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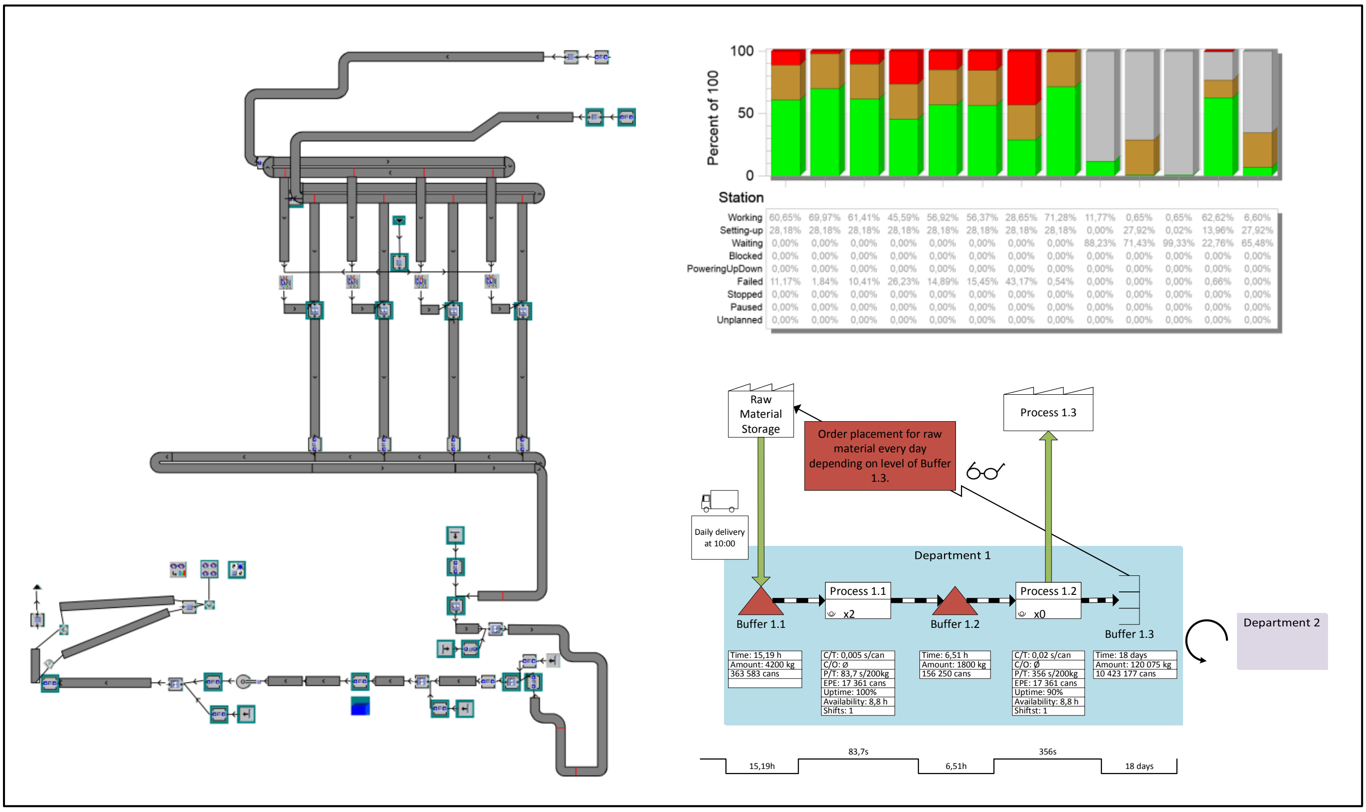

Identifying Organizational Improvement Potential using Value Stream Mapping and Simulation

A Case Study at Swedish Match Göteborg

Master of Science Thesis in MSc. Production Engineering, MPPEN 2015

EDUARD KAPOUN
TOBIAS BÖRJESSON

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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TOBIAS BÖRJESSON

Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
The cover picture illustrates a part of the simulation model, value stream map and statistical analysis used in the study.

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ABSTRACT

With manufacturing companies competing among each other for valuable customers, production systems are often in need of optimization or redesign in order to keep up with the competition. This report therefore covers a case study performed in cooperation with Chalmers University of Technology as a master thesis at Swedish Match Göteborg. The aim of the case study is to investigate possibilities of increasing the flexibility of the company's production in terms of product variety as a basis for a future production-wide paradigm shift for an increased number of produced product types in the company.

To investigate the possibilities of increasing flexibility, a VSM was created in the first hand which then formed the basis for a simulation model. Both the VSM and the simulation model were used to examine possibilities of modifying the production to better serve a higher product variety. A comparison of VSM and simulation was also conducted in order to explore the advantages and disadvantages of using both tools for production improvement both in this case study and in general. More specifically, the VSM was used for a first hand overview of the production and as an aid to narrow down the areas in need of investigation. The simulation model was then used to modify the production in greater detail while enabling a detailed analysis and generation of possible improvement scenarios.

The results from the study show that an increase of 37,57% in output is possible while increasing the flexibility from two product types produced per day to a possible of eight per day while maintaining output, if the study's production-specific improvement suggestions are implemented. However, the study has also shown improvement potential within the managerial and organizational aspects of the company which, if implemented, have potential to further increase output and flexibility.

Keywords: Value Stream Mapping, Discrete Event Simulation, Flexibility, Production Planning, Lean Production, Lean Management

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Lastly, we would like to give a truly very special thanks to our supervisor at Swedish Match Gothenburg, Hans Meyer, for providing nothing short of excellent support and guidance during our thesis. Without his profound experience of the production system, his strong ambition to improve processes as an engineer, his ability to see the true potential before anyone else, as well as his unique insight into problematic areas, this thesis would only be a fraction of the standard it is today.

We wish Hans Meyer, the rest of Swedish Match Gothenburg, Chalmers University of Technology and Siemens Industry Software a big collective thank you.

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1. INTRODUCTION

1.1 Background

Companies around the world are either in the process of adapting to changes or have certain plans to do so in the future. With competing companies in different product markets, it is imperative for companies to stay ahead of their competition by innovating. However, not all companies successes revolve solely around innovation (Hermann, S. (2009)). Taking Henry Ford as an example, the Model-T Ford and the moving assembly line was certainly one of the greatest innovations of the 20th century which certainly put Ford and its cars at the forefront of engineering and innovation. Despite this, as time had passed, several budding auto manufacturers had adopted Ford’s production line and some have gone so far as to refine it. Toyota became famous for its Toyota Production System which shook the very foundations of western production and what was believed to be efficient and economic. This new, radical and highly efficient production system was adopted among many western manufacturing companies and had after some time adopted the name “Lean Manufacturing” (Liker, J. (2004)).

Relating very close to lean manufacturing and the Toyota Production System was also a new concept of quantifying the flow of value through a company, from supplier to customer. This concept and process of putting an entire company’s supply chain under strict scrutiny in terms of customer value was named Value Stream Mapping (VSM). Coupled with the principles of lean manufacturing, companies could very efficiently produce a simple diagram over a company’s production process and supply chain.

VSM proved to be a valuable tool yielding a quick overview of important areas to focus on when conducting improvement work. However, as time has progressed so has innovation in different areas of technology, which has consequently led to the development of simulation models used as software in computers. Today, simulation has proven itself to be one of the most important tools of a modern company employing a manufacturing strategy, due to the rapid development of alternative models which yield results in seconds for a near infinitesimal cost compared to real life implementation and testing. (Banks, J. (1998), Rother, M. and Shook, J. (2003))

With VSM and simulation software in hand, it is not only important to know that both exist and are very potent tools, but also to know whether they work well together or not and in what ways. A case study on a company where a Value Stream Map and a simulation study are conducted would therefore be beneficial in order to investigate these two tools and how they interact.

For the case study, a company on the west coast of southern Sweden within the tobacco industry has been chosen. The company in question, Swedish Match, are among the world’s leading companies that develop, manufacture, and sell quality products with market-leading brands in the product areas snus, other tobacco products (cigars, chewing tobacco and snuff), and lights (matches and lighters). The organization is split up into several divisions around the world, including Sweden, the U.S. and Latin America with production sites located in Sweden, Brazil, the Dominican Republic, the Netherlands, the U.S. and the Philippines. The production facility in Gothenburg, Sweden is one of the two divisions within the SMD Logistics AB operating unit distributing mainly tobacco products within the Swedish market to around 10,000 stores, effectively covering the entire Swedish retail sector.

Swedish Match has earlier had a monopoly on snus production, but recently this has changed as new and competitive players have emerged on the market. In order to remain competitive on the market, Swedish Match feels that a continuous improvement on their snus production is of utmost importance.

1.2 Problem Definition

Value stream mapping (VSM) is known to be the doorway to lean implementation. It is a tool that many companies use to fully understand the current production and what improvements that are needed to fully utilize the advantages of lean production. It is however questionable how VSM can be used when evaluating the production in detail. Instead, discrete event simulation has grown when it comes to evaluating production systems. The tool has proven to be very useful when it comes to investigating production systems in detail. It is however a tool that needs a greater knowledge level while proving to be time consuming when simulating larger and more complex systems. The first question (RQ1) aims to answer this dilemma of the usage of these improvement tools.

RQ1: How can Value Stream Mapping and Discrete Event Simulation be used to support organizational improvements?

Swedish Match has a large variance in customer demand, variance of products, long changeover times, as well as an estimated product throughput time of 26 days. Because of the highly shifting demand and the long throughput time, the company needs to have a large finished goods stock which results in a lot of work in process, inventory costs and tied up capital. In order to expand their product portfolio while keeping up with varying demand and decrease the finished goods stock, the company needs to decrease Work-in-Process (WIP) and increase the flexibility of their production while maintaining its output. To achieve this the company needs to analyze the current production flow and improve the stations affecting flexibility in terms of producing a greater amount of product types per time unit. The second question (RQ2) aims to narrow the scope of the investigation to problem areas within the company requiring immediate attention.

RQ2: Which areas of Swedish Match production provide the largest improvement potential in regards to increasing flexibility while maintaining output and lowering finished goods stock?

1.3 Aim

The use of VSM and simulation for process and production improvement should be conducted as a case study in order to evaluate their integrity individually and when used in conjunction with one another. As the company in the case study wishes to remain being the competitive market leader, the case study should provide the company with improvement recommendations based on the results gained from the VSM and simulation study. More specifically, they feel the need to increase their production flexibility while maintaining production output and meeting customer demand.

The project's aim is therefore to start by performing a current state Value Stream Map, analyze the value stream for areas of improvement and then continue by creating a current state simulation model of the area in need of improvement. This model will then be validated and verified in order to evaluate which part of the production process that affects the flexibility the most, and how this area can be improved upon. Finally, proposed improvements to the production facility should be presented visually within the simulation model or as an improved future state VSM over the affected areas, as well as comparing the simulation results to the Value Stream Map and determining the differences between the conclusions reached using both improvement tools.

1.4 Delimitations

Firstly, the project will only focus on the production facility in Gothenburg, Sweden. Moreover, since this production facility produces several different types of snus, the production flow of PortionsSnus Original (PSO) will be of focus.

In addition, the economic aspects of any production improvements proposed within this study have not been taken into consideration. No economic calculations or effects of implementing any improvement proposals have been taken into account and are therefore regarded as outside the scope of this study. Any improvement proposals discussed which do not entail the purchasing of additional machinery, hiring of additional workers or any such additive process is regarded as an improvement potential requiring no additional monetary cost for implementation.

The study did not develop any of its own experiment suggestions, instead the experiments that were performed were created from ideas regarding material flow and layout changes that Swedish Match wanted to investigate.

The project will start the 19th of January 2015 and will continue for 20 weeks at 100% capacity corresponding to 30 university credits (högskolepoäng).

2. THEORY

2.1 Previous Research regarding Simulation and VSM

The notion of using simulation and value stream mapping on a separate basis has previously proven ground within the research community. However, variations of the use of these two improvement tools have also proven to yield a multitude of research data in the prospects of production improvement, based on type of production, scope, and other parameters. From this previous research, these tools present both advantages and disadvantages in their own right. As a consequence of this, a new area of research within these two tools has spawned different perspectives regarding the use of these tools in different ways for a more efficient production improvement. In addition to a more efficient way of quantifying improvement metrics, the research has also posed an improvement of the presentation of results for management and lean specialists.

With that said, VSM requires less skill than simulation to produce, however the diagram is a great deal easier to understand. Simulation on the other hand may prove more difficult to understand at first glance, but the possible output is of much greater detail and usefulness. The apparent differences between these two tools seems to be their constraining factor when used separately on the same object of study. Therefore, the need for investigation regarding the combination of these tools has risen in an attempt to verify whether the tools can be combined or used in another way to gain the benefits while complimenting themselves on their individual disadvantages.

Helleno, A.L. et al. (2015) researched the possibility of using both VSM and simulation as a basis for a company to base production improvement decisions on, more specifically within operations management. As a result, the study concluded that the display of results from both the VSM and simulation was successful and that management decisions regarding production improvements could very well use this data as a basis for economic calculations and tests for feasibility of implementation. However, the study was conducted with the tools being used separately, producing separate results.

In close relation to this, Abdulmalek, F.A. and Rajgopal, J. (2007) investigated the positive effects of implementing lean manufacturing practices alongside a VSM with the help of simulation. The study resulted in both VSM and simulation being used but as separate tools. The VSM was used primarily to identify areas with great potential of implementing lean principles, while the simulation study was used to better quantify the improvements between the current state and future state VSM, in terms of numbers and other metrics to upper management.

Moreover, research has also been done in an attempt to more specifically streamline the process of producing an improved future state model of a production system utilizing VSM and simulation. Schmidtke, D., Heiser, U. and Hinrichsen, O. (2014) conducted a study where the result was a new framework for presenting production improvements in this way, where a true integration of simulation into the VSM framework was done. Of note was that simulation was proven to be a good aid to motivate the improvements found in the VSM, in the way that an analysis of tradeoffs between different factors of importance within the production was done.

In a slightly more unconventional study from the previous ones mentioned, Solding, P., and Gullander, P. (2009) proposed using VSM and simulation as two tools fused into one. The result is a proposed method of using both tools in an attempt to harvest the benefits of both while minimizing the disadvantages, where the tools are combined in order to produce a "moving" value stream map based on underlying simulation data. The goal was to produce a new way of presenting VSM and simulation data which is accurate and dynamic, in order to further motivate change within a company and enable external parties to gain more insight and knowledge into proposed improvements. In this way, the static nature of VSM was combined with the dynamic nature of a simulation model to produce a dynamic VSM.

Even Coppini, N.L et al. (2011), and Detty, R. and Yingling, J. (2000) demonstrate the wide variety of attainable results from combining the two tools instead of conventionally using one over the other.

2.2 Lean Production System

The Lean Production System as known today started out as the Toyota Production System (TPS), initiated by Taiichi Ohno who collaborated with Sakichi Toyoda in Japan when he founded the company Toyota Industries, today known as one of the world's largest car manufacturers. For the past ten years, the lean manufacturing movement has dominated the manufacturing industry, proving that companies strive to conduct operational excellence while offering excellence in quality.

As can be quoted by Taiichi Ohno, the founder of TPS: "*All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes."* (Ohno, 1988)

The philosophy of lean manufacturing is to enable the possibility of a company to provide more for their customers with less resources, without sacrificing criteria set by customers. Dennis, P. (2007) explains how companies can achieve this with less time, less space, less human effort, less machinery and less materials. An important aspect to have in mind is that lean production is not solely applied to a manufacturing line of a product. In fact, the term should apply to all areas and branches of a company; from the shop floor with machinery to the offices of the upper management. The necessary tools to implement a lean organization should be implemented throughout the company, on all hierarchical levels, in order to reap the true benefits of transforming an organization to that of lean production.

Using less resources and less human effort does not automatically entail hitting budget roofs or enforcing employee layoffs. The lean production system encourages the exact opposite of this, as actions such as layoffs are seen as counterproductive to the lean philosophy and hitting budget roofs is a waste (Liker, J. (2004)). It is instead encouraged to redistribute capacity and resources, even employees, in order to fully maximize the company's manufacturing potential (Ohno, T. (1988)), (Liker, J. (2004)). Dennis, P. (2007) further explains how the process of employee involvement in continuous improvement work helps build motivation among employees. Their involvement directly affects the success of improvement implementation. The more success they experience, the greater the rewards are both internally within the company and externally outside the company. Having happy employees generates a multitude of benefits no company should overlook.

Lean production should also not be viewed as a goal, it should be viewed as a continuous journey as described by Morrey, S.R. (2000). The lean journey should never end, it should always be regarded as a continuous process of improvement, where the process of improving never stops. A great emphasis is made by Dennis, P. (2007) when portraying lean production as a way of thinking rather than a practical method or tool to use. Dennis presents a table describing the conventional way of thinking versus the Toyota/Lean way of thinking (see Table 1). A thorough understanding of the differences and how they affect an organization's philosophy is of tremendous importance for a lean transformation not to fail.

Table 1. A Summary of conventional mental models versus the Toyota/Lean mental models (adapted from Dennis, P. (2007)).

Typical thought processes in companies today	**The Toyota/Lean way of thinking**
Keep the production going despite quality errors/production stops.	Stop the production immediately. Fix errors.
Produce as fast and as much as possible.	Produce only what has been ordered.
Produce large batches slowly.	Produce according to one-piece and continuous flow.
Leader has authority and should be respected.	The leader is the teacher.
No standardization of work tasks/processes.	Simple and visual standards for all things of importance.
Others create standards, we don't have time.	Staff closest to the work create the standards.
Sweep problems under the mat - they are too small to make a difference anyway.	Make problems visible and fix them right away.
The shop floor is not for upper management, only for shop floor staff.	Genchi Genbutsu: Go see for yourself. All areas of the company should inspect the production.
Make decisions and build more decisions upon these.	PDCA-cycle: Plan-Do-Check-Act.

The TPS can be summarized with various schematic graphs and pictures which dictate the essence of the Toyota way and what lean production is all about. An example of this is the 4P-system; one of several systems Toyota strives to follow in order to uphold their lean production philosophy and remain on the list of the world's most competitive auto manufacturers.

