow perspective, the only important thing to consider, is therefore that all products are ready and packed in sterile boxes before they are sent to the sterilisation process. The time spent on sending products back and forth between the blister packaging station and the sterile box packaging station will be reduced. It will however be important to monitor how the changed workload will affect both the blister and final box packaging stations, as these stations previously were considered as critical from a bottleneck perspective.

Another change, that is already under development, is to merge the manual ethanol operation with the downstream station base and acid. This can free up yet another operator, since base and acid is an automated machine. Further, the ethanol station and its buffer would be removed, resulting in a simpler and more efficient flow. That is, less WIP and in turn, a decreased production lead time can be achieved (Monden & Ohno, 2011). This change will of course lead to an increased cycle time of the entire workstation, but if the machine is fed properly, it should be able to manage this. Thanks to the change, the setup time of the old ethanol station will be completely removed.

5.6.1.3 Paperless production

Looking at the information flow, a big change is the removal of all manual orders. In other words, instead of performing the order handling digitally and then printing a manual one, the order handling will only occur digitally. This change is going to remove the wasteful activity of doing the same work twice. Furthermore, this will remove production space by not needing printers in the cleanroom, as well as remove walking distance between stations, the printer and the manual order rack located in the far end of the cleanroom. As is the case with merging the ethanol station with the base and machine, there is already an ongoing project, striving towards paperless production.

5.6.1.4 Removing documentation control station

Thanks to the implementation of paperless production, already existing quality controls throughout the flow, and a final quality and control check performed at the quality department, the last workstation in the production flow could potentially be completely removed. What the quality station essentially do today, is to compare the products with the manual order papers and the digital order on the computer. If something is strange, the station also includes some investigation or corrections to make things correct. However, the removal of paper orders and that every station upstream has thoroughly compared the product order against the digital order, it is deemed as sufficient. Moreover, since the quality department takes a final look, it should be enough to only have the smaller controls throughout the production flow.

The removal of the documentation control station can free up an operator and remove the upstream buffer. As this change might affect the work at the quality department, an alternative to removing the workstation, could be to expand its responsibilities. This should however only be considered if it is necessary to reduce the pressure at the quality department.

5.6.1.5 Applying TOC to bottleneck stations

In the bottleneck analysis in section 5.3.2, there seemed to exist shifting bottlenecks. The shift was deemed to occur between the blister packaging station and the final box packaging station. It was though also concluded that it does not exist a takt time bottleneck. However, the suggestion of merging the sterile box packaging station with identified bottlenecks will, unfortunately, increase their workload.

Regarding the blister packaging station, the operator working there is already supported by an additional operator when performing changeovers, which is a practice that should be continued. It could also be fruitful to check if there are any improvement potential in the changeover procedure. For instance, there is today a requirement that two different operators visually check and approve the quality of the first blisters being printed in an order. Another thing, corresponding to the second and third step of the TOC methodology, is to let the operator at the upstream etching process deliver the products and material for the upcoming order to the workstation. Since the etching operator already delivers the products to the downstream buffer, the workload will not be increased considerably. For the blister packaging operator, the time spent on finding the correct order to process as well as fetching the right products will be removed.

When studying the final box packaging station in reality, it was obvious that the number of short breakdowns and stoppages increased its cycle time and limited the productivity. Therefore, any efforts to improve its uptime and reliability should be considered. Such activity could preferably be assigned to the engineering department, process technicians or similar. Increasing the reliability of the station, will not only reduce the cycle time, but also the ability to manage the sterile box packaging station as suggested. Additionally, it is important, matching the third step of the TOC methodology, that the machine always is working while there are products available to process in the buffer.

5.6.2 Implementation plan

Several improvements have been suggested in the previous section, which this section is meant to concretise into a plan of action in order to improve the productivity of the flow. In practise, it is sought after to go for the low costly improvements, i.e. focus on low-hanging fruits at first, since these can generate profits quickly by removing wastes in production. The plan is shown in Table 5.6, shortly describing the effects of suggestion improvement, and when action should be taken.

The first plan of action would be to switch to lower batch sizes as is, according to Rother and Shook (2009), preferable from several perspectives. Consequently, a more stable production rate means that it is easier to plan the workforce. Oppositely, if having a higher production volume, then resources such as inventory and work force must be balanced to it, which mean that there will be waste of overcapacity during instances of lower production volumes (Monden & Ohno, 2011). Therefore, testing of producing in batches of 300 pieces is suggested. This will not only maximise the use of the carriers, but also ensure the smoother flow mentioned. That is, utilising the resources more evenly as seen in Figure 5.2, where the processes still can produce according to takt. Doing this will result in less idle time of the machines and in turn also the operators have a more even work distribution. Reducing the batch size should be possible to do with some minor adjustments in the production order environment. A possible, and rather problematic issue that might occur when reducing the batch size, is shortage of carriers. However, due to the complexity of the flow, it is difficult to decide whether this is a problem or not, which is easiest tested with a practical trial and error approach. Creating a simulation model of the production flow could be another approach to check the feasibility of a batch size reduction. Such simulation model could naturally also be appropriate for other production improvement activities.

Regarding the second improvement suggestion in Table 5.6, its feasibility can be tested immediately since it is only a question about operator manning, that is scheduled at a daily basis. By dividing the work tasks of the sterile box packaging to final box packaging and blister packaging, two operators are being more utilised. This can be done instead of having one worker being idle a lot of time. If the final box packaging is struggling however, it might need a second worker during these times, but also pointing towards a maintenance activity to fix said machine and its temporary problems down time problems.

Improvement suggestions three and four, are already ongoing projects, and the company should be encouraged to complete these projects as soon as possible since they will both improve the flow considerably. Merging of the ethanol station with base and acid is a more costly change, since it will require more efforts in how to perform it. However, the cost of succeeding in this change, is at an early phase deemed to be an important step of reducing WIP and lead time. This since it will result in the removal of one buffer and one workstation. Further, it will also free up operator time. Regarding the paperless production, it is likely that this project will lead to reduced cycle times for all workstations. Since production orders are already partly managed digitally, this change should not be too cumbersome or complicated to complete.

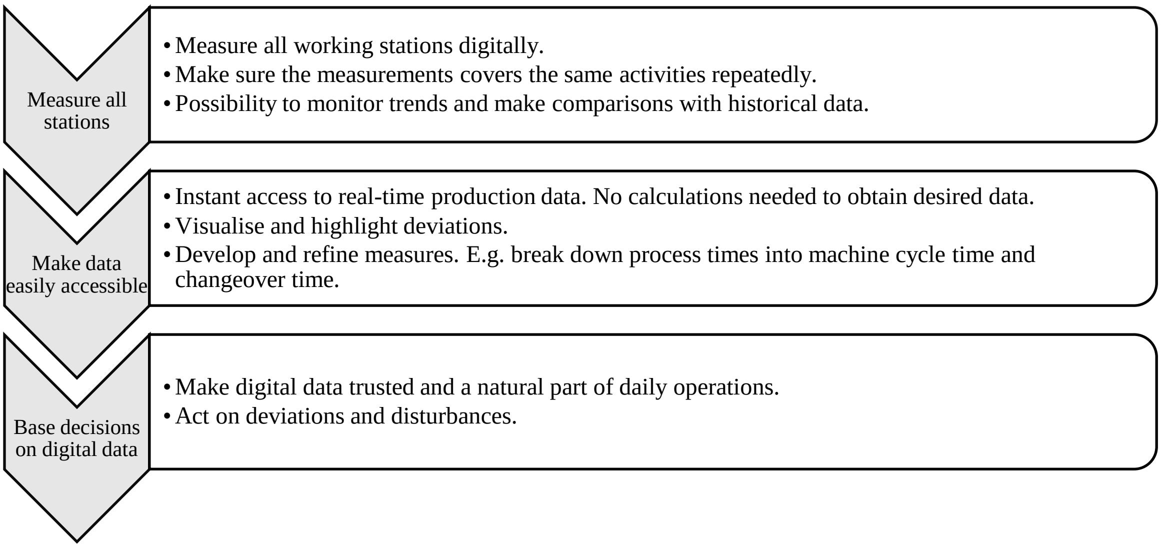
Table 5.6 Implementation plan

No	**Improvement suggestion**	**Effect**	**When to take action**
1	Lowering the batch size	Reduced WIP and shortened lead time	Immediately
2	Divide the responsibility for the sterile box packaging to upstream and downstream processes	Reduced workforce with maintained output	Test feasibility immediately
3	Merging ethanol station with base and acid	Reduced WIP and shortened lead time. Less operator time required.	Already ongoing
4	Paperless production	Reduced cycle times due to less order handling	Already ongoing
5	Remove final documentation control station	Reduced workforce with maintained output	Start investigation immediately

Another improvement, in addition to the ones presented in the implementation plan, is to standardise the operations at the different workstations. During the production visits, different operators were seen working in different ways, resulting in different cycle times and possibly inconsistent quality. A good idea is to take a group of skilled and experienced worker to standardise the different tasks and implementing it throughout the production system. Moreover, training the rest of the personnel as well as future hired workers according to the standardised work methods. This will result in more stable cycle times, and irregularities will be easier to spot when cycle times start to vary. Important to note, it is a more time-consuming initiative, that also is seen as an ongoing process to continuously improve the work methods.

5.7 Roadmap towards digitalisation

As stated at several instances in this thesis, VSM is a static tool, only resulting in a snapshot of the production system. Since the studied production flow seems to have a shifting bottleneck, a single snapshot could possibly be misleading. Further, the manual measurements might be unreliable due to the small sample size. However, and as shown in section 5.4.2 and 5.5, it is possible to mitigate described drawbacks when using VSM by utilising digital data. The studied company are currently utilising digital data in their production system in a limited way. Figure 5.8, suggests a digital roadmap for the company, serving as general guidelines for increased digital data utilisation. As suggested by Morteza (2018), successful guidelines should be adapted to the circumstances at the company being studied. Thus, the roadmap presented here is based on the present situation, focusing on changes that will not require substantial investments for implementation.



- Measure all working stations digitally.
- Make sure the measurements covers the same activities repeatedly.
- Possibility to monitor trends and make comparisons with historical data.

- Instant access to real-time production data. No calculations needed to obtain desired data.
- Visualise and highlight deviations.
- Develop and refine measures. E.g. break down process times into machine cycle time and changeover time.

- Make digital data trusted and a natural part of daily operations.
- Act on deviations and disturbances.

Figure 5.8 Roadmap towards digitalisation

The first step in the suggested roadmap towards digitalisation, measuring all workstations, should be evident. Without measuring all stations, it is difficult or impossible getting a holistic view of the production system. It is also important that the measures are reproduced in the same way over and over again. As it is now, the outcome of the digital data is reliant on when operators start and finish production orders. It is in the present system possible to monitor trends and historical data. However, before being compared, the data must be screened and adjusted, which in stressful situations might be too cumbersome. Both technical prerequisites and the competence needed for taking this first step is already in place, and there should thus be no hesitation completing it.

Regarding the second step of the roadmap, it will require some more attention than the first one. The data itself is already in place, but it is not that accessible nor real-time available since it must be downloaded before being used. By having instant access to the data, it will also be possible to make instant actions, possibly improving the overall productivity. The refinement of the measures can be an ongoing process, constantly searching for better ways to use the data. In the third and final step of the digital roadmap, the rewards from the digital data utilisation will be clearly visible. For instance, when highlighting deviations, resources can be reallocated to cope with them quickly. This could entail operators being moved between workstations, or maintenance team called for attention. Overall, the entire system will be easier to overview, simplifying both planning procedures and lead time prediction.

5.8 Internal production assessment standard

Developing an internal template or standard for usage in different production facilities with different digital data computer programs, even if it is within the same company can be a difficult task. This because a VSM starts with mapping of the production flow and taking measurements of all processes, which will differ due to different products and different steps within the value chain. Besides referring to Learning to See by Rother and Shook, it is not that straightforward to explain to each unique production system how to perform a specific VSM. In other words, different systems have other types of processes, thus standardising how processes should be measured or what value adding time should be, is not possible without the knowledge of the specific value stream. Thus, this proposed internal production assessment standard is more a set of guidelines and pointers on what the authors has experienced and learned during this project, followed by practical how, why and when this production assessment standard should be performed.