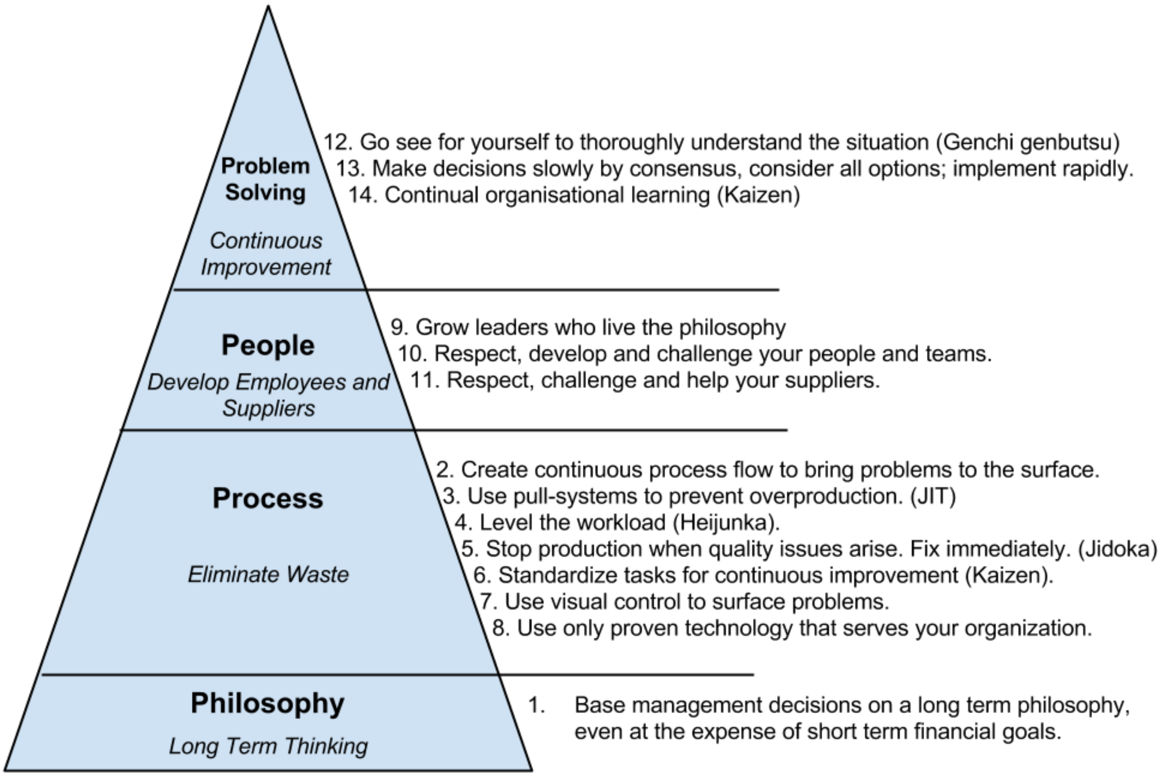

Figure 1. The 4P-model as developed and used by Toyota in the TPS. (Adapted from Liker, J. (2004))

The picture depicting the 4P-model in Figure 1. The 4P-model as developed and used by Toyota in the TPS. (Adapted from Liker, J. (2004)) should be viewed from bottom to top, where the bottom of the triangle symbolizes the base from which the forthcoming P's build upon. Liker, J. (2004) conveniently adapts his proposed 14 management principles to the four categories of the 4P-triangle as presented by Toyota, further easing the understanding of the pyramid and its true power. For this case study, a concentration on the Process-step of the pyramid is of great importance, since the throughput time of the product and WIP need to be reduced and flexibility of production needs to be increased. In addition to this, a number of lean principles are present in this section of the pyramid, many of which are of great relevance to the further improvement work to be done.

However, even though the principles 2 through 8 are of primary focus, even principle 12, also referred to as Genchi Genbutsu, manifests itself as a primary step for further work. This is to ensure that the process is fully known before any improvement work is done on it, lest any improvement work that has been done could be of little use.

Following Liker's (2004) management principles, an application of his lean principles is recommended if lean improvements are to be made.

2.2.1 Customer Order Decoupling Point

When viewing a production system and its potential for improvement, one major factor for potential improvement is the Customer Order Decoupling Point (CODP). According to Bellgran and Säfsten (2010), the CODP is the point in the production flow that decides how the production plan will take form, essentially splitting the flow into two types - producing to forecast and producing to order. To further explain, Bellgran and Säfsten describe two types of CODP's; upstream and downstream CODP's. An upstream CODP is based more on forecasting data and less on customer demand while a downstream CODP is customer order initiated rather than forecast based. These types of CODP's lead to a number of different production planning categories where a number of CODP's are valid based on the type of production. The categories mentioned by Bellgran and Säfsten can be seen in Figure 2 below:

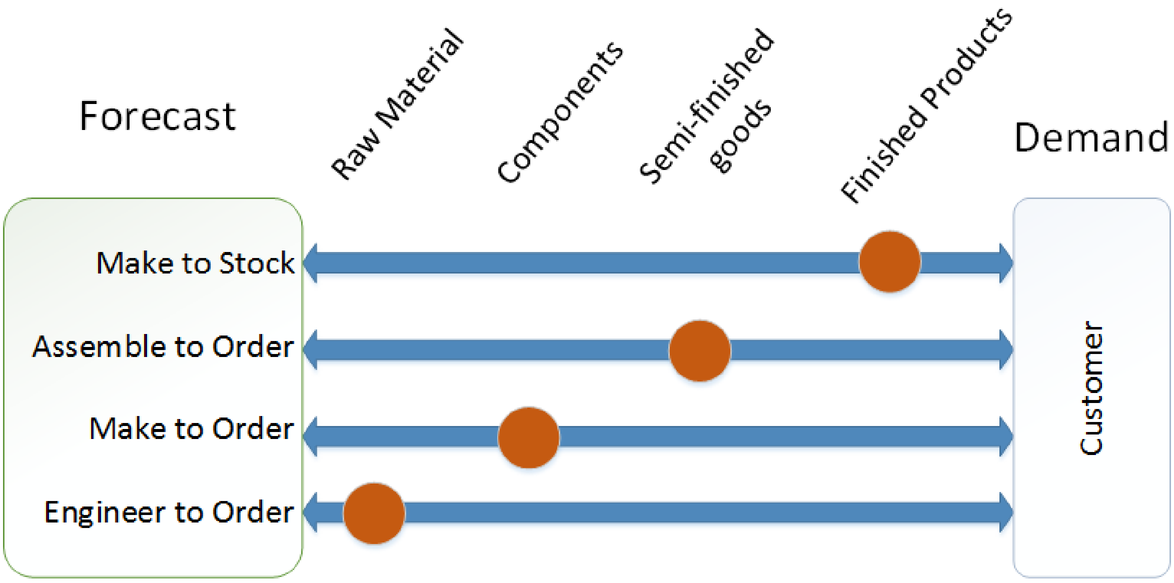

Figure 2. A diagram over CODP categories (Adapted from Bellgran and Säfsten (2010)).

From Figure 2 it can be seen how the different CODP categories relate both to each other and in relation to supply (forecast) and demand (customer). The closer the dot is to one side, the more of the other side is relied upon. For example, in the Make to Stock (MTS) scenario, the dot is on the far right, close to the demand side. This means that great weight is put into forecasting the demand for the product in order to produce finished products to a stock that the customer can purchase from. There is little to no customization of the product, which is the case in mass production scenarios. When comparing the other side of the spectrum in the Engineer to Order (ETO) scenario, there is little to no forecasting of product demand, while great care is taken to leverage customer orders based on immediate customer demand. A scenario like ETO is most likely found in craftsmanship-like production strategies, regardless of technical complexity.

In the middle of the two extremes we find the Assemble to Order (ATO) and Make to Order (MTO) CODP categories, where the varying stages of the finished product are presented above its respective CODP placement. The MTO's CODP consequently divides the flow from components and onward, while the ATO's CODP divides the production flow from semi-finished goods and onward. From this it may be simpler to understand that the ETO CODP primarily applies to highly customized products with low production volumes, such as airplanes, while the MTS CODP primarily applies to low customization with high production volumes, such as matchsticks.

In both these example cases of airplanes and matchsticks, airplanes have the CODP pushed very far upstream to the raw material stage of production, since different airplanes may need a different metal alloy. Further on from this point, the airplane is continually customized for the customer's specific demand until it becomes a finished product which the customer purchases. On the other hand, matchsticks have their CODP pushed very far downstream since there is little customer demand in regards to product customization. Therefore, the matchstick's production process can afford to produce large amounts of product to stock according to forecast, since the product itself is not tailored to customers specific needs.

With ever increasing customer demands on products, the traditional mass production strategy is starting to fade, leading to new horizons in refining today's production strategies for tomorrow's customers and demands (Coletti, P. and Aichner, T. (2011)). This trend seems to be leading toward mass customization; the production strategy enabling a high production volume while maintaining flexibility (see Figure 3).

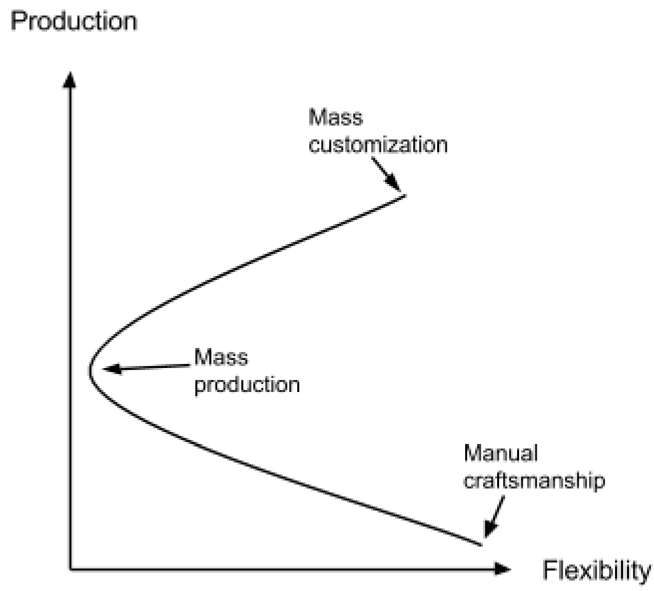

Figure 3. An adapted illustration depicting the shifting production paradigms described in Coletti, P. and Aichner, T. (2011), from mass production to mass customization.

With the different CODP's in mind, the placement of the CODP in the production flow is crucial for a company in order to meet customer or forecasting demands while maintaining the desired level of flexibility. However, as technology moves forward and customer demands shift, the production process and number of product variants for a company may change. In this case, care needs to be taken in order to evaluate where the CODP is currently within the company and where it should be when accounting for the future.

A recent study by Hedenstierna, P. and Ng, H.C., A. (2011) suggests that placing a CODP as far downstream as possible is preferable, however even a CODP placed upstream can be beneficial. The study further explains that this "beneficial in both ways" CODP placement largely depends on the frequency and amplitude of a company's demand curve. More specifically, for an ATO-type production, placing the CODP far downstream yields a smoother production and higher inventory response rate for smaller demand fluctuations. This CODP placement however comes at a cost, as placing the CODP downstream will need further reevaluation of the production system regarding necessary safety stock.

Furthermore, Mattsson S-A and Jonsson P (2003) describe the different production strategies in comparison with the three factors of importance for production; time to consumer, production volumes and product variation (see Table 2). Considering the placement of CODPs, these factors become closely related with each other.

Table 2. A display of competitive production factors versus CODP placement (adapted from Mattsson S-A and Jonsson P (2003)).

Production Factors	Engineer To Order (ETO)	Make To Order (MTO)	Assemble To Order (ATO)	Make To Stock (MTS)
Time to consumer	Long	Average	Short	Very Short
Production Volume	Small	Small	Average	Large
Product Variation	Very high	High	High	Low

2.2.2 The Toyota Way of Production Leveling

Meier, D. and Liker, J. (2006b) bring up several aspects to be accounted for when an organization is to implement leveled production on their lean journey. When looking at product varieties, it is often common in traditional manufacturing to produce large batches of each product type in order to mitigate the long changeover times. However according to the lean philosophy and the TPS, product varieties should be produced in small batches and in alternation.

The objective of *heijunka* is to level the production volume and mix and create a smooth flow over a specific time period. The overall goal is to be able to produce parts in varying volumes and mixes for every reasonable cyclic period for the company, for example every few hours, every day or every week. The shorter the cyclic period the better the production mix is leveled, as a shorter cyclic period results in a production more in line with true one-piece flow.

Creating a Starting Point for a Leveled Production Schedule

To achieve a leveled production, a proper starting point is needed. In this case, Meier, D. and Liker, J. (2006b) recommend to first initiate basic process stability. Many factors uncover the indicators of process instability. Such factors are listed as varying output, but also a great variation in time taken to perform a certain task or run a certain process, which varies greatly between operators, shifts or generally over time. The indicators of varying output and especially varying time to complete processes are very relevant to the case study. The recommended level of reliability to adhere to according to Meier, D. and Liker, J. (2006b) is 80% or better.

Once this basic level of process stability is ensured, an acceptable takt time can be calculated which will be central for creating an even flow and leveled production. According to Meier, D. and Liker, J. (2006a), three parts of the production need to be leveled - the production volume for a certain period, the product mix which ensures the correct ratio of product types to produce during manufacturing during the same time period, and the product sequence which ensures the correct sequence of the product mix based on the production volume.

Many production facilities produce products which have a higher demand and sell more, while others have a lower demand and sell less. Both types of products may be relevant for a company to produce, but leveling both the same way may not be feasible. For production leveling to work in this manner, Meier, D. and Liker, J. (2006a) recommend to isolate high volume-high demand products from low volume-low demand products. In this way, the high volume-high demand products can be leveled within the production to meet customer demand in a MTS strategy, while the low volume-low demand products are produced in an appropriate product mix and sequence based on an ATO strategy. To establish a necessary production level, previous 12-month periods of sales and demand can be investigated in order to determine peaks and troughs in demand, enabling the calculation of an average across weeks, months or years depending on the scope.

However, taking the average of all months and using that level may not be beneficial due to the possibility of highly varying demand. As a guideline, Toyota use 80% of maximum demand as the production level with the motivation that the final 20% can be utilized by employing overtime hours, however the guideline for 80% is not static as the final level is highly subjective based on the production, forecasting data and process variability.

Equally as important to take of note is that a large enough span of data is observed. A large span of data causes noise in the form of demand spikes in historical data to be filtered out. Likewise, the observation of historical data may not be a guarantee for the future data to be similar. This is especially true when a company is within a product changing phase, such as with the case company. New products mean new and fluctuating demand curves which means that there is no historical data for new product releases. This ties closely to the notion that a division of actual demand from placed orders should be enforced, as many companies tend to view orders placed by the MRP system as their actual demand, when these numbers in fact depend on many other factors and therefore do not reflect the real demand for a product.

The next step is to determine the level pattern in the form of multiples, seeing the scope as a production week. Meier, D. and Liker, J. (2006a) therefore recommend that products which are in high demand and may require production every day should therefore have a multiple of 1, and products with lowering demand should have production days in multiples up to 6. For example, Product A has a high demand and needs to be produced every day, meaning it has a multiple of 1 day. Product B has half the demand of product A, meaning it can be produced every second day - a multiple of 2. Product 3 has a very low demand, one sixth of Product A to be exact, and can therefore be produced every 6th day. An approach to leveling in this way is a good beginning, as adjustments are sure to be made to accommodate for the specific production process.

2.2.3 The Bullwhip Effect

In order to properly implement a leveled production, it is important to realize that the bullwhip effect may be the cause of disorganized and chaotic production. The effect describes the discrepancy between customer orders and how these small variations magnify the further upstream within a process you go. With an unleveled production, fluctuations in customer demand will reveal large weaknesses within a production system, such as large safety stock buffers and pressure put on suppliers who must maintain materials for any number of shipments depending on the wildly fluctuating customer demand. The idea behind *heijunka* is to minimize the bullwhip effect by transforming uneven customer demand into a more predictable demand curve where resources are better utilized.

By neglecting the true underlying cause of uneven customer demand, a leveled production plan will be profoundly difficult, if not near impossible to implement. A leveled production plan relies greatly on standardized work procedures in order to level work across process operations within the production system. This leveled work across process operations is based on the customer takt time, which in turn relies on the customer demand. Given that the customer demand shifts greatly, the takt time therefore shifts and so does the work across process operations, causing it to become unleveled.

The leveling of demand is therefore another aspect of *heijunka* which is crucial in order to build common and standardized ground to build improvements upon, also called the “basic leveling” (Meier, D. and Liker, J. (2006b)). For a production system with many product varieties, achieving a level production is possible by investigating high-volume/high-sale products and producing those to stock, while producing the other products which are low-volume/low-sale in an ATO fashion (Liker, J. (2004)).

2.3 Swedish Match Production System

There exist many similarities in the Swedish Match Production System (SMPS) when compared to the lean production philosophy, originally known as the Toyota Production

System. As a company, Swedish Match regard themselves as lean philosophy followers, claiming to be implementing lean tools such as 5S, continuous improvement and Six Sigma among others. Similarly to the TPS, the SMPS provides guidelines for employees to follow, such as illustrating the core values and vision of the organization as a schematic house. Similarities can be drawn from the SMPS "house" compared to similar guidelines from Toyota, where a base is established portraying the vision of Swedish Match from which all other parts of the organization build from (see Figure 4).

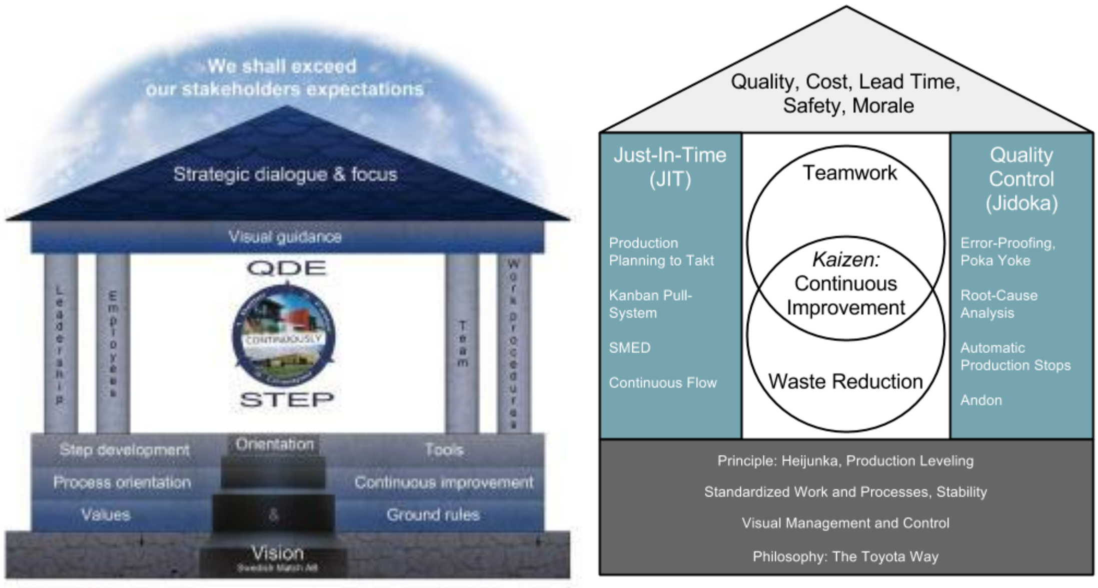

Figure 4. The SMPS house (left) (Swedish Match Documentation (2015)) compared to the TPS house (right) (adapted from Liker, J. (2004)).

Core values such as their QDE-STEP indicators provide a link and supporting foundation to visual control, strategic dialog and focus, with the sky symbolizing the ambition to overshoot stakeholder's expectations. The SMPS simultaneously makes an important note of process orientation, continuous improvements, values, way of working, leadership and teamwork to be the foundational base and pillars of the house.

QDE-STEP stands for Quality, Delivery, Economy, Safety, Technology, Environment and Personnel. Throughout the organization these indicators are displayed on wall-mounted boards with relevant graphs and information below each letter, showing employees the state of the indicators. According to Swedish Match themselves, the QDE-STEP model serves as a guide to how they can produce their products better, faster and cheaper than their competition. The model aims to state how the organization effectively communicates, prioritizes, sets goals and follows up results. Especially within the QDE model, Swedish Match finds it important to find a balance between quality, delivery and economy. They take great pride in their products and feel that employee involvement is one of the keys to innovation and success.

With the different production systems in mind, improvements to a system must start from somewhere, where lean production and its improvement tools may prove to be useful.

2.4 Value Stream Mapping

More than being a permeating philosophy an organization should strive to achieve, lean production makes use of several tools for aiding a company's lean transformation. A definition of VSM is presented by Che Ani, M.N. et al. (2014), stating that it is an effective tool to create an overall current state schematic of a production system Lovelle, J. (2001) further describes VSM as a tool that aims to devise a current state analysis of a company's production while providing the ability to identify waste in the process flow. With the current state VSM in mind, a future state VSM with proposed changes to the process flow from the current state is produced.

This future state map should then act as a goal for the company to strive for regarding the value stream of materials through the organization and waste reduction. In essence, a VSM is a schematic diagram over a company's operations. From customer orders, to production control, supplier deliveries and the transformation from raw material to product in a manufacturing process. It is these steps which in detail need to be analyzed with proper and honest data in order to build a current state VSM to improve. Along with the current state VSM, other lean tools such as 5S, Six Sigma, leveled production scheduling (Heijunka), policy deployment (Hoshin Kanri), Single Minute Exchange of Die (SMED), continuous improvement (Kaizen) and many more may be required to fulfill the desired future state VSM.

Lovelle, J. (2001) recommends starting the documentation of the VSM by splitting the schematic diagram into two parts done separately with different departments. First, an external mapping should be done, which includes information relating to customer orders, production control, supplier orders and deliveries. Production control receives orders from customers expressing demand, while also sending material orders to suppliers for the delivery of raw material for production. Next, an internal mapping should be done which consists of the internal processes for turning raw material into a sellable product. Here, all the machines, buffers, intermediate inventory, personnel and other process steps are accounted for, both from value adding and non-value adding perspectives.

For the internal mapping to be successful, it is important for related employees conducting the VSM to observe the production from the shop floor by physically being present. Liker, J. (2004) emphasises the importance of being present on the shop floor, regardless of the hierarchy one might be present in within the company structure. *Genchi genbutsu* - the act of personal involvement; to see, analyze, question and evaluate - is of central importance to the TPS and lean production overall. However, to conduct a VSM in the proper way, a thorough and correct understanding of the production process is necessary, further encouraging a physical hands-on approach to a process.

Dixon, D. (2008) takes the hands-on approach one step further and extends it from "walking the floor," i.e. physically touring the production process, to "walking the office." The meaning of producing a value stream on the grounds of upper management and office space is equally as important as producing a value stream of the actual production of a product. For a value stream to bear truth and be meaningful as a base for continuous improvement, both management and production need to sort out their value-adding and non-value adding activities in relation to the customer. It is not only the actual machines and production process which add value to the end product, it is also the methods and frameworks from which management operate in terms of purchasing, such as materials or machines, and also planning of production and meeting the strategic goals of the company that add value.

The VSM schematic itself usually takes the form of a standard set of pictures, arrows, boxes and other shapes to designate processes, buffers, personnel and material as well as information flow. Different sources of literature recommend different shapes and pictures, however they are mostly of the same shapes and colors, following what is very close to an industry standard (see Figure 5).

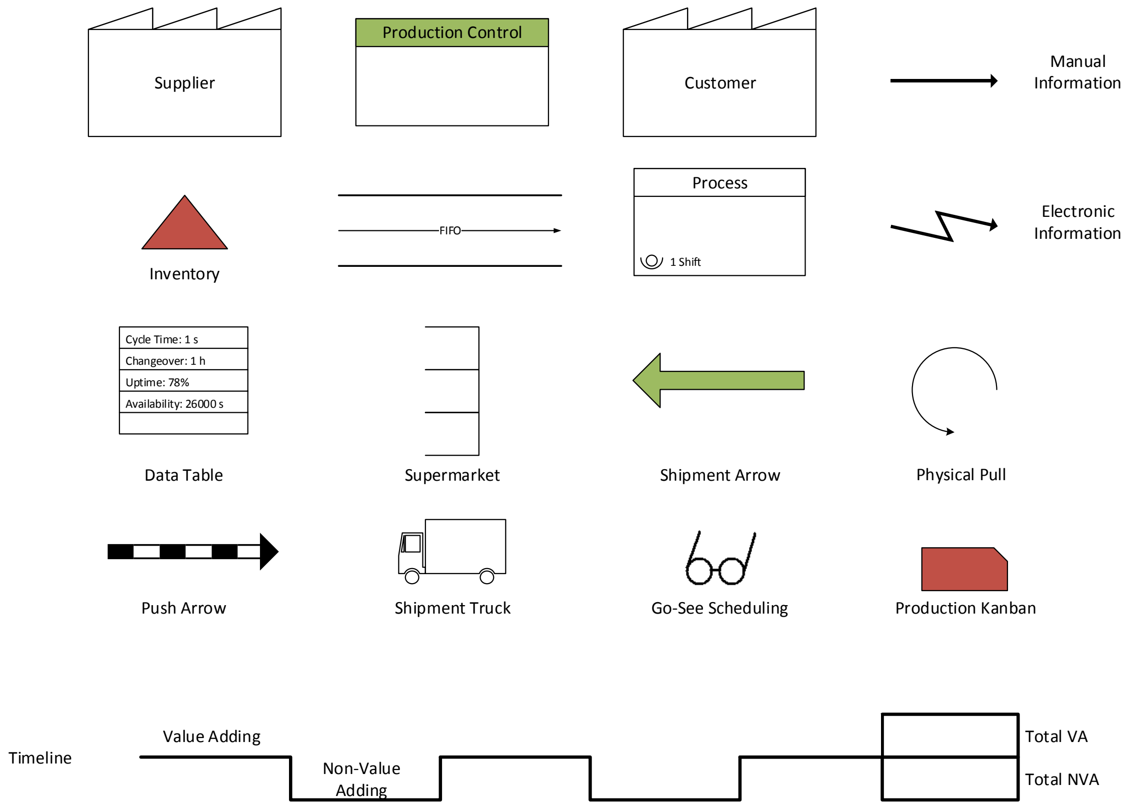

Figure 5. A standard set of icons used when mapping value streams (adapted from Rother, M. and Shook, J. (2003)).

According to Tapping D., Luyster T. and Schuker T. (2002), a value stream enables the observation of several key pieces of information regarding how a company is run and how its processes work. The article describes the process of mapping a value stream in 8 overall steps:

1. Commit to Lean
2. Choose the Value Stream
3. Learn about Lean
4. Map the Current State
5. Identify Lean Metrics
6. Map the Future State

7. Create Kaizen Plans
8. Implement Kaizen Plans

Beginning from step 4, a number of key points within this step need to be addressed in order to successfully begin mapping the value stream:

- As a team, draw a rough sketch over the selected production areas of focus.
- Go to the production floor. Once there, start with the most downstream operations and collect actual process data. When collecting data, a process attribute checklist should be prepared beforehand, where 7 to 10 attributes are chosen by the team as most important.
- Regroup and debrief about the results of the data gathering and if all necessary data has been gathered.

Tapping D., Luyster T. and Schuker T. (2002) provides a checklist over examples of attributes which may prove useful when collecting data for a VSM. As shown in Table 3 below, the attributes are non-static, and should be decided with the team of employees relevant to the different areas of the value stream that are to be mapped. Therefore, a devised checklist could look very different in its chosen attributes depending on the way the production process looks, how the management works or the level of detail for the value stream that has been chosen.

Table 3. A process attribute checklist for creating a VSM (adapted from Tapping D., Luyster T. and Schuker T. (2002)).

Value Stream Mapping: Checklist for Data Collection	
Number of shifts	Setup times
Time per shift	Cycle times
Planned downtime	Work-In-Process (WIP)
Available production time	Number of operators
Schedules for supplier delivery	MTTF, MTBF, MTTR,
Parts per delivery and/or shipping batch	Conveyor belt speeds
Quantity of products/parts shipped per time unit	Other...

Once the necessary data has been gathered, the next step is to draw the first most important boxes of the value stream (from right to left) - the customer, production control, and the supplier. Once these are drawn, the necessary daily requirements of the production are calculated, and mapping the transportation flow to the start of the production process can be done, with accommodation for the entire production process toward the bottom of the paper. Here, all the machines, buffers and operators are drawn out as processes with attribute-boxes below, where the attributes gathered from the physical tour of the production process are filled in for each machine, buffer and operator. Finally, the information flow should be drawn between their respective processes, noting if the information flow is electronic or manual. A schematic of an example of a VSM is shown in Figure 6.

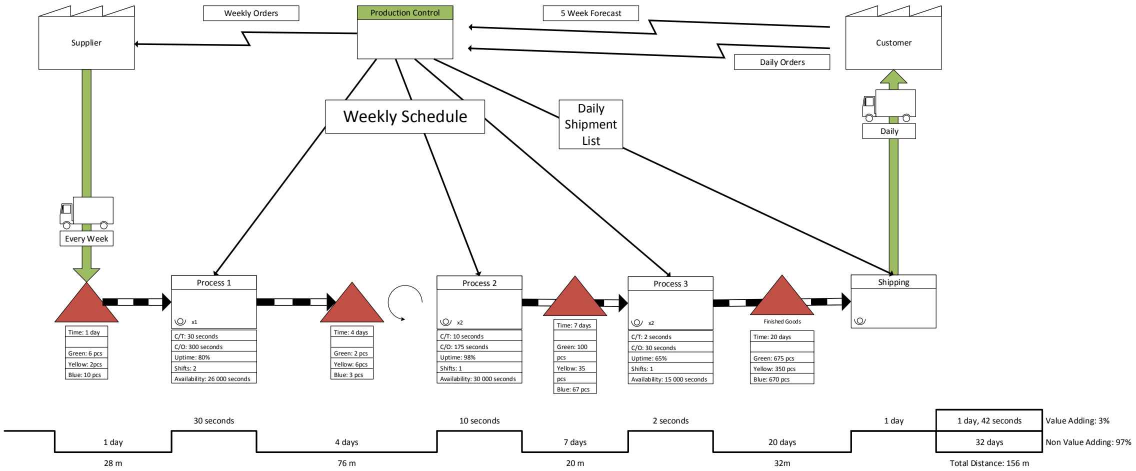

Figure 6. An example of how a VSM looks (With adaptations from Rother, M. and Shook, J. (2003)).

Despite VSM proving itself to be an excellent tool for production evaluation even outside the manufacturing industry (Rahman El Sheikh, A.A. et *al* (2008)), there are other tools which can be used in conjunction with a VSM in order to provide a better, clearer or more detailed understanding of a problem at hand, where simulation is an example of a tool suitable for the modern age of computing power.

2.5 Simulation

Simulation is the reproduction of a real system with its dynamic processes in a computer model Bangsow, S., (2010). With a simulation model it is possible to make implementations, experiments and analyses on a production system in a virtual environment without disturbing the real production. It is a cheap tool which makes it possible to change the condition of a production flow and yield results instantly. An example of a simulation model's power is how a whole shift, or an entire year's worth of production can be examined in a matter of minutes, while also allowing for the possibility of scaling time in speed in order to observe processes in more detail. Banks, J. (1998) summarizes a simulation model as a visual tool which makes a complex process easier to understand.

Although simulation is hailed as being a groundbreaking tool of the modern computer age, it does have some disadvantages. One such disadvantage is that it is time consuming (Bangsow, S., (2010)). By defining the aim of the project it can be determined if simulation is the best approach and in that case which level of details the simulation must have. It is a trade-off between time, cost and possible profit (Sargent, R.G. (2013))

Building a simulation model requires special training and experience (Banks, J (1998)) meaning that the cost of education must be considered when introducing simulation in a company. Another disadvantage is that the simulation can give a precise impression even if the input data can be questioned (Skoogh, A (2013). It is therefore essential to document the data collection and every limitation and assumptions that has been made so that these factors can be taken into account in the result.

An alternative to simulation is to make a mathematical model of the system, a sort of production system analysis based on formulas. It is less time consuming but in such a model a lot of simplifications need to be made. It is also increasingly difficult to make a mathematical model the higher the complexity of a system is (Li, J and Meerkov, S.M. (2009)).

Simulation software today is primarily focused on discrete event simulation. This means that the models are stochastic, dynamic, discrete and event oriented. These terms are explained in the following paragraphs (Cassandras G.C. and Lafortune S (2007)).

Stochastic

Stochastic models describe a number of different events that can occur while remaining impossible to predict exactly which event will happen. Randomness, with a probability distribution, decides which event that occurs. The opposite is a deterministic model which describes only one physically possible future which is dependent on prior occurrences.

Dynamic

In a dynamic model, variables can change during the passage of time without external influences. The opposite is a static model which is time-independent and has direct and instantaneous connections between its variables.

Discrete

A discrete event model is advancing time in discrete steps only when an event occurs. The system then calculates the new state for the system based on all events that occurred during that discrete point in time.

Event oriented

These are systems that are designed by human beings, where changes take place in terms of discrete events.

As can be seen from Figure 7, Banks, J. (1998) proposes a number of steps that should be done when conducting a simulation study.

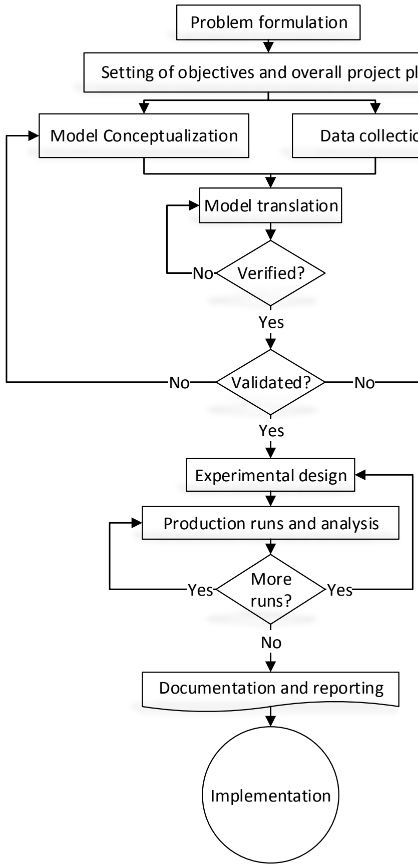

Figure 7. A proposed methodology on how to conduct a simulation study (adapted from Banks, J. (1998)).

For the construction of a VSM and simulation model to begin according to the described methods and methodologies, it is necessary to gather a sufficient amount of the correct data.

2.6 Data gathering

Data gathering is an important step in the creation of both a simulation model and a VSM. If wrong data is gathered it will affect the mapping of the VSM, and consequently the whole simulation, resulting in a differentiation of reality versus simulation metrics. It is therefore highly important that the data gathering is furrow. Lehtonen, J. and Seppala, U, (1997) strengthen this sentiment by concluding that before it is possible to even define the problem definition of the project, data needs to be gathered. If a strong empirical approach is not used there is a risk that the project will be based on wrong data which will lead to a wrong or irrelevant problem definition. Lehtonen further points out the importance to see the data gathering as a simultaneous stage of the project and not a subsequent one.

Regarding the simulation, an early part of data collection should involve creating a list to identify what data that is necessary (Foster, R.W and Kester, J.E (1990)). This will make the gathering more efficient since it will be more focused on finding the relevant data, while all other data can be disregarded. It also needs to be investigated which data that is currently available and which is not and in that case investigate how it can be collected. What data that is required is directly dependent on the desired level of detail for the simulation. It is therefore important to early on decide the purpose of the simulation and from that decide what level of detail that is necessary. A lot of time can be saved in this matter by not creating a simulation model that is more detailed than necessary. The higher the level of detail, the longer time it will take to create the model. (Foster, R.W and Kester, J.E (1990)).

Moreover, all data that is used in the simulation model needs to be documented. It should be described how the data was obtained, how it was used and if there are any limitations or assumptions built into the data or collection method. Foster, R.W and Kester, J.E (1990) say that data obtained without a corresponding definition of the conditions under which it was acquired can be virtually meaningless. Documentation will also make future simulation projects easier since it will then be possible to look back at previous projects and use the same methods and perhaps the same data.

As can be seen from Figure 8, Foster, R.W and Kester, J.E (1990) proposes a number of steps that should be done when collecting data.

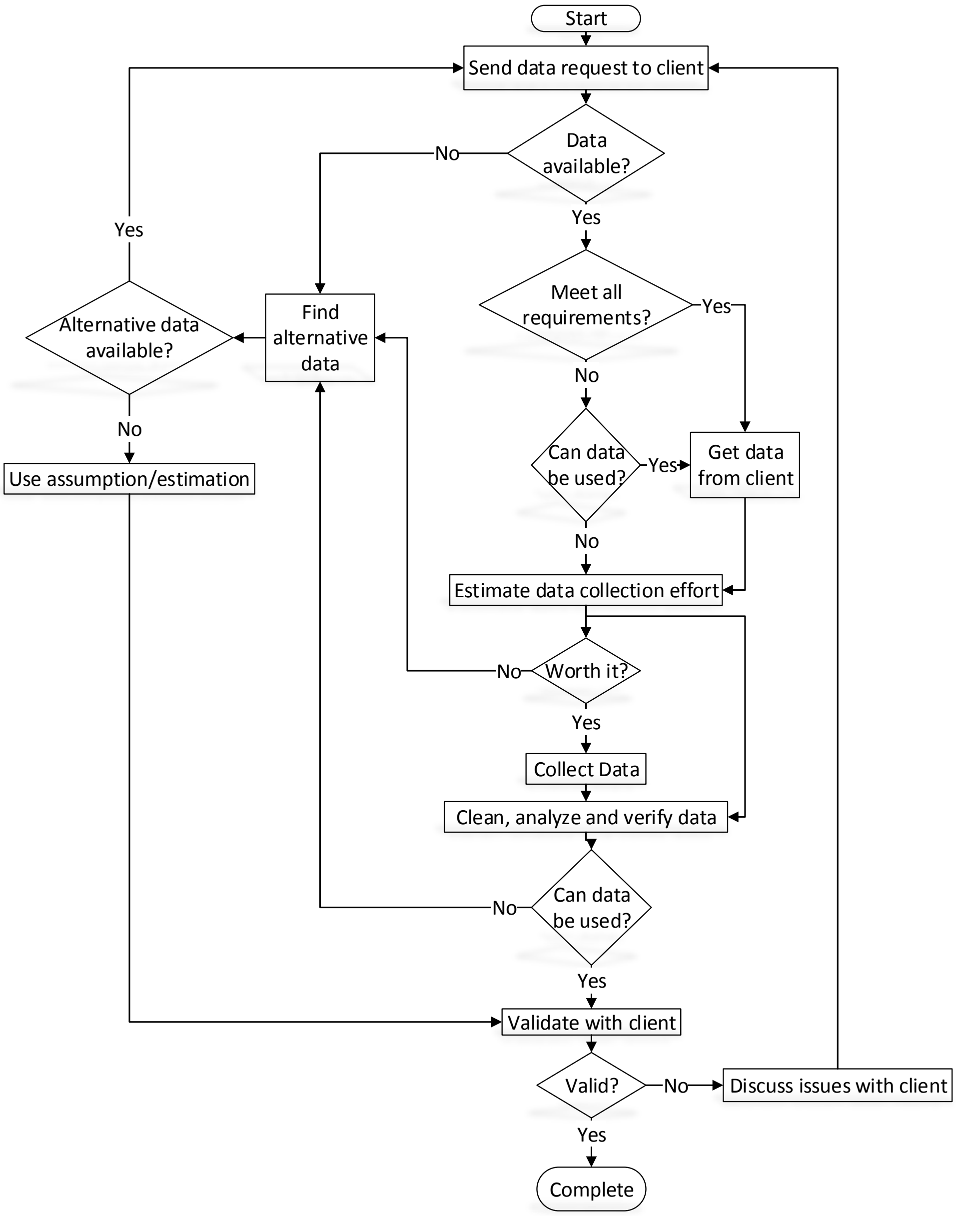

Figure 8. A framework for collecting data before creating a simulation model (adapted from Foster, R.W and Kester, J.E (1990).