As was done in this report, performing an VSM means to interpret the tool and adapt it to fit the production flow in mind. This includes having to make assumptions, which is important to transparently highlight as to why and how they were made to increase the credibility. Otherwise it is hard to justify it as a support tool in decisions. Besides doing a manual VSM should be complemented with digital data to make it more extensive. This to retrieve measurements that are difficult to manually find, such as scrap rates, rework, uptime of machines et cetera. If the digital data seems to be valid having done a comparison as in this project, then it is proposed to switch to using digital data. However, with only digital data the benefits of the traditional VSM disappears. Thus, doing continuous VSM is advised, but at a lower rate than updating the VSM with digital data for more quicker analyses. A large benefit with digital data is that all product families can be present. However, performing a manual VSM for each product family is time-consuming and requires several VSMs that each show one product family, otherwise making it too complex.

The strategy is to perform a traditional VSM approximately once a year. Having said that, if the manual and digital data start to differentiate, then another VSM should be done for updated values, which can work as a validation between the data as well. The time measurements of the processes should be done during a day. Important to note, a few synchronised knowledgeable employees of the production system should perform it. With synchronised meaning that the people must be aligned regarding how the measurements are done, otherwise there should be only one person perform it to have the same approach throughout the system. It can for instance be a team of a production engineer and an experienced production worker that practically knows the system well. The buffers on the other hand, it is advised to have a mean value, to avoid any extreme situation which means that looking up buffer sizes previous in time as well as the current situation. Worth remembering, there is a fine trade-off between spending time and resources on an extensive VSM and the achieved value gained from it.

The complementary digital VSM should always be present with real-time data, which also should be displayed for everyone to see. This will result in easily accessible information and decisions can quickly be made in the production. Moreover, trends can be found on a regular basis, without having to manually update the VSM. If a big decision coming up and an extensive analysis is sought after, then the digital data can be complimented with a manual VSM before. Then again, having regular VSMs already done, the benefits of ‘go and see’ is continuously achieved. Thus, it is deemed to not be necessary. In order to make the production assessment method more standardised throughout the company, then all the different branches must have the same digital data software. Only then a more extensive method can be established.

Note that the layout of the internal production assessment standard is not attached in this report due to company confidentiality.

6 DISCUSSION

In this chapter the contribution made by this thesis to both academia and industry is discussed. More specifically, the contribution made to the studied company and how it can be applied to other companies. Then, the research questions stated in this thesis is answered. The chapter is finished with discussions regarding the choice of methodology, how the stated limitations have affected the result, and finally some future directions for the case company is pointed out. Below, the main results and deliverables are summarised in bullet points.

- VSM is still a valid tool to use for creating improvement suggestion regarding reduced WIP and shortened lead times.
- A traditional VSM approach can be combined with digital production data to reduce some of its drawbacks.
- The ‘go and see’ aspect used in the VSM is a good complement to digital data since it can help to discover problems or inefficiencies that are difficult to notice by only using digital data.
- An internal production assessment standard is developed to support future attempts in increasing productivity, both in Sweden and at other production plants globally.
- A roadmap towards digitalisation is developed to support an increase in level of digitalisation at the company.

6.1 Academic contribution

VSM is a static tool, only giving a snapshot of the prevailing production system. During the time the tool was developed, when the business environment was more stable in general, it was shown to be very efficient in production development. Today however, there are higher requirements on flexibility and adaptation ability, possibly making the VSM tool less effective in use. In research today, considerable attention is aimed towards digitalisation, that is often described as a flexibility enabler. At a first glance, it therefore seems to be a possible match with utilising digital data in a traditional VSM. An empirical survey with lean experts, performed by Lugert, Völker, and Winkler (2018), concludes that traditional lean tools have the chance of being improved by utilising some benefits from digitalisation. Huang et al. (2019) share this view and draw similar conclusions.

In this project, the idea of combining the traditional VSM approach with digitalisation, was put into a company with low level of digitalisation. Hence, the project focused on firstly showing how the available data can be used as it is, and secondly what can be done to achieve a higher level of digitalisation in the future. The former was presented in sections 5.3.2-5.5, and the latter in section 5.7. It is not empirically proven that the available data can be utilised to represent the production flow in a realistic way, but the digital measures was validated using the manually gathered measures. Regarding the digitalisation roadmap, it is not anchored in a certain theory or methodology but has been inspired by several of the scientific articles used in the frame of reference chapter. How well the roadmap is working in an industrial setting must be tested before drawing any conclusions. However, since the steps are rather general and broad, it could at least work as a support for the thinking process when turning more digital.

6.2 Industrial contribution

For the company being studied, the project has contributed at several instances. Firstly, a thorough production assessment using VSM, resulting in an updated view on the prevailing production situation, has been delivered. To maximise output, the VSM was tailored to fit the studied production flow, as suggested by Kurdve, Zackrisson, and Harlin (2014). Secondly, it has contributed with production improvement suggestions together with a concrete implementation plan, allowing the company to act on this report immediately. Thirdly, a roadmap towards digitalisation has been presented, potentially helping the company be digitalised faster. This both to mitigate drawbacks of the VSM itself by making it more dynamic, and by generally increasing the usage of digital solutions, which is in line with the ideas presented by Lugert, Völker, and Winkler (2018) and Huang, et al. (2019). Lastly, an internal production assessment standard has been developed to support future productivity improvements within the company.

To other companies, the thesis shows that a traditional VSM approach is still useful when trying to understand the dynamics of a production flow, and to discover built-in inefficiencies and wastes. It can also give other companies an idea of what type of digital data that can be beneficial to utilise when performing a VSM, and also an understanding that quite much can be accomplished with limited and rather unsophisticated data. It further shows that the VSM can still be of use when trying to discover productivity potential, even though a company have a high level of digitalisation, due to implementing the ‘go and see’ aspect which can find other types of inconsistencies in the production system than digital data does.

6.3 Answering the research questions

The thesis was intended to answer the following two research questions:

RQ1: How can VSM help the company increase their productivity?

Performing a VSM helps the company realise where in the production system WIP and lead time is built up, causing a lowered productivity. When having problems identified, the approach in this project combining VSM with the TOC methodology, also helps finding solution suggestions for said problems.

RQ2: What can be achieved by combining VSM with digital data in production flow assessments?