Parameters that are common to collect are the following (Skoogh, A., (2013)):

- Cycle Times
- Mean Waiting Time (MWT)
- Mean Time to Repair (MTTR)
- Mean Down Time (MDT)
- Mean Time Before Failure (MTBF)
- Mean Time To Failure (MTTF)
- Times for tool changes
- Velocities (e.g. for conveyors)

Setup Times
Scrap Rates
Arrival Times for Raw Material
Production Schedules
Working Hours
Environmental Effects
Etc.

Descriptions of the mentioned mean-times are illustrated below, for definition purposes (see Figure 9 and Figure 10).

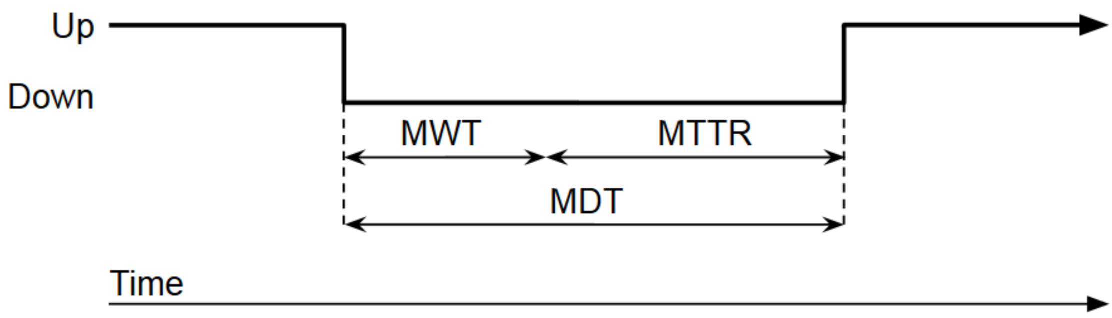

Figure 9. Definition of MWT, MTTR and MDT (Hargrave, F (2001)).

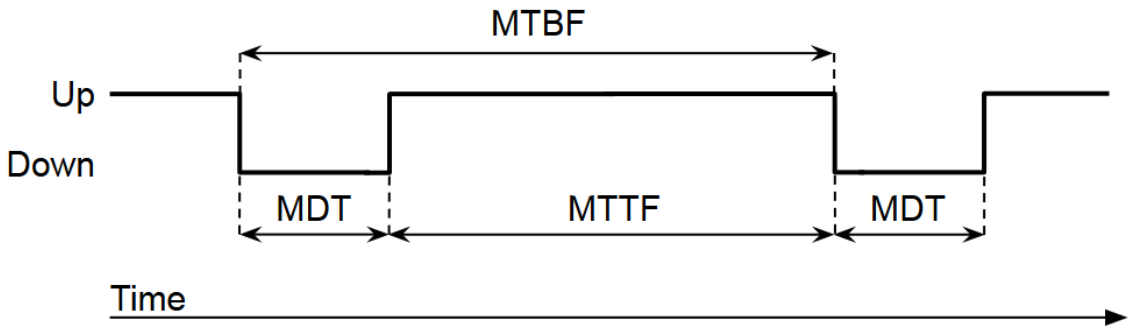

Figure 10. Definition of MDT, MTTF and MTBF (Hargrave, F, (2001)).

Creating a VSM and a simulation model based on the VSM will require that the validity of these models, especially the simulation model, are of a satisfactory standard.

2.7 Verification and Validation of a Simulation Model

The verification and validation of a simulation model determine if the simulation model represents the real system within an acceptable accuracy and precision. Experimentation in the model should give the same result as the result would be if the experiment were performed in reality. It is however not economically viable to create a model that is absolutely 100% valid (Sargent, R.G. (2013)). As can be seen in Figure 11 the cost increases exponentially while the value subsides as the model reliability approaches 100%. It is therefore not always profitable to achieve higher reliability values for an exponentially higher cost, when lower confidence values yield results within acceptable tolerances with a lower cost, thus retaining the value of the model and avoiding diminishing returns.

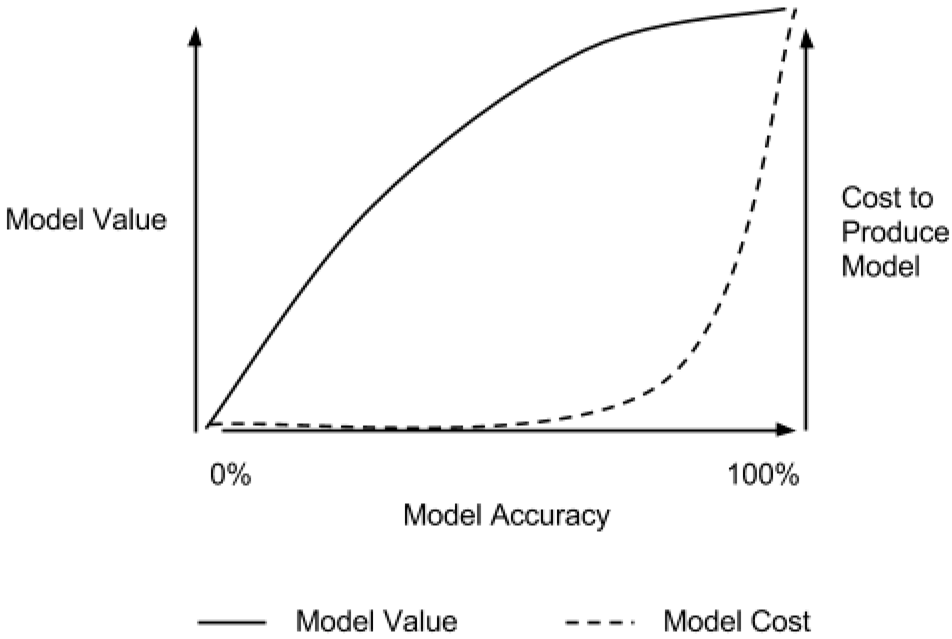

Figure 11. Graph of the relation between model confidence and a) value and b) cost (adapted from Sargent, R.G. (2013)).

The following chapter defines the two concepts; verification and validation. However it can be said that even if they are distinct they overlap in practice (Bratley, P. Fox, B.L. and Schrage, L.E. (1982)).

Verification

Verification determines whether the simulation model is correct with regard to the conceptual model. As Banks, J. (1998) states, structural programming is an important step in the verification. If the code is easy to read and understand, it will be easy to compare the code with the conceptual model. A method to ensure this is to create a detailed plan of the simulation model before starting to program. Furthermore, the coding should be written in a logical and organized way. Everything that is not self-explanatory should be commented in the code. Even graphics should be explained in some cases to ease understanding. However it may be advantageous to make information possible to hide under certain circumstances, such as presentations to third parties.

Another method to verify a simulation is to let another person, who has not been involved in the programming, inspect the code and compare it with the conceptual model. The input and output data can also be analyzed to see that it behaves as expected. Studying the animation is also a powerful verification tool, in the sense that the flow can be studied as it "moves," as well as verifying visually whether the correct time distributions for breakdowns, repairs, downtimes etc. are correct (Banks, J. (1998)).

Validation

Validation determines if the conceptual model describes the real system in the right manner. The most straightforward method to validate is to let an expert of the real-world production flow examine the conceptual model and validate it. The expert's knowledge is most likely based on how the system actually works in reality, and not on output numbers or how the theory states the system should work. Such information such as practical knowledge from a person with extensive experience of the production flow to be simulated is essential when constructing a simulation model. Further, a sensitivity analysis can be made by changing input values and observing how the output changes. The input and output values of the model can then be compared with the real operational system. If historical input and output data exist, these can be implemented in the model to see if the numbers concur within an acceptable statistical error (Banks, J. (1998)).

In order to begin improvement work on a validated simulation model, the analysis of the simulation model in the form of possible bottlenecks and constraints is crucial.

2.8 Constraints

2.8.1 Analysis of Constraints

There exist many definitions of what a bottleneck is. Betterton C.E. and Silver S.J. (2012) has summarized definitions that exist in present literature, where examples of the definitions discussed, among others, are:

- *The resource with the strongest effect on the system's throughput.*
- *The resource that runs out of capacity first, and thereby limits system throughput.*
- *The resource at which the long-run utilization is the maximum.*
- *The resource for which a change in isolated production rate has the greatest impact on system performance, that is, the resource to which the system performance sensitivity is greatest.*

Regardless of the definition, Betterton et al. (2012) concludes that the bottleneck is the root of the limitation of the production capacity.

According to Lima, E., Chwif, L. and Barreto, M. (2008), there are three types of bottlenecks: simple bottleneck, multiple bottleneck and shifting bottleneck. The simple bottleneck is one resource within the production that is the bottleneck during the entire period considered. The multiple bottleneck is when more than one resource is the bottleneck, but the bottleneck remains on the same machines during the entire period. The shifting bottleneck means that there is not one resource that remains as the bottleneck the entire time. Instead, the bottleneck moves between several resources during the studied period.

To detect which resource that is the bottleneck in a production, different methods can be used:

Utilization

The utilization method represents a percentage of the overall time that the resource is working, where the value is calculated for all resources, resulting in the resource with the highest utilization being the bottleneck (Lima, E., Chwif, L. and Barreto, M.

(2008)). Roser,C. et al. (2003) define the utilization method of bottleneck detection similarly to Lima, E., Chwif, L. and Barreto, M. (2008), however includes the information that both working times and repair times can constrain a system. It is therefore needed to redefine the utilization method as the combined working and repair time percentages which results in the percentage of the time a machine is active.

Arrow

This method compares how often a resource is blocked or starved compared to adjacent resources. If a machine (machine 1) is starved more than its upstream machine (machine 2) is blocked, an arrow is drawn from machine 1 to machine 2. If machine 1 is starved less than machine 2 is blocked, the arrow should be drawn in the opposite direction. The bottleneck machine is then located where the arrows change direction in the schematic (see Figure 12) (Jingshan, L. and Semyon, M. M., (2009)), (C.E. Betterton and S.J. Silver 2012).

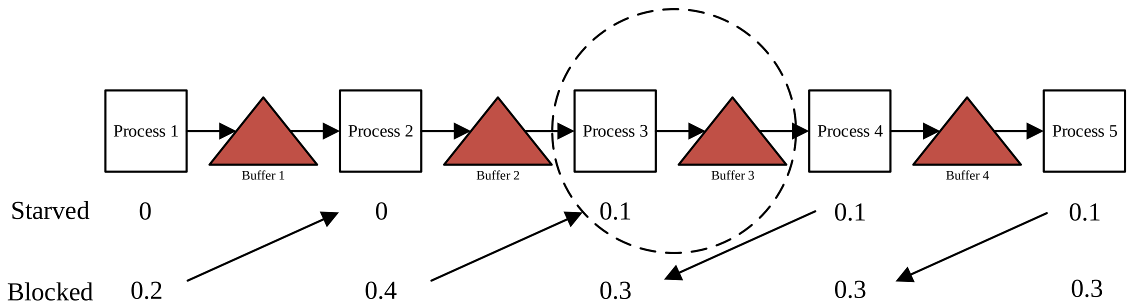

Figure 12. A schematic of a bottleneck detection method using the probability of starved and blocked states, where the circle is pointing out the bottleneck (adapted from Jingshan L. and Semyon, M. M., 2009).

Longest Queue

The longest queue method measures the number of products in an upstream buffer. The machine with the longest queue is then the detected bottleneck (Lima, E., Chwif, L. and Barreto, M. (2008)), (C.E. Betterton and S.J. Silver 2012). On the other hand, Roser, C. et al. (2003) mention that the longest queue method of defining the bottleneck as the longest queue is only suitable for linear systems containing only one type of part. A recommendation is therefore to look at the waiting time, since systems processing multiple part types may present an occasion where a machine slowly processing a few parts constrains the system more than a machine processing a lot of parts in a small amount of time.

Waiting Time

(Lima, E., Chwif, L. and Barreto, M. (2008)) and (C.E. Betterton and S.J. Silver 2012) define this method as the amount of time a job spends in a queue waiting to be processed. The downstream resource of the buffer where the product needs to spend the longest time is the bottleneck. This is a simple definition, however there are additional limitations to this bottleneck detection method as proposed by Roser, C. et al. (2003). One proposed limitation is that buffers need an infinite capacity since waiting time is difficult to measure if the queue capacity is limited. Also, the system capacity should exceed the supply to the buffers in order to avoid buffers which are constantly full. It is therefore unsuitable to use the waiting time method if the supply is infinite while using limited buffers. The waiting time can certainly be measured in this case but the measured time will be useless due to the inherent flaw of filled buffers.

Active Period Method

In this method it is considered that a machine has two states: up and down. The sum of the overall duration a machine is active is measured. The machine with the highest active period is the bottleneck, while the machines with the lowest active periods (and consequently higher down-states) are starved. In some bottleneck detection situations it may be easier to detect a bottleneck from a starved machine rather than an active machine, since active machines do not always propose a bottleneck. Starved machines however always propose that there is a bottleneck in some form upstream from the starved machine. Of course, if a machine is very active and the machine after is starved, it is reasonable to presume that the former is the source of the bottleneck. Both starved and active machines need to be taken into consideration. (Lima, E., Chwif, L. and Barreto, M. (2008)).

Shifting bottleneck

Here the method is very similar to the utilization method. In the shifting bottleneck method, not only is utilization investigated, but also when a machine is active or not. It is this detail which separates the shifting bottleneck method from the utilization method. While the utilization method determines the percentage of time that a machine is active, the shifting bottleneck method determines the same, but within a certain period of time. Here it is also defined that the time in which the machine is active should be active without interruptions. Thus, the method provides a clearer understanding and much more reliable method of detecting bottlenecks than solely relying on the utilization method. Roser, C. et al. (2003) further motivates the statement of reliability based on previous research conducted on other types of systems as well (Roser, Nakano, and Tanaka (2002a)), (Roser, Nakano, and Tanaka (2002b).

To summarize how the method is supposed to work, it should be possible to at any given time determine the level of activity of a machine, and the machine with the longest period of activity in the viewed timespan is thus regarded as the bottleneck. Roser, C. et al. (2003) also make a point of defining activity as the time a machine works, including breakdowns, tool changes and other times which constitute a constraint on the system. Inactivity is defined similarly as the time in which a machine is starved of resources or is blocked by another process or machine downstream, incurring waiting time. A comparison made by the same article illustrates how the utilization and shifting bottleneck methods illustrate different results, thus encouraging the fact of utilizing different bottleneck methods to arrive at a concluding and final bottleneck detection.

2.8.2 Bottleneck Detection Reliability

In the article by Roser, C. et al. (2003), a comparison between the majorities of bottleneck detection methods is made, name between the utilization, longest queue, waiting time and shifting bottleneck methods. Although the article describes the bottleneck detection results from the perspective of Automated Guided Vehicles (AGV), the methods mentioned have been referred to even within manufacturing environments (Lima, E., Chwif, L. and Barreto, M. (2008)), as well as garnering support from Roser, C. et al. (2003) in addition to the AGV study. The comparison of methods showed that despite using different methods, the results were not conclusive. Each method yielded a different bottleneck detection, pointing to several different causes of system constraints.

One can ask whether bottleneck detection methods, considering the comparison of methods, are of any use if no conclusive results have been made from them, however it largely depends on the type of production and the interaction between material and machines (Roser, C. et al. (2003)). The results of the comparison concluded that the utilization method did not detect the bottleneck correctly in regards to if the AGV's or a certain machine was the constraint. The waiting time method was unable to detect any bottleneck at all due to the inherently limited nature of the manufacturing system in accordance with the infinite buffer sizes and larger system capacity relative to the supply of materials discussed in the earlier methods (see Longest Queue and Waiting Time methods in chapter " Analysis of Constraints").

The only method which provided reliable and correct bottleneck detection was the shifting bottleneck method. Not only did it detect the bottlenecks correctly, it also provided an insight into the underlying factors within the production line contributing to why the shifting bottleneck existed. This provided ample opportunity to investigate further and improve processes overall.

Despite the successful results of the shifting bottleneck method in this comparison, the bottleneck detection method most suitable for a given situation is highly dependent on the type of system analyzed. For Roser, C. et al. (2003), the optimal method was the shifting bottleneck method due to their use of AGV's in connection with machines and manufacturing processes, however in another system without AGV's or a different manufacturing and material handling system, the other methods presented may bear greater significance in their ability to detect bottlenecks.

2.8.3 Theory of Constraints

The theory of constraints was first introduced by Goldratt (1984) in his novel *The Goal*, explaining the theory as a methodology of improving a process. As discussed *The Goal* but also Şimşit, Z., Günay, N. and Vayvay, Ö. (2014) the Theory of Constraints (TOC) describes a production or manufacturing process as a chain, where each process or activity within the chain is a link. Much like the links of a chain, the chain cannot be stronger than its weakest link. The theory therefore proposes a step-by-step methodology of identifying a system's constraint and adapting the system in order to rid the system of the studied bottleneck.

The proposed steps by Goldratt (1984) are the following:

1. Identify the system's constraint.
2. Exploit the system's constraint.
3. Subordinate all other processes to the constraint.
4. Elevate the system's constraint.
5. If in any of the previous steps a constraint is broken, go back to step 1.

Goldratt further explains that the aim for a company should be to create a profit both in the short term and long term perspectives. Naturally, to sustain or increase profits, a production system needs to minimize its operating expenses while lowering inventory and increasing throughput. Logically according to Goldratt, the first step would in this case be to identify the weakest link of the chain described as the production throughput, inventory and operating expenses and work through the proposed five-steps in the TOC.

For the first step, the identifying of the constraint can be done in several ways. Banks, J. (1998), C.E. Betterton et al. (2012), Lehtonen, J. and Seppala, U, (1997) and Roser, C. (2003) among others all recommend using simulation to narrow the scope of where constraints in a system can be found due to its inherent computing power, time saving capabilities and low cost. Since the TOC can be applied to any form of organization, regardless of their size, and in any part of an organization, regardless of their department, a constraint can take many forms. For instance, a constraint could be physical, such as materials, machines, people, demand level from customers, orders from suppliers etc. However, companies often have managerial constraints rather than physical constraints (Rahman, S. (1998)). These managerial constraints constitute activities and processes such as policies, rules, procedures and methods among other forms of bureaucracy.

Once the constraint has been found, the constraint will need to be exploited. Exploiting by definition in regards to the TOC philosophy can be defined differently, based on the type of constraint found in the system. As previously mentioned, physical constraints and managerial constraints are different although they both constrain the system. Rahman, S. (1998) explains that if the constraint found is physical, the constraint should be made as effective as possible, while a managerial constraint should instead be eliminated. In place of the eliminated managerial constraint, a policy should be set in place which encourages a higher throughput, therefore mitigating or eliminating the physical constraint found earlier.

The third step in the TOC methodology is to subordinate all other processes to the level of the process in the second step. Practically, Rahman, S. (1998) explains this as adjusting all other non-constraining processes to fully support the maximum effectiveness of the current constraint. As a constraint affects the throughput of the entire system, adjusting the other processes to maximize the efficiency of the constraint will therefore lead to better resource utilization. However, Rahman, S. (1998) makes a point by noting that if a non-constraining process is used beyond its productive capacity, the only thing that non-constraining process will contribute to is unnecessary inventory, one of the eight wastes discussed by Liker, J. (2004).

According to the methodology, the constraint has now been found, maximized in efficiency and had all other processes in the system subordinated to its advantage. The fourth step in the methodology is to elevate the system's constraint or constraints. Here it is imperative to investigate whether the constraints still remain the most critical. If so, the constraints will then need individual attention and thorough improvement work. Only then can the surrounding processes be adapted to the newly improved (and former constraining) processes, resulting in an overall improvement of the entire system's performance (Rahman, S. (1998)).

The final step of the methodology should actually be kept in mind while conducting the previous four steps. The final steps states that if in any of the previous steps a constraint is broken, then one should re-start the methodology from step 1. Although some processes may exhibit quick changes to throughput or overall flow when maximizing constraints and subordinating other processes, it is important to realize that systems may present a lag-time before improvements or changes can be measured or observed.

Consequently, keeping this in mind will prevent the system's inertia from becoming the constraint, which could result in constraint-chasing (Rahman, S. (1998)). The article further explains that the implementation of step 5 is crucial for the survival of a company when applying the theory of constraints, as without a follow up of progress or results, the breaking of any constraints within the previous steps will be unknown, which could lead to disastrous constraints. Keeping in mind that no solution made is the absolute solution for the future is also important, as the constraints within a system can change depending on how the organization grows, shrinks or changes in any other way (Goldratt, 1984).

3. METHODOLOGY

The following chapter presents the methodology that was used in the project to be able to answer RQ1 and RQ2.

To investigate how VSM and DES could support organizational improvements (RQ1) a case study was made at Swedish Match production in Gothenburg. A VSM was created over the whole factory of which the result was analyzed to conclude which section of the factory that had the largest influence on flexibility. A simulation model of this section was then created to further analyze improvement potential. The methodology and creational process of both the VSM and simulation models, as well as the results gained from these was then compared and analyzed. RQ2 could then be answered as a result of answering RQ1.

A flowchart is presented in Figure 13 which shows the order the work has proceeded. Each area is then described in more detail.

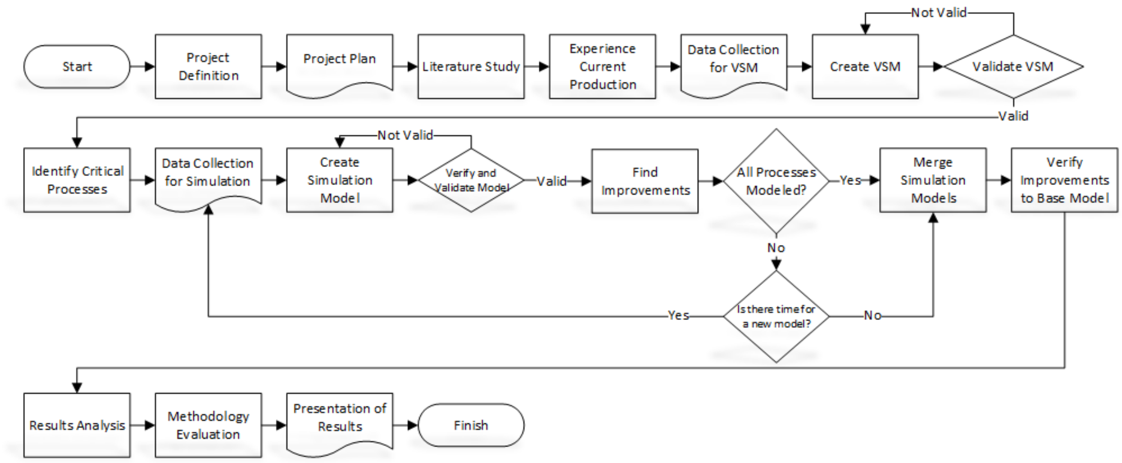

Figure 13. A flowchart of the case study's procedure.

3.1 Result Generation

For result generation, both the VSM and the simulation model were analyzed. First, the VSM was analyzed from the aspects of flexibility and WIP in order to determine which part of the production on a grander scale was initially deemed necessary for further investigation. Coupled with this analysis of the VSM was also determining the CODP of the production, in order to investigate how the CODP influenced flexibility and WIP in different areas of production. The original VSM creation was then used as a basis for creating the simulation model over the area in need of improvement, while the critical area identification of the VSM along with the CODP analysis were used as results for comparison between both improvement tools.

Once the creation of the simulation model had been conducted with the base information from the VSM study, the simulation model was validated toward the real production in order to confirm its integrity. A study into the information gained from the simulation model which couldn't be gained from the VSM and vice versa was then made, further leading to a comparison of overall results between the two improvement tools. An analysis was conducted regarding the accuracy and detail of result information regarding flexibility and WIP among other factors when comparing both tools used for potential improvements. Furthermore, a comparison between the VSM and simulation tools for the different aspects and scope of production were made in order to support the suitability of tool use depending on scope of study. By this methodology both RQ1 and RQ2 could be answered.

3.2 Literature Study

A literature study was conducted in order to achieve a more profound understanding of how other companies and researchers have used VSM and simulation. Some questions that were investigated were for what purpose the two tools have been used and how other companies have used the tools both separately and in combination.

Additionally, further research has been done regarding VSM and simulation in general as well as the relevant subjects that a simulation and VSM project involves. Necessary to research was also the knowledge required about the preconditions to a VSM and simulation study and the methods that exist to create these models. Moreover, various methods used both in research and industry to analyze a production system, and especially tools that can be used in the analysis of a simulation model, have been researched.

Some other examples of subjects that have been investigated are the Toyota Production System, also known as the Lean Production System, in order to research necessary tools and methods to improve a production or manufacturing process. The Swedish Match Production System has also been reviewed to understand the company's philosophy and understand their view of how a production system should function. A comparison between the lean production system and the SMPS has been made in order to establish a rough baseline as to how lean Swedish Match is both in theory and practice.

The database "Summon Chalmers" has been used extensively to find literature within several scientific research databases, as well as Chalmers own physical library when books have not been available as electronic copies. Some articles which have not been available either as physical or electronic copies have been ordered via the library. Some examples of keywords that have been used when searching for information are: discrete event simulation, VSM, theory of constraints, bottleneck detection and data gathering, although this list is not in any way exhaustive. Lastly, some literature from previous courses at Chalmers has been used, including lecture notes and presentations from relevant courses, such as lean production, simulation of production systems, discrete event simulation, production logistics, as well as design of flexible and modular automation among others.

3.3 Production Understanding: Genchi Genbutsu

To be able to create the VSM and simulation model it was of great important to first attain knowledge about the product flow and to see the production from an operator's perspective. Liker, J (2004) points out the great importance to be physically present on the shop floor, regardless of the hierarchy one might be present in, to be able to see, analyse, question and evaluate the production. At the beginning of the project, four days were therefore spent by being physically present within the different parts of production, where the aim was for the project members to work as operators. Along with this, another important reason for being present in the production was to meet with the operators working there every day.

In a large production system, the process may seem very complex and convoluted, however it is often the operators themselves that know the processes very well and are one of the most valuable sources of information when gaining knowledge about a new process. A close collaboration with the operators was therefore deemed necessary in order to successfully proceed in the project and deliver milestones in line with the case study's goals, as well as gain knowledge about the process to be able to answer RQ1 and RQ2 in the problem definition, which may have been difficult to achieve otherwise.

The departments of production that were visited were the mill, preparation, packing, and the storage and shipping department. A guided tour was then organized by a designated member of staff, whereupon information was received about the process. Each department had their own work procedures for incoming material as well as handling and preparation of material, which warranted its own set of questions in order to gain a proper understanding of the process.

3.4 Creating a Value Stream Map

After the production visits, an understanding of the process gradually began to manifest itself, from which the choice to start on the VSM was decided. Since data gathering had not begun yet, only a schematic version of the VSM could be drawn over the parts of the production which had been fully understood. It was created with the same appearance and with the same standard objects as illustrated by Rother, M. and Shook, J. (2003). Like Lovelle, J. (2001) recommends, the schematic diagram was split into two parts. First the internal mapping was created which consisted of all processes that turn raw material to sellable product, where Table 3 in accordance with recommendations from Tapping D., Luyster T. and Schuker T. (2002) was used to categorize relevant data for the internal mapping. The external mapping was then created which included information relating to customer orders.

The VSM was done via the computer software Microsoft Visio 2013, using the standard icons as suggested by Rother, M. and Shook, J. (2003) along with standard icons present in the software.

Relating to Tapping D., Luyster T. and Schuker T. (2002) eight steps to conduct a VSM (see chapter "*2.4 Value Stream Mapping*"), steps 1, 2 and 3 are in this case study assumed to already have been conducted by the company. To further explain, step 2 can be regarded as part of the problem definition for the thesis, as only a certain part of the production and thus a certain part of the value stream has been pre-selected. As mentioned earlier, Swedish Match claim to have committed to the lean philosophy and therefore the assumption is made that Swedish Match also have taken the initiative to learn about lean production and what it entails. However, the focus in this thesis will remain on steps 4 and 5 where the VSM will be the foundation for the simulation study conducted later, and the lean metrics the information needed both for a VSM and a simulation study.

3.4.1 Data Collection

Because of the size of the production it was not possible to gather all data for the VSM during one day. In order to achieve consistency in the VSM, it was decided it would be beneficial to be present at the current department of study at the same times each day. As an example, the visit to the mill for data collection was decided to be done between 10:00 and 11:00 in the morning, however more punctually the visits took place at 10:20. The same time (10:20) was therefore also used for the data collection visit in the preparation, packing and storage.

A large amount of process steps were studied in detail in order to decide whether data was available to gather for the specific process. Therefore, all steps of the production process of which data was available have been mapped out in the value stream. Some areas such as buffer sizes and dwell times have been gathered qualitatively via interviews of operators and other personnel in charge, as well as by using formulae to calculate necessary data.

To be able to conduct a full VSM, a review of the literature study was necessary in order to determine which data was relevant and needed to be gathered for each process. Since most departments and processes within each department were similar in the type of data that was needed for the VSM, a template for data collection was created where only the label of the department was changed in order to differentiate between the data collected. This template was mainly based on the checklist created by Tapping D., Luyster T. and Schuker T. (2002) which consists of examples of attributes that can be useful when conducting a VSM. An example of this template can be seen in APPENDIX A.

3.4.2 Interviews

Along with quantitative data collection containing information such as process times, startup times, changeover times and uptimes among others, even information regarding material flow and process steps was crucial in order for a VSM to be correct. Not all departments required interview information, while some could only provide information through interviews. As an example, a meeting was held with a production planner which answered questions purely qualitatively via interviews, but complemented the information provided verbally with access to files which were important for the progress of the VSM. Similarly, the preparation process' data collection was exclusively based on interviews while the packing department's data collection was exclusively based on measurements and observations.

Thus, where it was necessary, the operators were interviewed with short questions which gave answers to how the process of material handling functions, including directives from production planners, to the material handling in itself, and to the preparation of material for the next process. Since the departments and processes were so different, a standardized questionnaire was not devised. Instead, as questions arose during the walkthrough of the process, the answers were noted. The answered questions were then cross checked with the VSM in order to determine if there were any other questions needed to be asked to fully complete the VSM.

3.5 VSM Analysis, CODP and Critical Area Identification

When a full VSM had been created with all the relevant data gathered, the VSM was analysed to then be able to decide which department that was the most critical not only from a time perspective, but also in regards to flexibility and possible changeover times. The final decision of which processes to focus on was a joint conclusion both from the results of the VSM study and analysis, as well as Swedish Match's own needs and beliefs of the processes they felt were in most need of improvement.

3.5.1 Determining the CODP

To further continue with the analysis of the production flow in regards to flexibility and changeover times, it was necessary to investigate the point in the flow where the production changes from a MTS to MTO/ATO flow. Consequently, this point would then become the base for more intricate study of how to optimize the production to be more flexible. With the help of table 2 adapted from Mattsson S-A and Jonsson P (2003), determining the CODP for the case company was considerably more trivial due to the categorization of competitive production factors.

3.6 Creating a Simulation Model

When creating the simulation model the proposed methodology from Banks, J. (1998) was used (see Figure 7 in chapter "2.5 Simulation"). The first three steps of the methodology were however already performed where the VSM could be seen as the "Conceptualization Model." Some of the data collection was also performed since data collected to the VSM could be used.

For the simulation study to start, it was of great help to utilize the conducted VSM as the process flow was clear and laid out with all the relevant information in order to start building the foundation of a simulation model. From the VSM, the layout of the specific process to be modeled, as well as the steps in which the raw material travels through the process could be identified, which also provided a foundation for further improvement analyses.

When the data collection for the VSM took place, the specific production line within the product group of study was not determined. As such, the data collected for the VSM was not only useful to yield a snapshot view of the entire production process, but also of a randomly picked production line within the produced product group. Once the VSM was finished, and the most critical process for simulation identified, the specific production line was also decided upon by Swedish Match. Their decision was based partly on the results of our VSM study but also partly on which specific production line they felt was mostly in need of study.

The software used for constructing the simulation model was Tecnomatix Plant Simulation (hereby referred to as PlantSim), a part of a multitude of Siemens PLM software available. Although the project members had no previous experience with this specific simulation software to begin with, this was not felt to be a hindrance due to the very good support and help resources for the software available. Therefore, a simulation model could be modeled without greater difficulties.

3.6.1 Data Collection

The data collection for the simulation study had to be done partly from scratch due to the change of scope, but even so, some information from the VSM regarding the specific production process could be used since the production lines among themselves are somewhat similar. Nonetheless, the granular process information within the newly decided production line had to be collected anew due to differences in machinery, cycle times, process times and other data, despite other lines having the same process steps but with older machinery with different process parameters.

The framework for collecting data created by Foster, R.W and Kester, J.E (1990) (see Figure 8 in chapter "2.6 Data gathering") was used in the data collecting process. It was mainly focused on collecting the parameters that Skoogh, A, (2013) recommends (se chapter "2.5 Data Gathering") with some adaptations. For example, the environmental effects were not measured. However, the list was supplemented with other parameters that were relevant, such as conveyor lengths and buffer sizes.

In order to collect the necessary data, a multitude of outlets had to be expired to build a satisfactory simulation model. For some collection, it was necessary to physically be present and walk around the production line, examining, observing, timing and understanding the flow of material and the logic behind the processes in case of different production circumstances such as machine stops. For other data collection, the use of the company's internal logging system for collection of dates, times, durations and other relevant data regarding machine stops was imperative for an accurate model to be constructed.

Swedish Match has a database called ReportExpert which collects and stores information about the machine's status in real time. From this database it has been possible to retrieve data such as up- and down times of the machines in the production. There also exist manual logs where an operator from each line writes a summary report of the shift, containing information such as the total amount of products produced and for how long the production has been running.

At other times it was necessary to conduct smaller interviews such as contacting the appropriate person in charge of the specific information that was sought. For example, requiring information about the speed of a machine would require talking to a machine technician while gathering information about machine-stop reasons could both be gathered from a machine technician and an operator. Not all information about the production line turned out to be logged, which resulted in some data collection happening manually, such as measuring the speeds of conveyor belts, estimating buffers by counting the inlet of products versus the outlet of products under certain production circumstances to ease the counting effort, as well as estimating changeover times and resupply of consumable materials and other such data which there was no digital representation of.

3.6.2 Machine Failures

For a simulation model to be accurate, machine failures are of utmost importance to model correctly in order for the model to behave somewhat similarly as in real world production. However, there is little benefit in attempting to model a simulation of a system as close to reality as is reasonably possible. The cost of producing such a simulation model outweighs the value of the model for the end user. It becomes a case of diminishing returns, where the cost in this case study is the time spent on producing such a model (Sargent, R.G. (2013)). Therefore, care was taken as not to overdo the granularity of data and simulation accuracy in order to keep the construction of the simulation model within a reasonable frame of time in relation to the case study's time plan.

With this in mind, the first step of modeling machine failures was to collect the relevant data. As explained in *3.6.1 Data Collection*, the company's internal logging software was used in order to retrieve relevant data for the construction of the simulation model. However, despite having excellent software for retrieval of a vast amount of different production metrics, there was little use of a large amount of data that could be retrieved, since a large portion of it was uncategorized and therefore unreliable.

In this way, there was a lot of manual work to retrieve this relevant data, since data that was presented with actual values was not always reliable. To determine its reliability, often several searches within the software's logging database had to be conducted in order to verify the data which was needed. This proved very time consuming at times, since the validation data sometimes turned out to be unreliable according to sources within the company who work with the logging database on a daily basis.

The input to the simulation software was for determining the time distributions for the machine stops, in order to model these time distributions for the machines in the simulation and model a reasonably accurate system. Since the machines which the time data was gathered for were the same, it would seem reasonable to ease the process of time distribution modeling by having all the relevant machines in the production line have the same failure distribution, however this would be incorrect as the machines failed differently despite being the same, which was validated from the gathered data from the failure logging software. Therefore, the individual machine failure data for each machine was gathered and fitted to a suitable distribution.