By combining a traditional VSM approach with digital data, it is possible to mitigate the drawbacks of the otherwise static methodology. Further, the digital data makes it possible to increase the number of data points significantly, resulting in more reliable and stable measures compared to the manually gathered ones.

6.4 Methodology discussion

VSM, as presented by Rother and Shook (2009), is the main tool or method used in this report. Over the years, the method has been acknowledged and widely used in industry (Lugert, Batz, & Winkler, 2018). However, it is a rather old methodology, and its position as a reliable and successful assessment tool might be questioned in the presence of newer and more sophisticated methods. This could for instance be methods based on simulations or other data driven methods frequently researched. An obvious benefit with such approach would be the possibility to include all product types and production lines in the same analysis, creating a holistic result. However, even if this seems alluring, such approaches still require a good understanding of the production flow dynamics, which is effectively obtained with the help of a VSM. In other words, if wanting to create e.g. a simulation of the entire production flow, performing a VSM can be a reasonable starting point, serving as an input to the simulation model.

The use of the VSM renders in several concrete improvement suggestions in this report. It is though important to note that neither of the suggestions have been implemented in reality, and their real effect on the productivity can thus not be measured. Further, the methodology from start to finish is time-consuming, when including all time spent on measurements. Thus, before being completely satisfied with the outcome of the VSM, it must be considered whether the time spent on finding the improvement suggestions is reasonable in relation to the possible productivity improvement.

On a more technical level, it should be discussed whether the manual data gathered is valid or not. It could be risky drawing conclusions on data that is based on a limited number of measurements, which is the case in this report. The main reason for the limited number of measurements was the nature of the workstations, having long cycle time. Additionally, how operators are affected by being measured is another source of error important to consider, certainly in combination with the small sample size. It is though important to remember that this is the suggested course of action by Rother and Shook (2009), highlighting that a snapshot of the production can never lie. However, to mitigate the risk of having unstable and unrealistic measures, the manually gathered data was compared with corresponding digital data.

6.5 Limitations discussion

Since this thesis only addresses the production facility in Sweden, the whole manufacturing of the products is not considered. This means that the productivity of the plant in Sweden can be improved, but on a company-level the productivity can be further improved if looking at the whole value chain. Moreover, the suggestions are built on reducing WIP and decrease lead time which are only one way of improving the productivity. In order to fully find potential changes in order to increase the productivity, other sources that lead to an improved productivity must be considered.

The implementation plan describes what changes that can be done in order to succeed in obtaining the aim and purpose. However, the changes have not yet been implemented and therefore not certain to improve the production flow. In order to conclude an increase in productivity, the changes must be properly implemented. Moreover, making sure that it leads to an improved state, new data after the changes must be collected and compared with previous conditions. There might even be a decrease in productivity at first, before adjusting to the changes made in the production system.

This thesis limited itself by only looking at one product family. To increase the overall productivity of the company, all products would be preferred. Otherwise, the productivity increased on one product family might only increase a little on a company-level due to having several other products that are unaffected. Therefore, for an increased productivity improvement, the same production assessment should be done on all products manufactured at the plant. However, worth mentioning once again, the most valuable product family was considered in the analysis.

To get the most out of the production assessment it is important to have a good representation of the production system. In this thesis however, only 2-5 measures were made per process. Thus, the production assessment made might not be a fully representation of the system due to the low sample size. Although digital data was used as a complement and as a validation method, and therefore the measurements have some credibility, the credibility on the manual measurements themselves would increase with a larger sample size.

The production assessment limited itself from analysing how the machines processed products, such as, what chemicals are used and how long the products were processed in said chemical. This itself is a process that can be optimised which is not considered in this thesis. As of now, the chemical processing time is seen as value-adding time and thus, without any waste. However, this might not be the case, since the cleansing of products does not add any value to the customers. To have a more thorough analysis of the production system, these processes should be investigated as well.

6.6 Future directions for the case company

The case company is on the verge to implement two of the proposed changes in the implementation plan. These are recommended to continue go on with. This should be followed by continue with the other changes suggested in the implementation plan. Further, to improve the productivity on a company-level, other plants besides the one in Sweden should also be assessed in order to find potential improvements. This is where the production assessment standard is relevant in order to have a standardised way of finding how WIP and lead times can be decreased. However, before utilising this standard, it should be tested and validated, to gain feedback on how it works in practise. This to continue developing the standard and to make it globally adjusted, since it is currently based solely on the facility in Sweden.

To make further use of the production assessment standard, the roadmap towards digitalisation should be started to be implemented as well. This will enable a more thorough method of performing production assessments, decreasing the time taken for it by not having to manually measure every aspect of a production flow. Moreover, using digital data instead of manual measures can improve the quality and validity, since operators do in fact change their behaviour when being studied (Zandin, 2001). The road towards digitalisation is an ongoing process, and should thus be treated as such, meaning that a stepwise implementation in reaching a high level of digitalisation is a time-consuming and challenging process.

7 CONCLUSIONS

The purpose of this master thesis was to improve the productivity in a real-world company. In order to accomplish this, the aim was to reduce lead time and decrease WIP, since that is one way of increasing the productivity. If implementing the proposed changes in this project, the lead time is deemed to be decreased as well as the WIP being reduced. By doing the proposed changes, not only can the productivity be improved, but also achieving an overall more well-balanced flow, which enables a simplified planning of the production. Considering the whole company, implementing the standardised production assessment method, it is possible to apply an ongoing continuous productivity improvement on a company level, and not only in the plant in Sweden. However, in order to explicitly have a functioning assessment standard, the company itself must be more aligned with the same software and types of measurements to make improvements an ongoing process and the possibility to measure and follow up on them. When reaching this, a more sustained work towards continuous productivity improvements can be achieved. Lastly, combining VSM and digital data to achieve benefits from both approaches seems to be a good fit, where specifically the ‘go and see’ feature from the VSM is good in finding inefficiencies that are hidden within the digital data. In this thesis one way of combining them were presented. However, this can be done in multiple ways and might be successfully done in different ways for different companies depending on their current level of digitalisation.