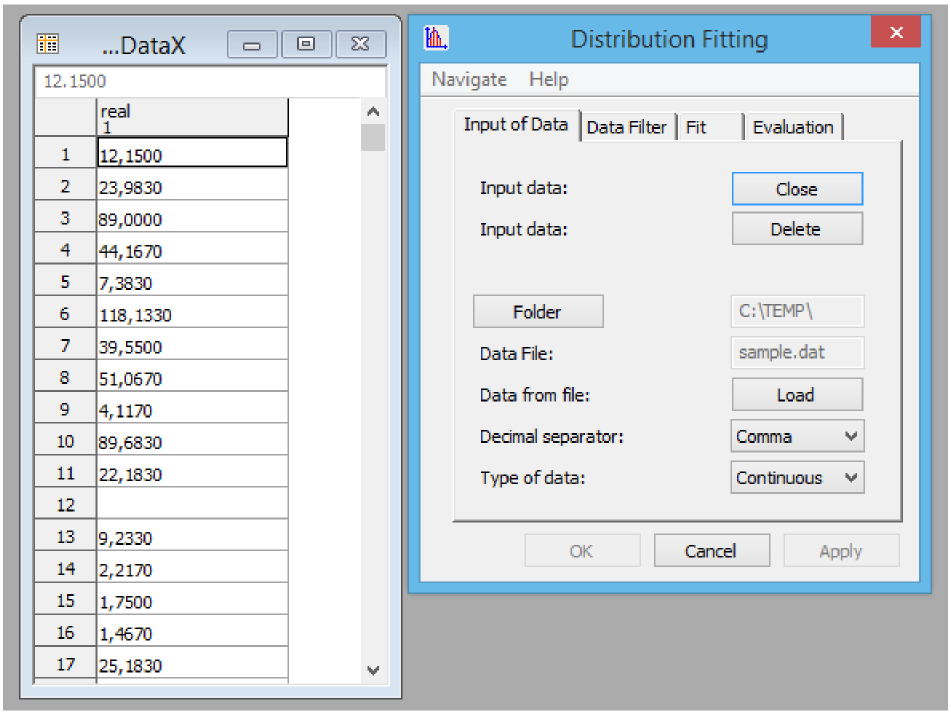

Figure 14. Displaying the "DataFit" object with a list of input data.

To fit the data to a distribution, the *DataFit* object within the simulation software was used (see Figure 14). This object exists specifically for having the computer attempt to fit a distribution to an input of data. The object allows for the input of data in a list, from a data file, and also whether the input data is comma or point separated as well as continuous or discrete. Furthermore, the object allows for the filtering of data before allowing the user to input suitable parameters for the "Goodness-of-fit test." In this test, the level of significance can be entered as a number between 0 and 1, as well as the possibility to enter the number of classes for a Chi-square test (with a software recommendation of a number of classes to use based on the input data).

Once this is done, it is possible to view a histogram of the input data to verify it before fitting a distribution to it. A multitude of distributions can be chosen to try and fit the data to, in which the results can be sorted according to the Kolmogorov-Smirnov, Chi-Square or Andersson-Darling criteria to determine which criteria best fits the histogram generated from the input data. Finally, a report over the distribution fitting can automatically be generated in order to verify the distribution fitting to the chosen distributions, as well as view the calculated parameters for the most suitable distribution fitted to the input data.

The parameters calculated were the needed for input to the machine failures. Each machine is modeled as a "SingleProc" object, meaning it is a generic process to begin with. This process can then be modified with parameters to behave as the targeted object for simulation. There are two ways to model failures in PlantSim - one way is to make use of machine availability data and an MTTR value for that machine (see Figure 15). The second way is to make use of the interval of failures and their durations. However, these two ways cannot be used simultaneously, as PlantSim calculates the "interval" and "duration" values if availability and MTTR are used as input.

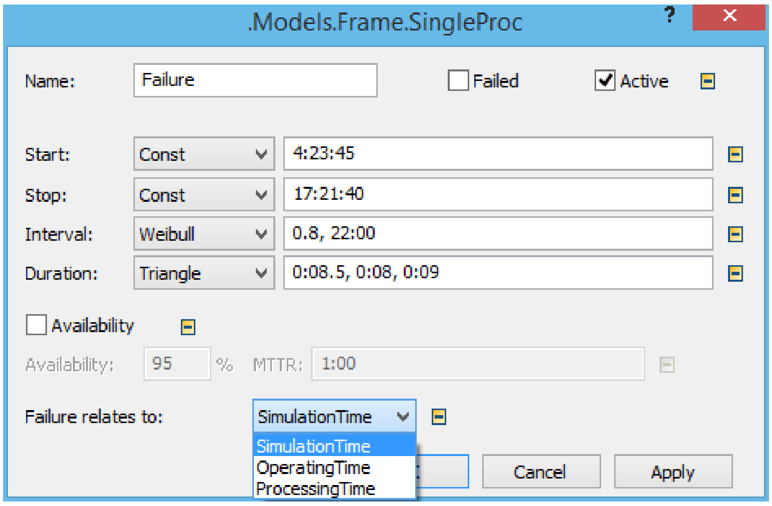

Figure 15. A sample of the "Failures" option for a generic process with example values.

In addition to these four values, there are "start" and "stop" fields to fill out, designating when a failure may begin to happen and when failures are not allowed to happen. These values are inputs in the form of time and relate closely to the "interval" and "duration" fields. If a value of time is used in the fields "start" and "stop", failures may only occur during those times in the simulation, relative to the simulation time.

3.6.3 Shifts

The shifts in the model designate when machines are operable. In this case study, the machines are operable only during shifts and can therefore only fail during shifts since they do not run outside of shifts. The last field in Figure 15 is therefore important, as the failures can relate to either the simulation time, the operating time or the processing time. Since the machines in the model rely on shifts to operate, and can only fail during those shifts, choosing that the failures relate to the operating time is most suitable in order to avoid failures when they shouldn't happen.

3.6.4 Personnel and Operators

For this simulation study, the focus on modeling operators and personnel walking around the production line was not regarded as important. It was only during one specific process of the production line where a worker moving in the simulation model was modeled. This was however done purely for reasons of visual aid, as that specific sub-process was beneficial to model in such detail to understand the flow of materials better when running the simulation.

Regarding machine failures, changeovers and setup times, operators and other personnel were not modeled as walking to and from the resting area of the production line in case of these reasons, as the visual representation in this sense was not needed and did not affect the simulation flow. As such, machine failures are more distinctly identified by the sudden disruption of material flow within the simulation.

3.6.5 Execution and Experiments

A number of simulations were conducted on three different simulation models where the output was compared to a real historical production plan spanning two weeks. The three models which were tested were the current state production line, an experimental model representing one product variety per packer, and an experimental model representing one variety per two packers.

For the first simulation runs, all three models were run for the duration of two possible working shifts per day - the day and evening shifts. Following the results from the two-shift simulation runs, the simulation models were then run only during one shift in order to investigate the relationship of production completion time between two shifts. Once the simulation runs had been completed, the results of the output were recorded to later be compared against the output of running the simulation model through a genetic algorithm. By using a genetic algorithm, the aim was to optimize the production plan used as input in order to further minimize the required production time and attain as much optimization as possible.

3.7 Ensuring Model Integrity

The validation of the simulation model was performed in different ways and by looking at different aspects of the production in order to provide further research within the case study with correct and reliable simulation data.

3.7.1 Visual Validation

To visually validate the simulation is a powerful tool (Bank, J. (1998)). The created simulation model was very much focused on being visually correct with the real production system. To have a member of staff familiar with the real production system study and examine the simulation was therefore an important step in the validation since the simulation software uses real metric data in order to scale conveyor belts and calculate distances, movement speed, movement time and other simulation-specific data.

3.7.2 Logical Validation

The logical validation was performed by studying the flow of materials during a simulation run as Bank, J. (1998) recommends and validate that the flow performed as had been observed in real life. Although visual errors could make impacts on simulation results, a flawed simulation logic could have even more profound impacts, meaning that a logical validation was crucial for the case study to progress. By looking at the source code and verifying that it operated both under the conditions set and under rare or extreme simulation conditions was important in order to confirm the model's reliability and longevity for producing quality results.

3.7.3 Machine Uptime

Machine failures were validated against real machine failure data that had been logged. A production timespan of three months was chosen to validate the failures of the machines in the simulation against the real world data. Several simulation runs were performed where the working time of the simulated machines was compared to the working time of the real life machines, both within a certain timespan and a randomly picked date.

3.7.4 Buffer validation

The production consists of lots of conveyor belts with different velocity and dimensions. It was a challenge to estimate how many products there were room for on the conveyor belts. This was especially true since there was room for one to three products on the conveyor belts width.

To test that the buffers in the form of conveyors in the simulation were of equal sizes as in the real production, a practical test was performed on the real production. A machine located downstream in the production was stopped until all preceding buffers were filled. The inflow of material was then stopped and the downstream machine was turned on. By studying the product outflow until all existing products had gone through the system, the total amount of products in the buffers could be determined. This experiment was equally performed both in the real production system and in the simulation to validate the model.

3.7.5 Production Output

This step of the validation is closely linked to properly maintaining a visually and logically validated model, as well as modeling machine failures as accurately as possible. Subsequently, the production output will correlate directly with the validity previously mentioned. Banks, J. (1998) states how a model can be validated through a sensitivity analysis by changing input values and observing how the output changes. This kind of test was performed by a day-to-day analysis of simulation output against logged production data. The input data that was changed was the batch sizes, but total production time was also changed according to the logged production data mentioned.

3.7.6 Production Time

The production time in this case relates to the time when the production lines stop for the day after having produced what should have been produced for that day according to the production plan. Unfortunately, there is no automatic log specifying when the production lines stop. What exists is a manual log where the operators write down the time they start and stop the production. Exactly which time that is logged is however unknown. For example, it is unknown whether the time that is logged depends on when the operator comes to the production line and starts preparing the station, or if it depends on when the line starts producing products.

Therefore, another factor affecting production line stop times was observed during a 15 month observation timespan. The observed factor in this case was a button which is pushed manually by an operator; once for the startup of the line for the day, and once again for the closure of the line for the night. However, as the button originally has a different purpose, the action of pressing it indirectly signifies a production line stop or start (for the day). For example, pressing the button to close the production line for the night logs the line as “closed” only in the logging software, but it does not necessarily mean that the shift is actually over. Other activities around the machines are not included in this time, for example the cleaning and maintenance of machines and such.

Since the result from the two methods differed by a noticeable margin of up to two hours, it was decided to trust the data from the operators as the automatic logging software proved unreliable in its integrity. As mentioned, the logged data from the button only records when the line should start and stop. Any work done before and/or after production is not included.

In order to validate the production time of the simulation model against historical data of real production, a number of simulations had to be made and compared to real world production data. Historical data from the period of 1st of January 2014 to the 2nd of April 2015 was collected and visualized in a scatter plot, where the x-axis represented the amount of hours the production had been running each day, and the y-axis the amount of products produced that day. A number of simulations were then made with evenly distributed production hours ranging from 2 hours to 18 hours with 20 minute intervals. This was done to reflect the difference in amount of products produced when comparing, for example, 12 hours of simulation time versus 12 hours of real production time from the gathered historical data, with a resolution of 20 minutes.

Consequently, the historical data and simulation data would therefore need to be compared between the number of product variants produced, which would yield two scatter plots - one plot for no changeover and one plot for one changeover. To do this, the simulations were run for a total of 98 iterations per scatter plot to be compared - 98 iterations for production data reflecting one produced product type per day (no setup) and 98 iterations for production data reflecting two produced products per day (one setup). Finally, the results of the simulations were placed in a scatter plot and overlaid on the respective scatter plot of historical production data to see how well the data correlated. To aid in validating the data integrity, trend lines were calculated in order to visualize the mean difference between the simulation and real data.

4. DESCRIPTION OF CURRENT PRODUCTION LINE

4.1 The Mill

The mill is responsible for supplying milled tobacco to the production. The department has a number of silos where they store the milled tobacco and the objective according to the department is to always achieve full silos.

Every morning the department orders raw tobacco from the main tobacco storage in Kungälv which arrives two days later to the Gothenburg factory. The order is based on the amount of tobacco present in the silos, meaning that the silo that has least tobacco gets filled first.

First, a machine tears the tobacco into manageable pieces to mill. The tobacco is then pushed forward into a hammer mill. The milled tobacco is then sieved where grains too large are transported into the mill once again until the flour is at a satisfying granularity. The desired granularity of the grains depends on the recipes of different tobacco mixtures. The different recipes often include a specific amount of different grain sizes. After the mill and sieving processes, the tobacco is transported into a mixing machine which blends the different grain sizes so that the compound is homogeneous. After the mixer the tobacco flour is placed into its respective silo.

4.2 Preparation

The preparation department is responsible for pasteurizing the tobacco, flavour it and pass it on to the packaging department. Most of the process is automatic although the process takes about 19 hours to complete. The department receives a production schedule every week which defines what to mix for the following week.

The process starts with a mixer that is filled with tobacco flour taken from the silos at the milling department. In the mixer, the tobacco goes throughs several steps in order to be infused with the desired taste and properties. It is heated, pasteurized, cooled and flavoured. To guarantee that right quality is met, an operator takes a sample from the mixer and hands it over to a chemical analysis laboratory to examine the sample. When the sample tobacco has been approved, the tobacco is emptied into 400 kg containers and stored in a buffer. When the packing department is ready to receive the tobacco, the containers are placed in an emptying machine which sends the tobacco to the packing department in small enough doses for the packing department to handle.

4.3 Packaging

The department is divided into several lines where each line consists of an assortment of packing machines, a labeling machine, a wrapping machine and a carton filler. The packer machines receive snus cans, lids, tobacco and sachet paper each from their own respective buffer or storage. The tobacco comes directly from the preparation department in a pipeline, while the cans and lids are transported on a conveyor belt. The sachet paper comes in the form of a roll which an operator needs to change once it’s empty.

The machines put the tobacco into the sachet paper which is then welded and cut. The snus portions are then placed into a snus can which is fitted with a lid when filled. The snus cans are then placed on a conveyor belt which transports them into the labeling machine and further on to the wrapping machine where 10 cans of snus are batched into a roll and wrapped with plastic. The plastic covered roll passes through an oven which shrinks the plastic film over the roll, and is then placed into a carton box by a robot. Each carton box is filled with 24 rolls of snus, where each roll consists of 10 cans of snus. When the carton box is filled it is placed on a palette which is in its turned transported by a forklift into refrigerator storage when filled. Each palette contains 30 cartons of snus.

4.4 Storage and Shipment

The storage and shipment department handles incoming deliveries from the company's suppliers of supplementary material for the entire production's departments. This means handling all material for the mill, the preparation and the packing processes. As an example, deliveries for the packing process contain (but are not limited to) material such as the plastic cans for snus, stickers, banner paper, snus paper and other consumables. In addition to this fairly large task, they store the incoming material within their material handling and storage area. Finished packages of packed products also arrive by automatic conveyor belts from the production lines and are packed onto pallets automatically by a machine. The department also handles the storage of finished products for delivery to the distribution center, where the products are later shipped to retailers.

5. RESULTS AND ANALYSIS

This chapter will present the results and analyses from this thesis. The first two subchapters go through the improvement tool's uses in regards to the different departments that were studied. The rest of the main chapter goes through the analysis of the results from using the tools on the production.

5.1 VSM and Simulation Usefulness

The evident problems with capacity, flexibility and a standardized approach, cannot be seen from a VSM alone. Conducting theoretical calculations with pencil and paper, it is possible to conclude that there is an overcapacity of machinery, but the steps necessary to fully utilize this capacity require both a VSM and simulation model to fully understand and rectify. A simulation model of the current state production has therefore highlighted various problems at a high level of detail which may otherwise have gone undetected. The simulation model thus in a way acted as a data collection tool where all relevant simulation parameters could be gathered and simulated.

The results of the simulation have also proven to be different than what had been expected in terms of the type of results. By investigating the possibility of increasing flexibility, the simulation model has uncovered several improvements necessary to be made to both areas relating to the production system, but also management and implementation of lean tools, some of which may not have been able to be seen from a VSM or simulation model alone.

5.1.1 "Department 1" and "Department 2"

Simulation of "Department 2" proved increasingly difficult as the model evolved due to the increasing number of human decisions which affected the process to such a magnitude that they could not be ignored. Because of the important decisions being made by staff, they lacked a prominent company- and production-specific standard of how to handle production specific questions. In addition to this, "Department 2" was also affected by other parts of the production which had not been taken into account for in this case study due to their inherent complexity, such as the material handling and cold storage of finished goods departments.

Because of this, a VSM was better suited for "Department 2" since the delimitations of the simulation model would otherwise become so great that it would cause simulation realism to suffer. A model of "Department 2" had been constructed, but the importance and full implications of any future improvement work in this area remain unclear due to the model's strong simplification and questionable usefulness in its current state.

A clear picture of the process which a VSM can yield may at first glance provide less detailed results than a simulation, however an overall schematic over a process and its potential improvement areas is of greater value than a simulation model which has been simplified to such an extent that its usefulness is questionable. The results of a thoroughly conducted simulation study of "Department 2" in its present state had not been worth the time that would have to be dedicated, hence further concluding that a VSM of the department is more suitable as a foundation to build improvements upon in regards to model confidence and time invested (Sargent, R.G. (2013)). The previous mentions of human decision making and lack of standardization also applies to

"Department 1." Even here the notion of an accurate simulation model should be considered only after a true commitment to standardizing work tasks is implemented.

Therefore, some conclusions can be made from these two departments based on this case study's observations. From the VSM it is evident that a large part of the throughput time resides in both of these departments due to their large buffers and processing times, but also that the departments in themselves need a standardization of work tasks in order to improve on a long term basis. Once completed, a future simulation study should prove an ample opportunity to demonstrate whether the implemented work task standard is appropriate or not, as well as prove itself as a positive confirmation to a future state VSM.

5.1.2 "Department 3"

In contrast to the preparation department, the packing department proved most suitable for a simulation study rather than solely relying on a VSM. However even so, the VSM over the department was useful when constructing the simulation model, acting as a blueprint and minimizing the risk of constructing the flow in a logically false way or overlooking details important for the simulation to function.

Solely using a VSM would not provide the same detail and information as a running simulation in regards to buffer sizes, dynamic or shifting bottlenecks and layout experimentation. Of course, the possibility of changing the layout in a VSM is possible, however the dynamic impacts of the process before and after the layout change are unclear. A VSM in this case may provide a good snapshot image of what a new layout may lead to, but without testing the layout will always remain within a static design and concept stage of a future state production system, until a risk is taken to physically implement this improvement which could prove costly. It is in these circumstances that a simulation study in combination with a VSM proves crucially useful in designing a concept (VSM) and testing the design against real world data in a simulated environment (simulation) to validate a hypothesis. Naturally, a simulation model will never be a 1:1 representation of a real world system, however as has been proven by this case study, a simulation model can be constructed to an advanced level of confidence within a reasonable time frame, enabling testing and evaluation of different hypotheses without the worry of physical implementation in order to see results.

With a simulation model, experimentation is easy as model parameters can swiftly be changed. Making the model as realistic as possible is also relatively easy given the access to necessary production information, such as machine specifications, failure rates, distances, times and other relevant data. A simulation model thus provides great flexibility in regards to further improvement work due to its rapid result generation, being able to simulate weeks of production time within seconds. Due to the static nature of "Department 3," the low level of human decisions made coupled with the high level of automation and somewhat standardized work procedures regarding machine repair and changeovers, made this department especially suitable for a simulation study.