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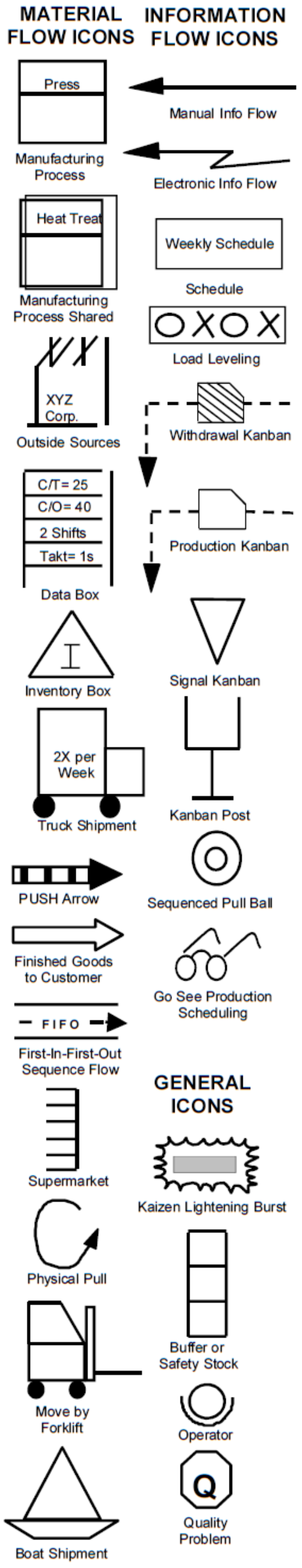
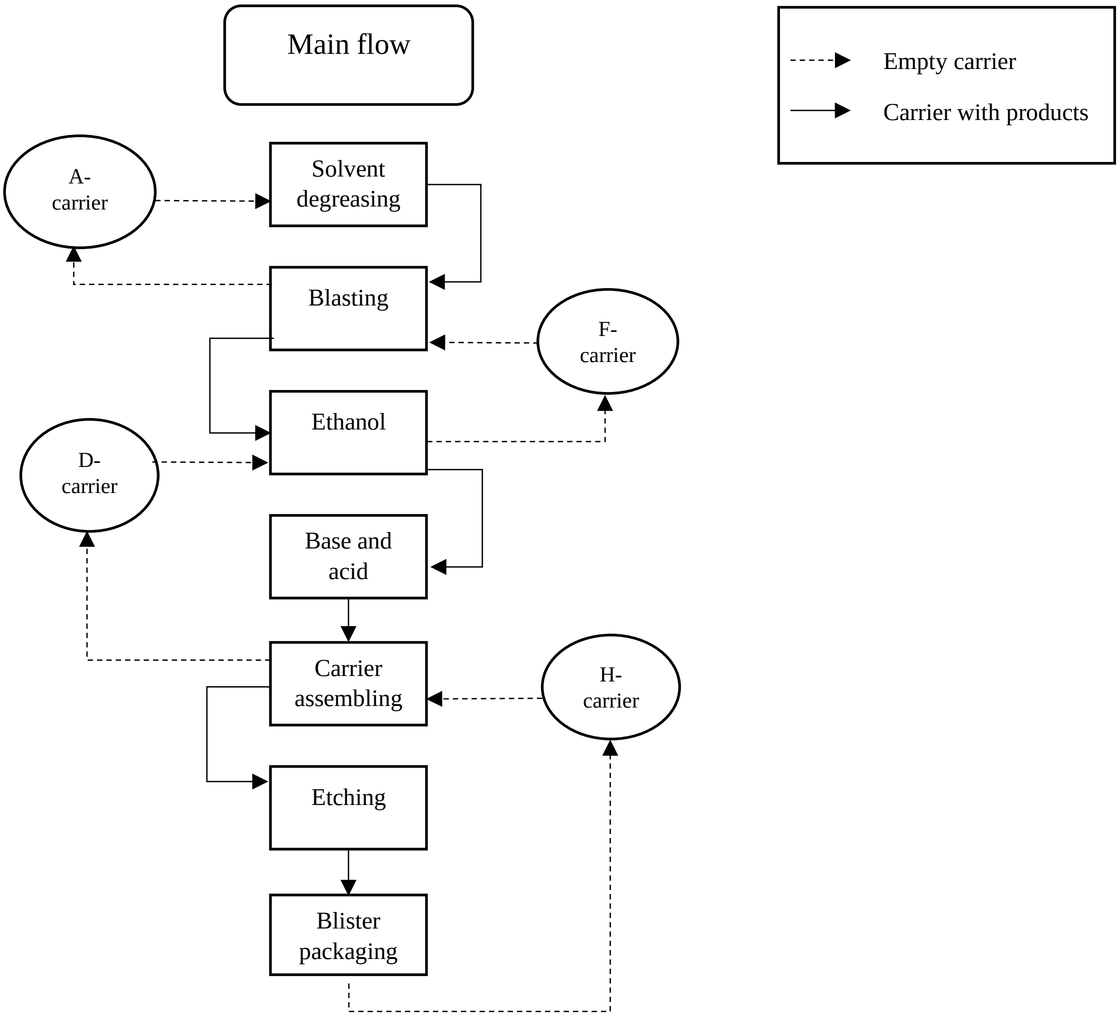
APPENDIX A – COMMON VSM ICONS