5.2 A Comparison between Simulation and VSM

Value stream mapping is an effective tool to create an overall current state schematic of the production (Che Ani, M.N. et *al. (2014))*. A simple schematic diagram of the production shows all the processes and buffers the products go through and the relevant information and parameters of these. It also shows how the production is organized and managed while simple to use and yielding fast and accurate result to start improvements upon. On the other hand, the simulation model yielded a more detailed state of the production with the goal to create an exact copy of the current state production but in a virtual environment. The simulation proved more time consuming compared to the VSM because of its requirement for a higher level of detail regarding input parameters to create the model, but nevertheless it is also a tool that has a wide range of applications outside of the manufacturing industry (Rahman El Sheikh, A.A. et *al* (2008)). The following paragraphs will compare the VSM tool with simulation and describe the advantages and disadvantages with each respective tool.

The most time consuming step of the creation of a VSM is the data collection. How long this step takes depends of course on the size of the target of study, which detail level that is needed and what information and data that the target has already recorded (Rother, M. and Shook, J. (2003)). A much lower detail level of input data has however proven to be one of the great strengths of VSM compared to the simulation model. The accuracy of the simulation model has shown itself to be directly proportional to the amount of correct data used as input to create the model. Furthermore, the result from the simulation is much more detailed versus the results from the VSM. The VSM may have needed less detailed input data, meaning that less time was needed for data collection, but it also meant that the result had a low detail level. With the simulation model in mind, this was the direct opposite. Much can however be done to reduce the data collecting time. The lean philosophy points out the importance to measure to be able to improve (Liker, J. (2004)). These measurements have in this case study proven to often be the same as the data needed in a simulation model, such as various machine parameters, conveyor belt speeds, buffer sizes and process times. If a company follows the lean philosophy they should be measuring the production constantly - if this is the case the data collection should not take long (Liker, J. (2004), Rother, M. and Shook, J. (2003)).

The biggest observed advantage with a VSM within the case study was the possibility to easily locate the value added time and the non-value added time in a production system. Since Value-Added (VA) time is defined as processes or activities which transform an input into a customer-usable output, any WIP in the case study production process not present in a process or activity which adds value is thus regarded as Non-Value Adding (NVA). In a production system where a lot of products are in motion where many conveyors and buffers exist, it can be difficult to calculate the amount of non-value adding time. In this way, VSM has proven to be a very powerful tool to show where the system's WIP is located and thus show if it is value adding or non-value adding.

However it can be difficult to know if the future state VSM is possible to implement in reality and if it yields an overall improvement. For example, a VSM does not show the physical layout of the production. It means that the changes in the VSM might not be possible in the reality due to the layout, producing the need for a VSM to be used in conjunction with blueprints in order to reduce possible re-work. In a simulation model it is possible to include the layout of the factory which in turn can show limitations of the physical layouts that cannot be seen in a VSM alone. Value adding time and non-value adding time is as easy to calculate in a simulation model as in a VSM, but the time needed to create the model in order to calculate this time is much greater than a VSM, making the VSM more efficient in this aspect. For example, if a larger factory should be evaluated regarding value adding and non-value adding time it will be much more time consuming to create a simulation model compared to creating a VSM. A conclusion of this is that VSM is beneficial when it comes to locating the value and non-value adding time while a simulation model is better when it comes to evaluating how to improve critical areas of the VSM.

A disadvantage of VSM is that it is created based on a snapshot of the production at the time of the VSM creation. Therefore it is important to conduct the VSM at a random time to minimize the risk of intentionally choosing a day that is unusually good or bad. It is nevertheless possible that the randomly chosen time is a time when the production performs better or worse than usual. The VSM gives in this case an incorrect picture of the production. A simulation model is however based on data from a longer time period, meaning that there is no risk that the model only considers days that are unusually good or bad, but instead also considers all days. In a way there is a greater risk of a VSM being created in a dishonest way in order to perceive the production as better than it is, while a simulation provides clear factual evidence. A simulation model should only be done honestly, since inaccurate input data renders the simulation useless.

Creating a simulation model requires not only programming skills but also experience in building simulation models. The model must be built in such a way that it can both be validated and flexible enough to easily enable varying experiments. Skill-wise, a VSM requires less skill compared to a simulation in order to create, however as mentioned earlier, despite this both have their strengths and weaknesses. However comparing the creation of a simulation model with a VSM, a VSM is easier to implement than simulation. With both of the tools in mind it is however beneficial to acquire knowledge about production engineering and lean concepts to be able to perform an analysis of the result from the two tools.

A simulation has a wide range of applications. Since it represents a virtual copy of reality it is possible to conduct the same investigations in the model as in reality and even more. The model allows for the disregard of limitations that exist in the reality, for example layout changes, the addition of machines and buffers, changing capacities and other experiments that cannot be done in reality due to time, money or other limitations. It is also possible to view and analyze all parameters existing within a production system, such as output, total setup time, WIP and even parameters like energy usage and amount of emissions, among others. It is only the input data and its accuracy that restricts the number of parameters that can be analyzed and how well the model functions. In a VSM, depending on the scope, there may be fewer parameters that can be analyzed since the detailed level could be low. For example, flexibility may prove difficult to analyze in a VSM since it states the setup time between product types but it does not show how often there is a change or how this affects the rest of the flow.

To make a simulation model of an advanced production system, the use of simulation software eases the process as has been observed within the case study. There exist a number of different software utilities with varying complexity, usability and price ranges. Which of the software to choose from depends on what the purpose of the simulation is, what kind of production system that is going to be modeled and the financial limitations in place. To create a VSM there is no need for expensive software; pen and pencil is enough as has been shown, albeit using free software in a digital format, however the principle is the same. The possibility of creating a VSM using only pen and paper makes VSM an extremely cheap and powerful tool.

Taking an example from this case study, it has proved difficult to make the simulation model behave exactly like the real production. In this case it was necessary to set certain delimitations in place in order to render the simulation model within a reasonable timeframe at a reasonable cost. At the same time, it has become useful and important to gain knowledge about which limitations that have been made and how they influence the result when conducting the simulation study, otherwise wrong conclusions could be drawn from the simulation model results. In contrary, the VSM showed a very simplified version of the production making it difficult to get a complete understanding of the production only by studying the VSM. With this in mind, for an external person who has not seen the production in reality it may be easier to understand and draw conclusions from a simulation model than from a VSM.

5.3 Placement and Analysis of the CODP

5.3.1 Results of CODP Placement

The Swedish Match Gothenburg factory has its CODP placed after the “Department 1” and before “Department 2” where the tobacco gets flavoured and pasteurized.

Table 4. Competitive production factors vs. production strategies and an optimal strategy for the case company highlighted. The circled areas are the current state strategy while the dotted areas are the proposed improved strategy (adapted from Mattsson S-A and Jonsson P (2003)).

Production Factors	Engineer To Order (ETO)	Make To Order (MTO)	Assemble To Order (ATO)	Make To Stock (MTS)
Time To Customer	Long	Average	Short	Very Short
Production Volume	Small	Small	Average	Large
Product Variation	Very High	High	High	Low

5.3.2 Analysis of CODP Placement

Table 4 shows two production strategies highlighted differently. The current state production strategy is a combination of MTS and ATO, where the time to consumer is very short, the production volume is large and the product variation is high. On the contrary, the ATO strategy is a preferred one due to the desired product variation being high while maintaining short Time-To-Customer (TTC) but compromising on production volume. This compromise may however in fact be beneficial due to the relation to large batch sizes and large finished goods stock.

When choosing CODP placement for a production system, while taking into account the recent studies in optimal placement (Hedenstierna, P. and Ng, H.C., A. (2011)), there is possibility for a dilemma to occur as shown in Table 4. Here, two strategies are highlighted differently. For the case study, the ideal solution would be to adopt a very short time to consumer, with a large production volume and a high product variation. This combination is represented as the circled cells in the table. However, as can be seen, the combination of factors discussed does not apply to a strict production strategy, as it becomes a combination of both a MTS and ATO strategy. The MTS strategy with very short time to consumer and large production volume only works well with a low product variation. Hence, according to the theory, the optimal solution presented with the circled cells does not work optimally.

A solution to the dilemma would be to compromise on the factors of time to consumer as well as production volume, in order to maintain a high product variation. Since the company in the case study wish to become more flexible, the higher the product variation the better, however this comes at a cost regarding time to consumer and production volume. A satisfactory conclusion as to which strategy to pick seems to therefore be an ATO strategy shown with a dotted line in Table 4, since smaller production volumes inherently enhances the possibility of increasing product variation while maintaining a "short" time to consumer.

On the contrary, the difference between "very short" and "short" regarding time to consumer is debatable. Since there is a lack of definition for which time spans apply to each respective word, the company would need to decide how much of a compromise in the time to consumer factor is worth the increase in production flexibility. Some product variants may need a very short time to consumer while others would not, further opening up for investigation whether a hybrid production strategy is suitable for this varied type of production.

Choosing ATO as a production strategy, the CODP should according to the literature (Hedenstierna, P. and Ng, H.C., A. (2011)) be placed downstream in the production system. The Swedish Match Gothenburg factory has its CODP placed relatively far upstream of the production which contradicts the literature and the type of production goals Swedish Match would like to achieve. However, Swedish Match has launched a project whose goal is to move the CODP further downstream, but it has yet to come to fruition.

5.4 Results and Analysis of the Value Stream Map

The current state VSM which was created can be seen in APPENDIX B while the future state VSM can be seen in APPENDIXF.

5.4.1 Results of the Critical Area Identification in the VSM

Figure 16 illustrates the WIP of the different departments in the production, which aided in determining the critical areas of focus within the VSM for continued study.

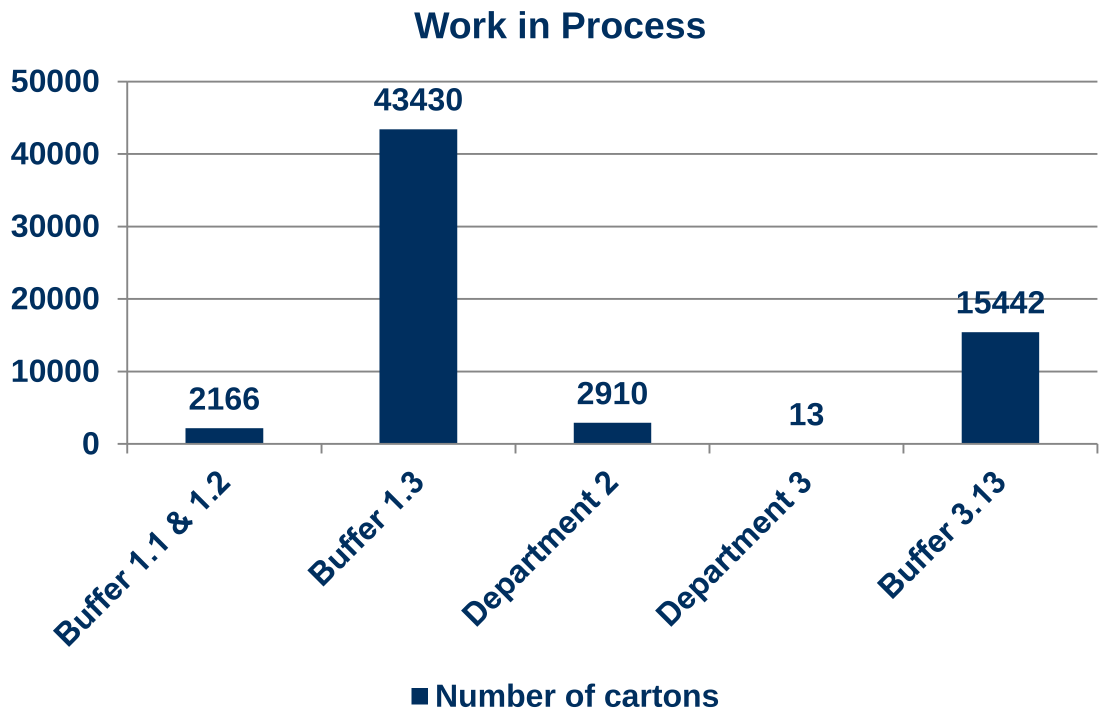

Figure 16. An illustration of WIP in the production visualized in cartons of snus.

5.4.2 Analysis of WIP and Critical Area Identification

It can be seen in the VSM that the throughput time and WIP is directly influenced by a number of large buffers present in the production chain. A quick analysis proves that for a total of 18,82 hours processing time, the product stays in buffers for a total of 30,22 days. To determine where the WIP is allocated a bar graph was created (see Figure 16). As can be seen from the bar graph, "Buffer 1.3" and "Buffer 3.13" contain the largest amount of WIP. However, "Buffer 1.3" has not been considered significant for improvement due to the placement of the CODP.

"Department 3" contains the least WIP of all the processes in the whole production line. However, it is important to note that despite having the least WIP, the department is inflexible. This is partly the reason why "Buffer 3.13" is large since it acts as a safety stock for the slow processing time of varying products due to long changeover times.

At the same time, it is important to remember that the CODP according to the VSM is currently between "Buffer 1.3" and "Department 2". This enables "Buffer 1.3" to act as a very large safety stock, both in case of an emergency breakdown of "Process 1.2" and for a new downstream placement of the CODP. In a way it is possible to witness the production of being within two states of identity, where two large safety stocks are used when only one or the other should be used. The "Buffer 1.3" safety stock is from an era where the reliability of "Process 1.2" was uncertain, while the safety stock "Buffer 3.13" is from an era of having the CODP placed too far upstream.

Placing the CODP downstream would enable the production to keep the needed safety stock that "Buffer 1.3" provides, while minimizing "Buffer 3.13" but only by making "Department 2" more flexible. Removing "Buffer 1.3" would make the production prone to shortage of products and very long lead times if “Process 1.2” were to break down, which is why the “Buffer 1.3” safety stock is not investigated.

As a result, “Buffer 3.13” has been deemed of greater importance for improvement due to its placement after the CODP, and also since the throughput time of this department has been calculated to 7,29 days. This is not optimal, as the goal should be to minimize the throughput time in order to minimize the Time-To-Customer after the CODP. For reasons as to why “Buffer 3.13” is so large, it seems to be mainly due to the large variety of products, long changeover times and the desired delivery precision of 99,7% coupled with the wrong type of production strategy. As a result, this means that the throughput time of products and “Buffer 3.13” are very closely related to the changeover times and flexibility of the production.

5.4.3 Flexibility Analysis

Regarding flexibility, there are two ways to look at the current situation at the case company. The flexibility issues tend to shift between “Department 2” and “Department 3” depending on the angle of observation. Moreover, the size of the finished goods storage is indirectly affected by the flexibility of the preparation and “Department 3.” Since today’s “Department 2” relies on few but large batches of products to process, this department can be seen as most influential on flexibility since “Department 3’s” production depends largely on the different products that come from “Department 2.”

Large batches mean fewer changeovers and therefore a fewer amount of product types produced. However, modifying the product after “Process 2.1” to effectively move the CODP further downstream enables “Department 2” to become much more flexible. A large batch of product can then be used for more than one product type, automatically increasing the flexibility of the department. In that regard, the flexibility issues instead shift over to “Department 3” which will then need to accommodate the production line for an increased number of changeovers and product varieties produced.

5.4.4 Results regarding Production Rate

To aid in determining the significant departments regarding production rate, a bar chart was created (see Figure 17) where the cycle time per can of snus for each process was compared to the calculated takt time of the production plant.

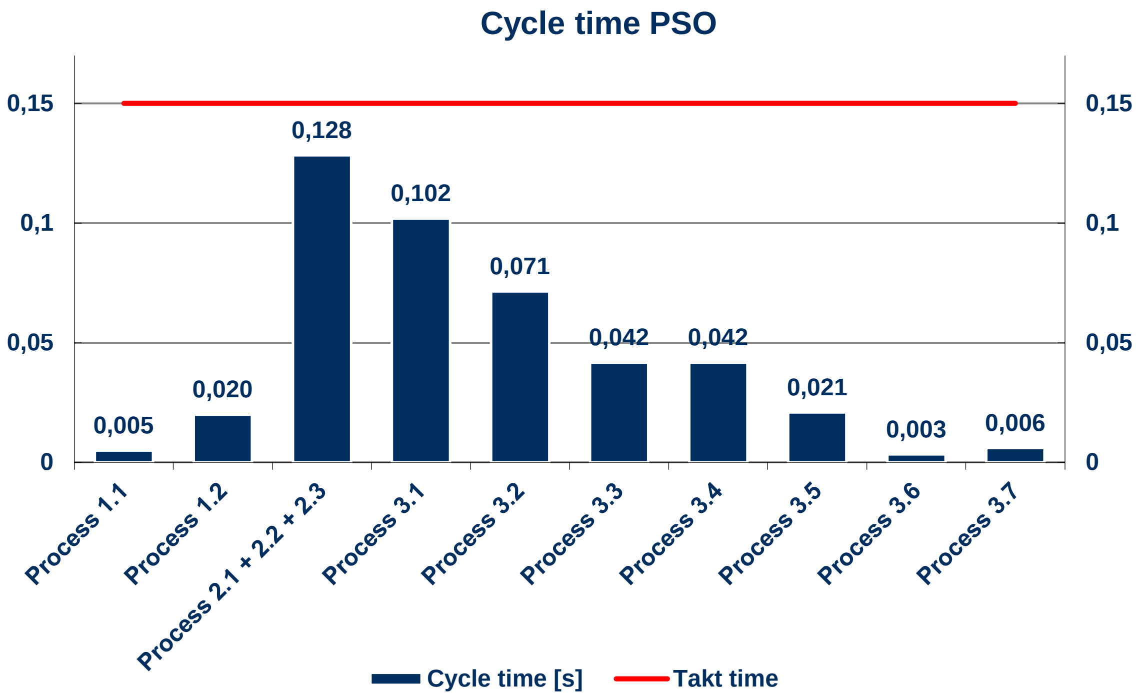

Figure 17. The production process' process times illustrated against the production's calculated takt time based on customer demand. "Process 2.1 + 2.2 + 2.3" are merged since these comprise the entire process for one mixing machine.

5.4.5 Analysis of Production Rate

Figure 17, which shows the process time, gives some insight into what department that takes the longest time to process products. From the VSM and Figure 18 it can be seen that "Process 2.1 + 2.2 + 2.3" have the longest processing time (16,38 hours) and also the longest cycle time (0,128 seconds per can). However, the machines in these processes also process during the night meaning that they operate over the course of 24 hours, further supporting the fact that the machines in "Department 3" are the largest constraint.

In contrast, Swedish Match are working with increasing the flexibility of "Department 2" which reduces its bottleneck effect due to the long processing times, but does not overshadow the bottleneck which are the machines in "Department 3" from a flexibility perspective.

From the results of the VSM it was decided that "Department 3" had the largest influence on the overall flexibility of the production. It was therefore decided to prioritize the creation of a simulation model of this department. Second in priority was to create a simulation model of "Department 2" to investigate how this department affects the flexibility of "Department 3."