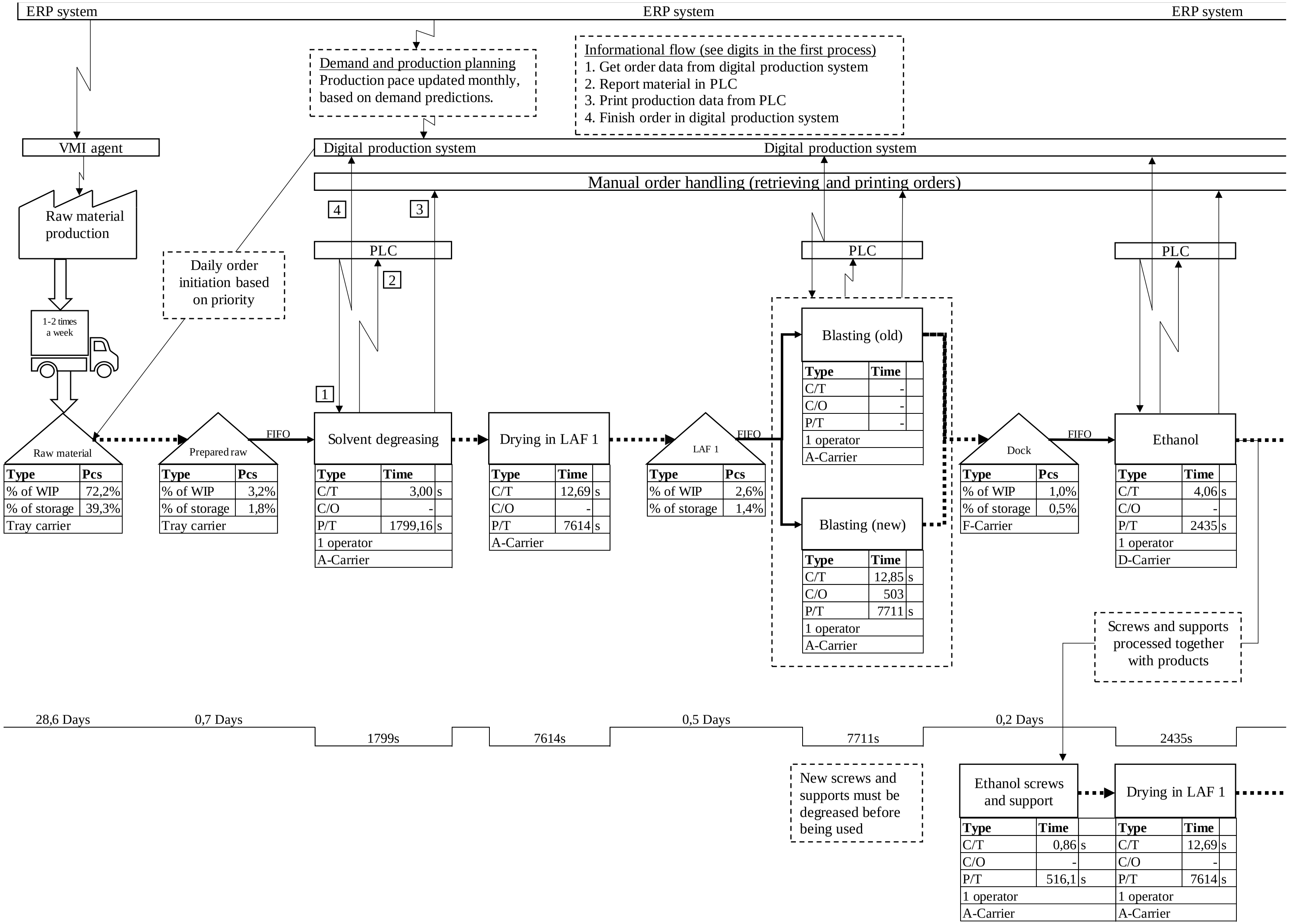
Common VSM icons, directly from Lean Enterprise Institute (2020).

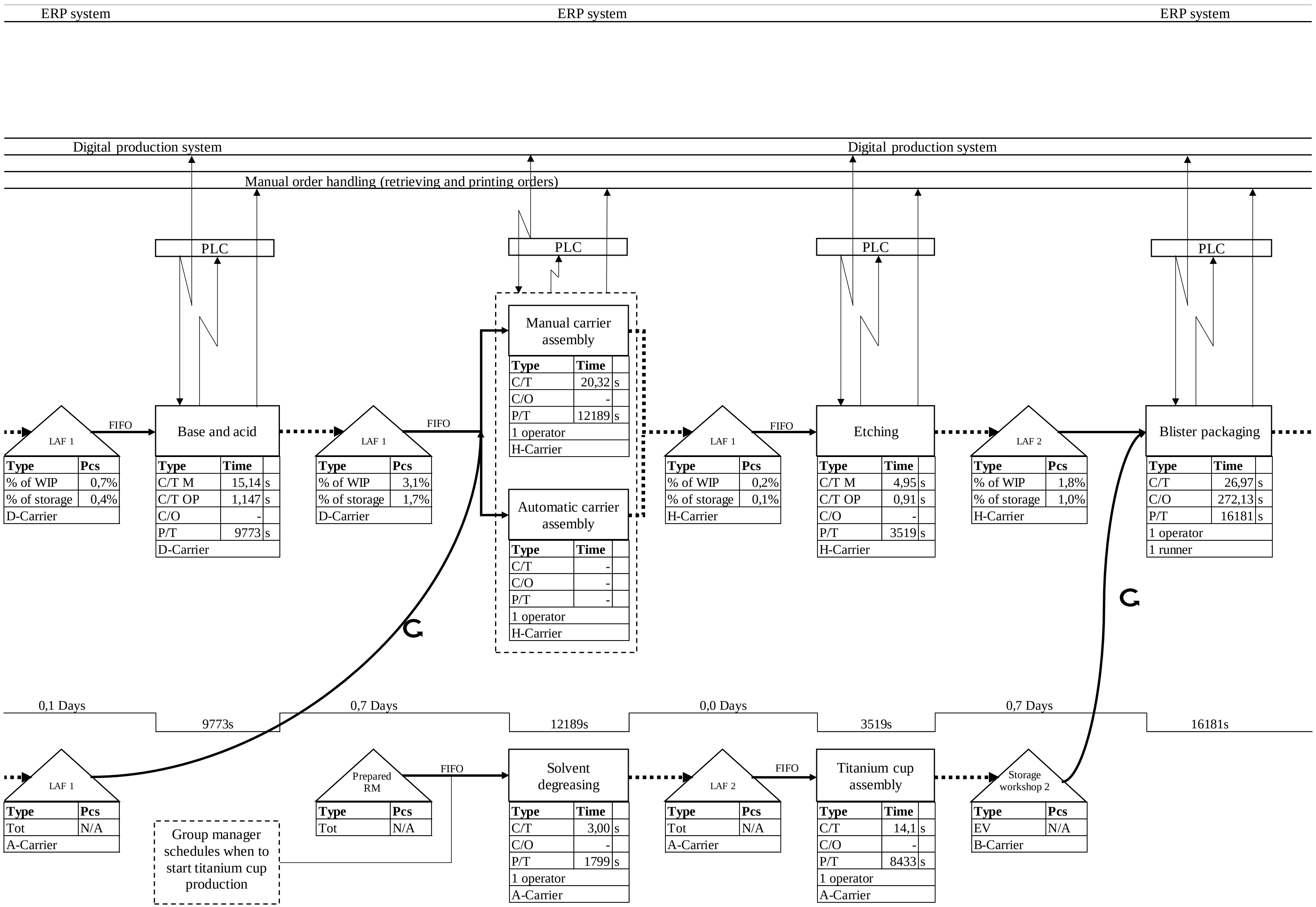


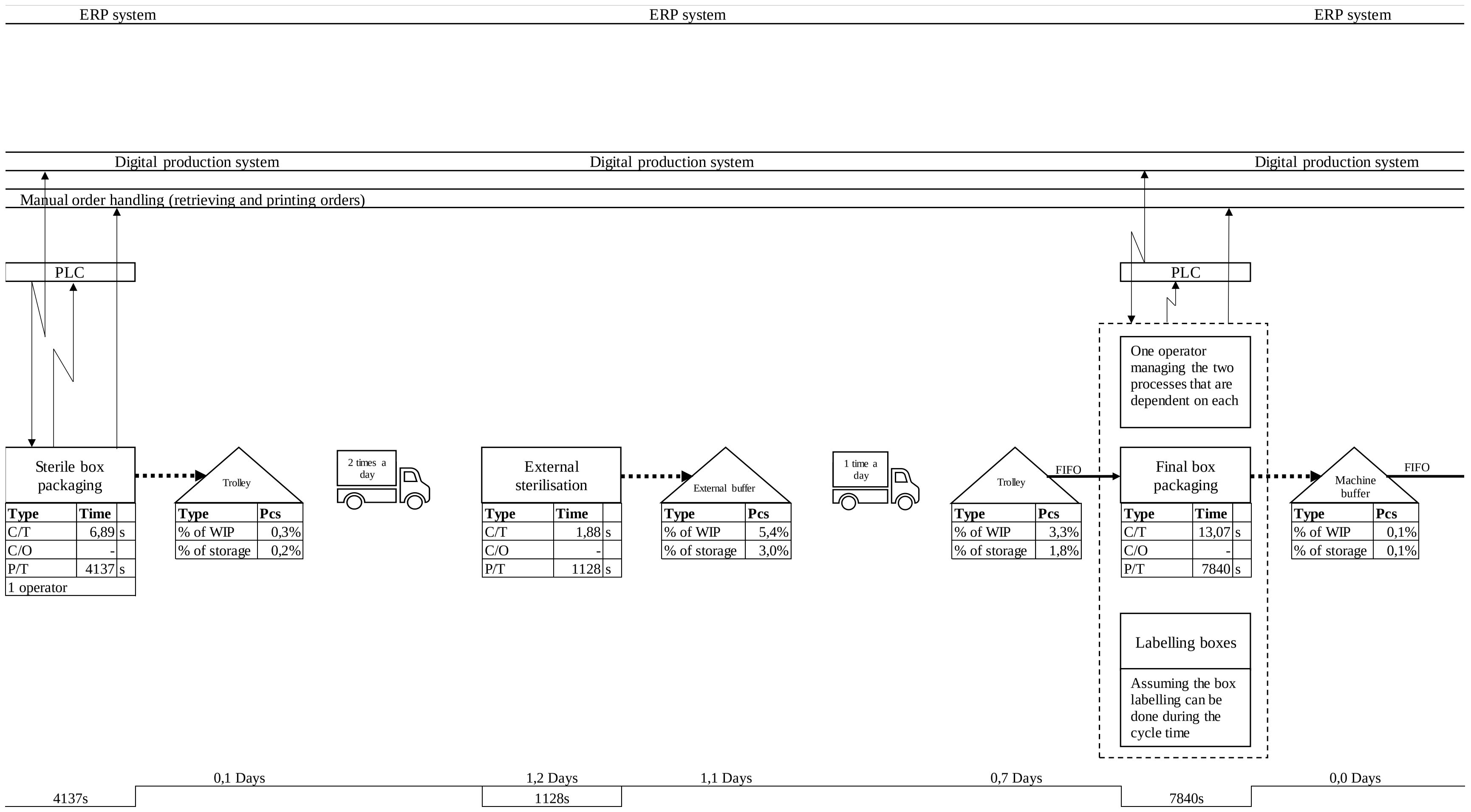
APPENDIX B – CARRIER FLOW

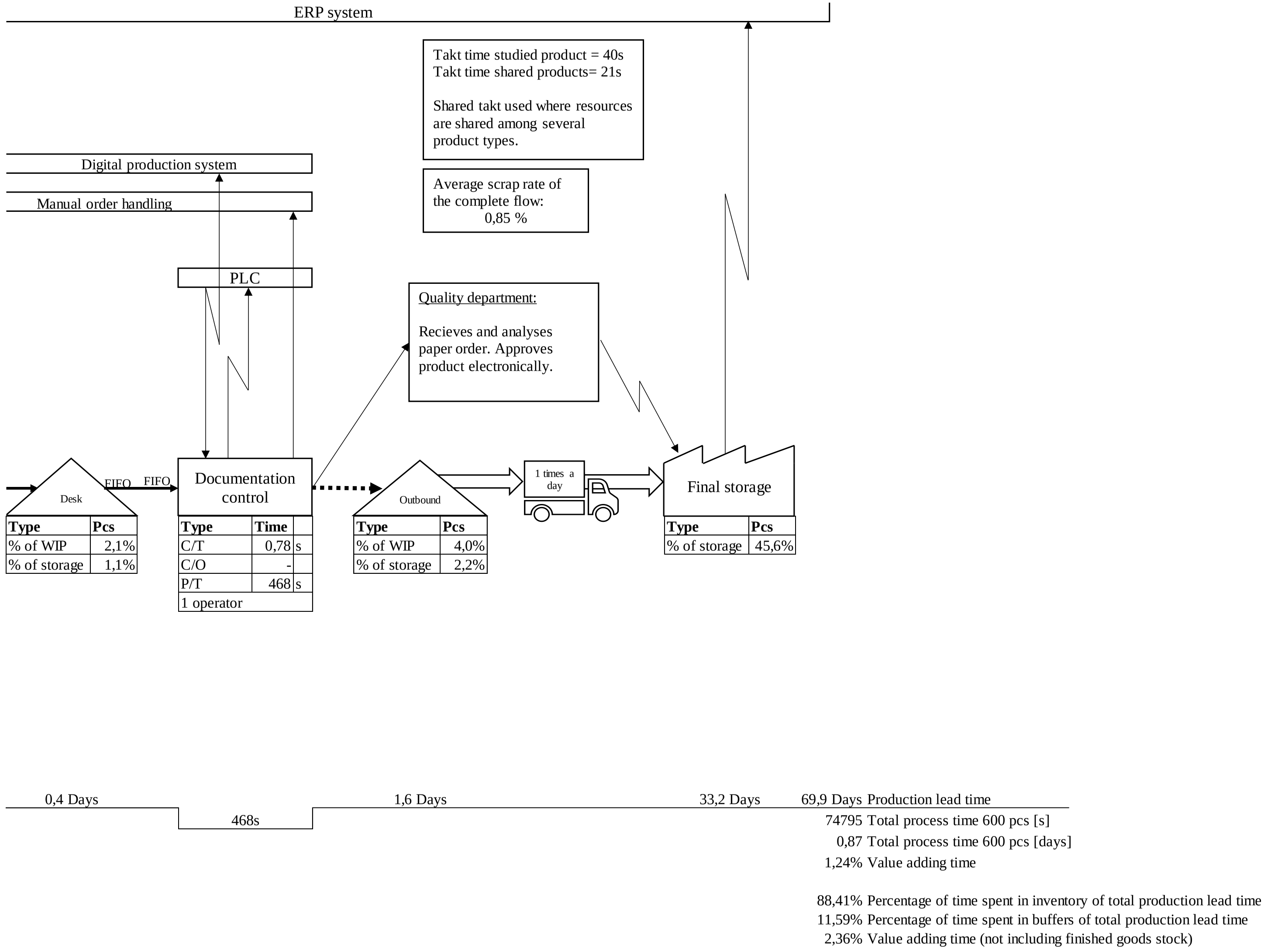


APPENDIX C – CURRENT STATE MAP




ERP system
ERP system
ERP system
Digital production system
Digital production system
Manual order handling (retrieving and printing orders)
PLC
PLC
PLC
PLC
LAF 1
FIFO
Type | Pcs
% of WIP | 0,7%
% of storage | 0,4%
D-Carrier
Base and acid
Type | Time
C/T M | 15,14 s
C/T OP | 1,147 s
C/O | -
P/T | 9773 s
D-Carrier
LAF 1
FIFO
Type | Pcs
% of WIP | 3,1%
% of storage | 1,7%
D-Carrier
Manual carrier assembly
Type | Time
C/T | 20,32 s
C/O | -
P/T | 12189 s
1 operator
H-Carrier
Automatic carrier assembly
Type | Time
C/T | -
C/O | -
P/T | -
1 operator
H-Carrier
LAF 1
FIFO
Type | Pcs
% of WIP | 0,2%
% of storage | 0,1%
H-Carrier
Etching
Type | Time
C/T M | 4,95 s
C/T OP | 0,91 s
C/O | -
P/T | 3519 s
H-Carrier
LAF 2
Type | Pcs
% of WIP | 1,8%
% of storage | 1,0%
H-Carrier
Blister packaging
Type | Time
C/T | 26,97 s
C/O | 272,13 s
P/T | 16181 s
1 operator
1 runner
0,1 Days
9773s
0,7 Days
12189s
0,0 Days
3519s
0,7 Days
16181s
LAF 1
Type | Pcs
Tot | N/A
A-Carrier
Group manager schedules when to start titanium cup production
Prepared RM
FIFO
Type | Pcs
Tot | N/A
Solvent degreasing
Type | Time
C/T | 3,00 s
C/O | -
P/T | 1799 s
1 operator
A-Carrier
LAF 2
FIFO
Type | Pcs
Tot | N/A
A-Carrier
Titanium cup assembly
Type | Time
C/T | 14,1 s
C/O | -
P/T | 8433 s
1 operator
A-Carrier
Storage workshop 2
Type | Pcs
EV | N/A
B-Carrier


ERP system
ERP system
ERP system
Digital production system
Digital production system
Digital production system
Manual order handling (retrieving and printing orders)
PLC
PLC
Sterile box packaging
Type | Time
C/T | 6,89 | s
C/O | -
P/T | 4137 | s
1 operator
Trolley
Type | Pcs
% of WIP | 0,3%
% of storage | 0,2%
2 times a day
External sterilisation
Type | Time
C/T | 1,88 | s
C/O | -
P/T | 1128 | s
External buffer
Type | Pcs
% of WIP | 5,4%
% of storage | 3,0%
1 time a day
Trolley
Type | Pcs
% of WIP | 3,3%
% of storage | 1,8%
FIFO
One operator managing the two processes that are dependent on each
Final box packaging
Type | Time
C/T | 13,07 | s
C/O | -
P/T | 7840 | s
Labelling boxes
Assuming the box labelling can be done during the cycle time
Machine buffer
Type | Pcs
% of WIP | 0,1%
% of storage | 0,1%
FIFO
0,1 Days
1,2 Days
1,1 Days
0,7 Days
0,0 Days
4137s
1128s
7840s


ERP system
Takt time studied product = 40s
Takt time shared products= 21s
Shared takt used where resources are shared among several product types.
Average scrap rate of the complete flow: 0,85 %
Digital production system
Manual order handling
PLC
Quality department:
Recieves and analyses paper order. Approves product electronically.
Desk
FIFO
FIFO
Documentation control
Outbound
1 times a day
Final storage
Type | Pcs
% of WIP | 2,1%
% of storage | 1,1%
Type | Time
C/T | 0,78 s
C/O | -
P/T | 468 s
1 operator
Type | Pcs
% of WIP | 4,0%
% of storage | 2,2%
Type | Pcs
% of storage | 45,6%
0,4 Days
468s
1,6 Days
33,2 Days
69,9 Days Production lead time
74795 Total process time 600 pcs [s]
0,87 Total process time 600 pcs [days]
1,24% Value adding time
88,41% Percentage of time spent in inventory of total production lead time
11,59% Percentage of time spent in buffers of total production lead time
2,36% Value adding time (not including finished goods stock)

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