5.5 Results and Analysis of the Simulation Model

5.5.1 Results from Simulation

The goal was to make a simulation model of one production line in "Department 3" and a model of "Department 2" that delivers tobacco to the modeled production line. It was however soon discovered that there were too many human decisions involved in "Department 2's" way of working, with too few working standards to make an accurate simulation model. An effort to create a model of this department was still attempted but with simplifications of such magnitude that the validation of the model could not be approved. Since this part of the production was not prioritized in regards to the final results, it was decided to not make any more effort in trying to improve the model of "Department 2." However, a highly detailed model of a production line in "Department 3" was created which could be verified and validated with good results. A picture of the simulation model can be seen in APPENDIX C.

5.5.2 Results of the Validation

Below are two pictures (see Figure 18 and Figure 19). Both images represent the amount of products that have been produced (y-axis) during a certain amount of production time (x-axis). The squares represent the result from the real production and the triangles are the results from the simulation. The first plot (see Figure 18 is the result where no setup has been executed and the second plot (see Figure 19) is the result where one setup has been executed.

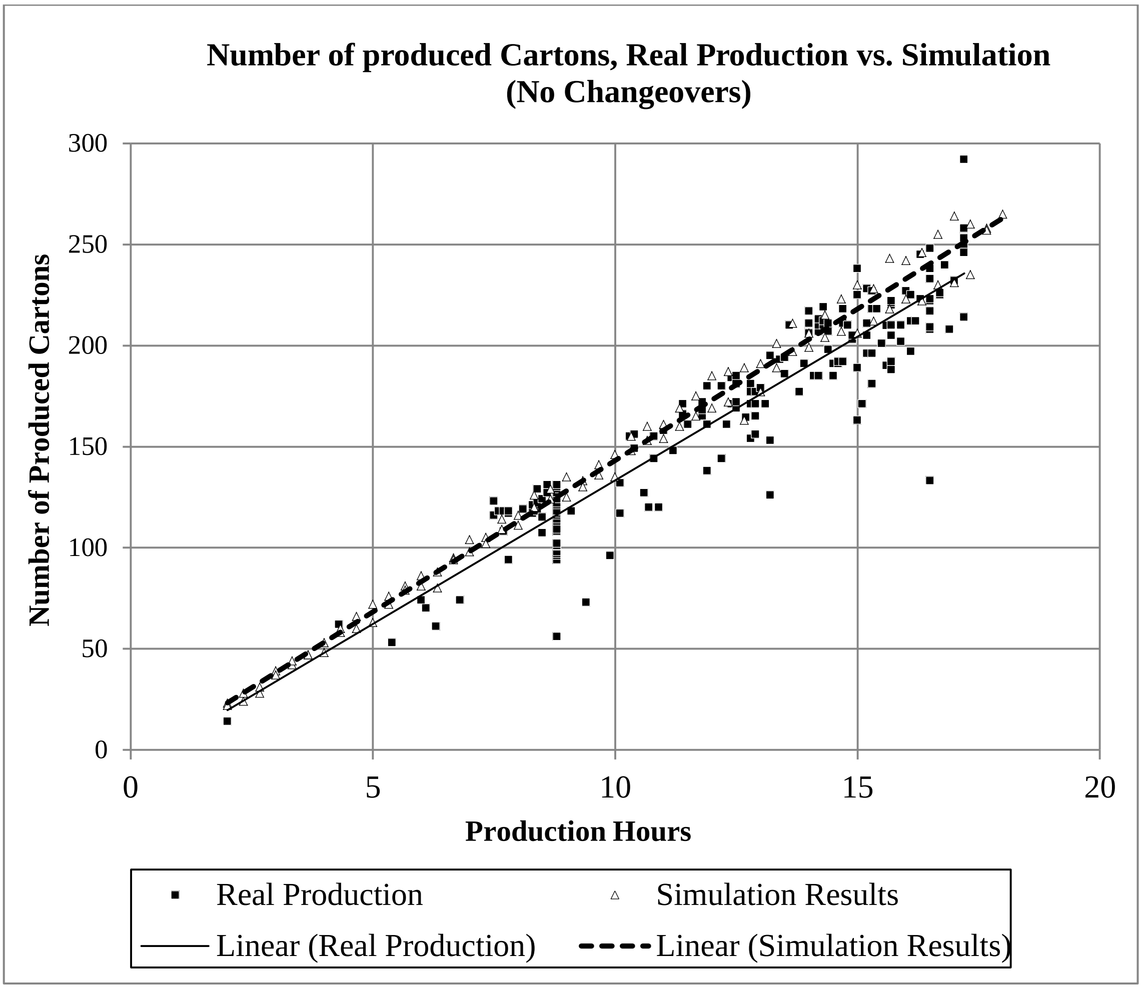

Figure 18. The first validation depicting the number of produced products with no changeovers, versus production hours utilized.

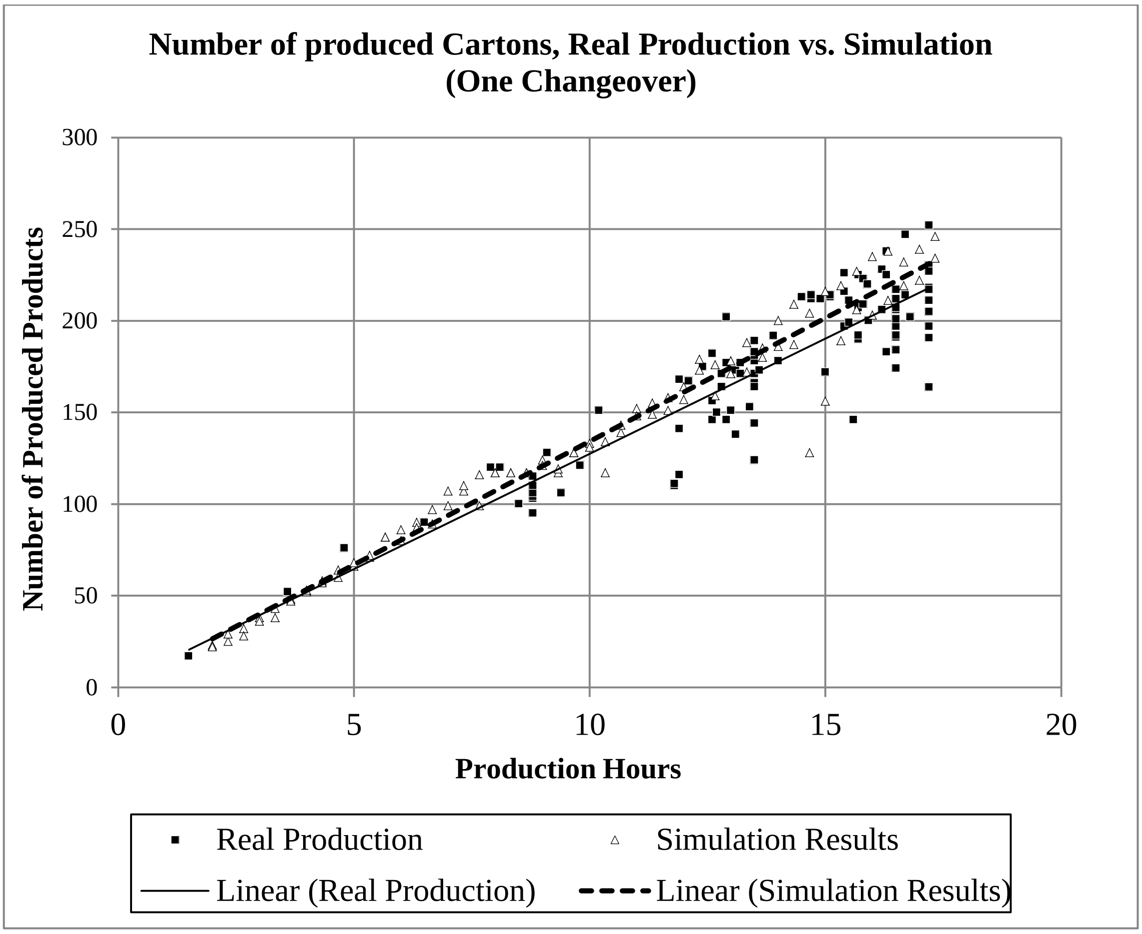

Figure 19. The second validation depicting the number of produced products with one changeover, versus production hours utilized.

Trend lines have been added to the plots to easier compare the results. The upper trend lines belong to the simulation results, designated by triangles. The nether trend lines belong to the squares which represent the result from historical production data.

Another validation test was performed by running the simulation model against a real production plan spanning two weeks. The simulation model took half the time to complete the plan compared to the time it took for the real production, i.e. the simulation took about one week to produce what it takes two weeks for the real production plan to produce, making the simulation model roughly double as effective. Another two production weeks were tested from a random period during a previous year. Here, the simulation model finished its production plan within an hour of when the real production plan was logged to be finished which while further validating the correctness and accuracy of the simulation model, also provided contradicting evidence to the previous two weeks tested. What differed between the two tests was the size of batches. The first test where the simulation was finished a week before schedule, the batches were relatively small while the second test had larger batch sizes.

5.5.3 Analysis of Simulation Validation

Since there was no data available regarding variations in the time it took to perform certain actions during a production run, as well as unpredictable human behavior, it was expected that the simulation model would have a more narrow spread of variance compared to the real world data. As can be seen in Figure 18 and Figure 19, the trendline for the simulated value differs for a maximum of 7% at 17 hours of production from the trendline of the real production when no setup is made, and for a maximum of 6% at 17 hours when one setup is made. This proves to be a satisfactory validation of simulation behavior.

One factor that is known to affect the error margin is production stops that are not registered by the company's internal logging system Plant Metrics, they are reported manually and externally from the automatic logging system. These faults were often long in relation to the production time, many times ranging more than 30 minutes per fault. The failures discovered had many categories, some of which could be failures in the form of electricity problems or setup problems and such - failures which are only reported manually in the production log. How these failures are followed up is unknown. Through interviews with staff it was also realized that faults under 15 minutes were not logged at all, and while trivial and of short time, these times also contribute to significant time losses due to faults which could possibly have been prevented by implementing different work practices.

When running the simulation model against a real production plan spanning two weeks the simulation took half the time compared to the real production. This proves that even if the simulation has been seen valid in regards to number of products produced during a fixed number of production hours, it is not valid in regards to amount of production hours utilized per week. The conclusion that was drawn from this result was that the real production does not utilize as many production hours as the simulation. In comparison, the simulation model operates according to all available production hours, and dynamically calculates the time it takes to complete the next batch. The model aborts production for the day if the batch size exceeds the production time limit imposed from the calculation. This is supposed to resemble manual operator decisions regarding production of products and time left of available production hours. However the simulation of the two week production plan made it clear that the same method was not used in the real production system. This made it clear that an investigation had to be made to clarify how many of the available production hours that were truly utilized.

As described in the results of the validation, the reason behind the contradicting results between the two simulated production weeks was the batch size of products. For the first two weeks tested, batch sizes and amount of varieties were low, thus resulting in the simulation model being able to produce its production plan quite rapidly. This was because more batches could be produced per day, thus utilizing more production hours per day. The real production did not utilize as many production hours partly due to production stops and an inefficient production plan. Hence, even if there were time to produce a new batch this was not done. For the other two weeks which were tested, the batch sizes were much larger. This meant that most days only one batch and therefore only one product type could be produced. Even if there was more time available it was still not enough to produce the next batch.

The way the model operates is the primary cause for the disparity in production completion time between the simulation model and the real world production completion time, since it operates from what could be said as the 'ideal' production state of the production line. The model's logical functioning is therefore constructed by design, since the sporadic changes in production completion of the real world production is difficult to simulate due to a number of unique reasons which are non-repeatable and difficult to apply to a statistical distribution since this data is not logged in its entirety. These unique circumstances are also at the mercy of a lack of standardized work tasks.

5.6 Utilization of Production Hours

5.6.1 Results from Utilization of Production Hours

The following graph shows the utilization of available production hours from January 2014 to March 2015 (see Figure 20).

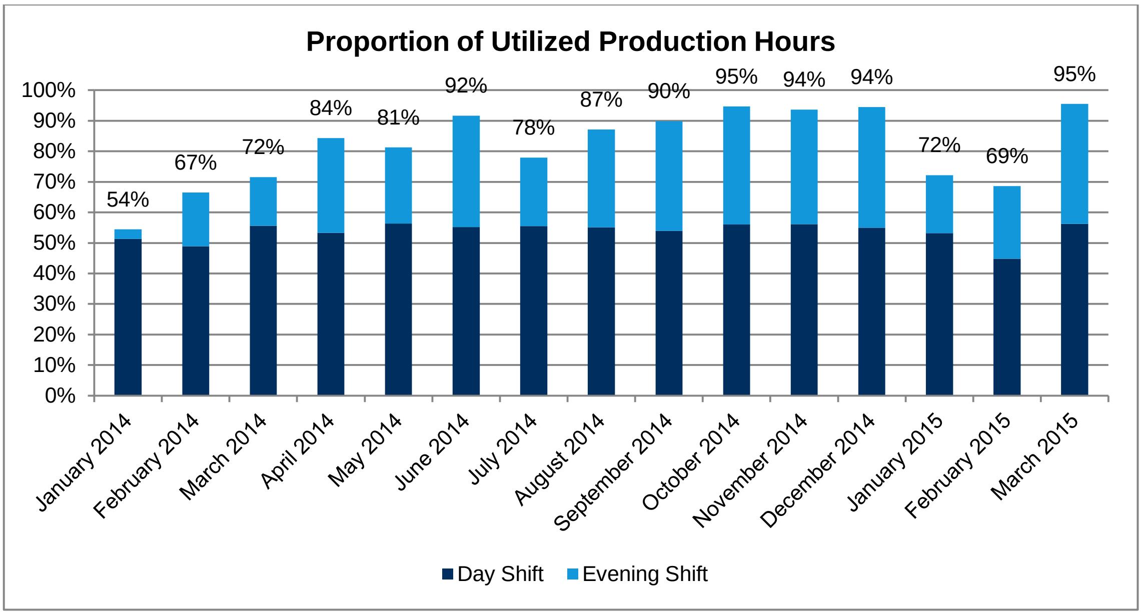

Figure 20. A depiction of average utilized production hours on a monthly basis. The data labels represent the total amount of time utilized, where 100% is all available production time.

5.6.2 Analysis of Production Hours Utilization

From January 2014 to March 2015 only 82% of the available production hours were utilized on average, which equates to 12.8h of 15.6 per day (see Figure 20). The reason why the production was not fully utilizing all hours was found in the manual logging system where it was observed that many production days had successfully produced the amount of products according to plan, but long before the actual day was over. It was therefore evident that for the observed span of production, the amount of available production hours were severely underutilized causing a substantial waste of capacity. Today, the company meets customer demand by chasing the demand curve rather than leveling the production for their own and their supplier's benefit.

5.7 Customer Demand

In order to define the company's customer demand, data for amount of sold products was compiled over the previous 16 months in order to calculate an average of sold goods per week, where the sold goods are number of cartons of snus. A summary of the complete data set can be seen in Table 5.

Table 5. The average number of cartons that have been sold per week from historical data, forming a baseline for number of cartons to be produced in order to meet customer demand.

Product Name	Average
Product 1	318
Product 2	19
Product 3	8
Product 4	9
Product 5	163
Product 6	11
Product 7	217
Product 8	22
Product 9	69
Product 10	43
Product 11	31
Product 12	22
Product 13	63
Product 14	57
Total average per week:	1050
Total average per day:	210

Investigating the current state of the case study company, it can be seen from Table 5 that the average production quantity should be 1050 cartons per week in total for all varieties, which becomes 1050/5 days = 210 cartons per day in total for all varieties.

5.8 Experiments

5.8.1 Results from Simulation Experiments

A schematic picture of the current state of "Department 3" is illustrated in Figure 21. Experiments were made in the simulation to investigate if flexibility could be increased by separating "Processes 3.1," thus making it possible to produce more product varieties in the same time and in that way reduce the number of changeovers while meeting the calculated customer demand. Two experiments were created where the layout was changed. In the first experiment (see Figure 22), the layout was rearranged so that two product types were produced per two "Processes 3.1." In the second experiment (see Figure 23) one product type was produced in each "Process 3.1" resulting in four product types produced simultaneously on the line.

In both experiments, the flow of material was changed along with the layout change. More specifically, a buffer system was put in place after the decoupled “Process 3.1” in order to separate the production line in terms of changeovers and cycle times. Since the changeover- and cycle times of “Process 3.1” are considerably longer than that of the downstream processes, decoupling these two areas of the production line with a buffer system should enable a more flexible production due to the decrease in changeover times and more rapid packaging of semi-finished goods.

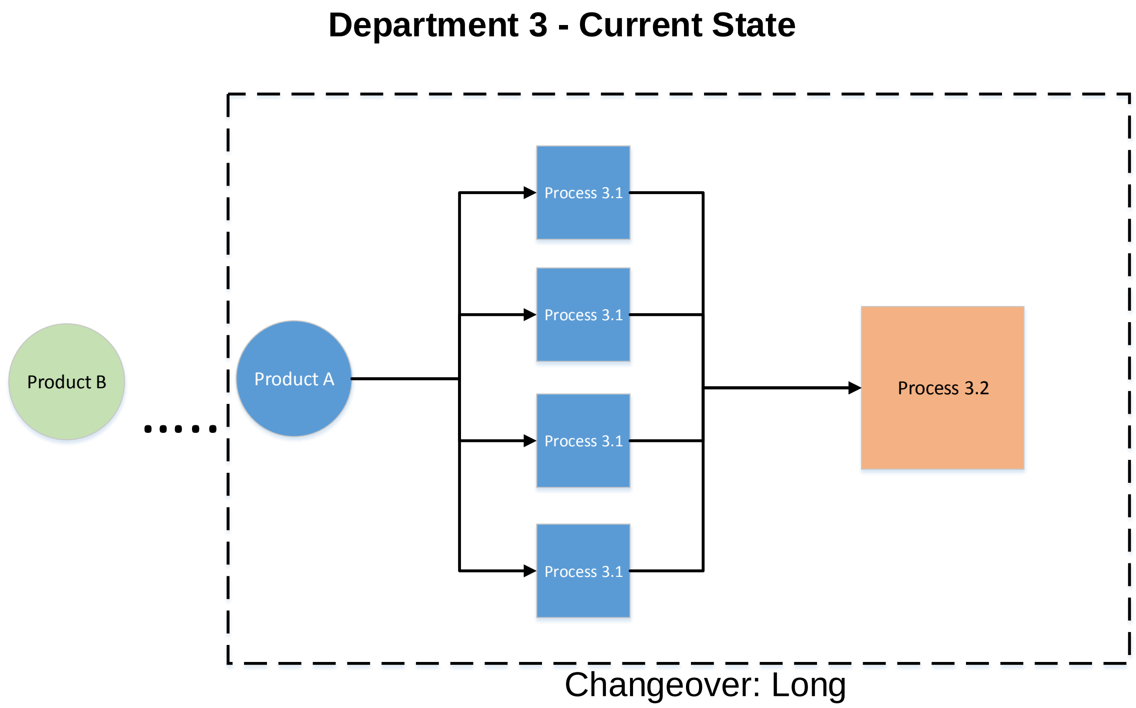

Figure 21. The current state production illustrated with material flow. All “Process 3.1” process the same product type in very large batches.

Department 3 - 1 Product Type per 2 Processes

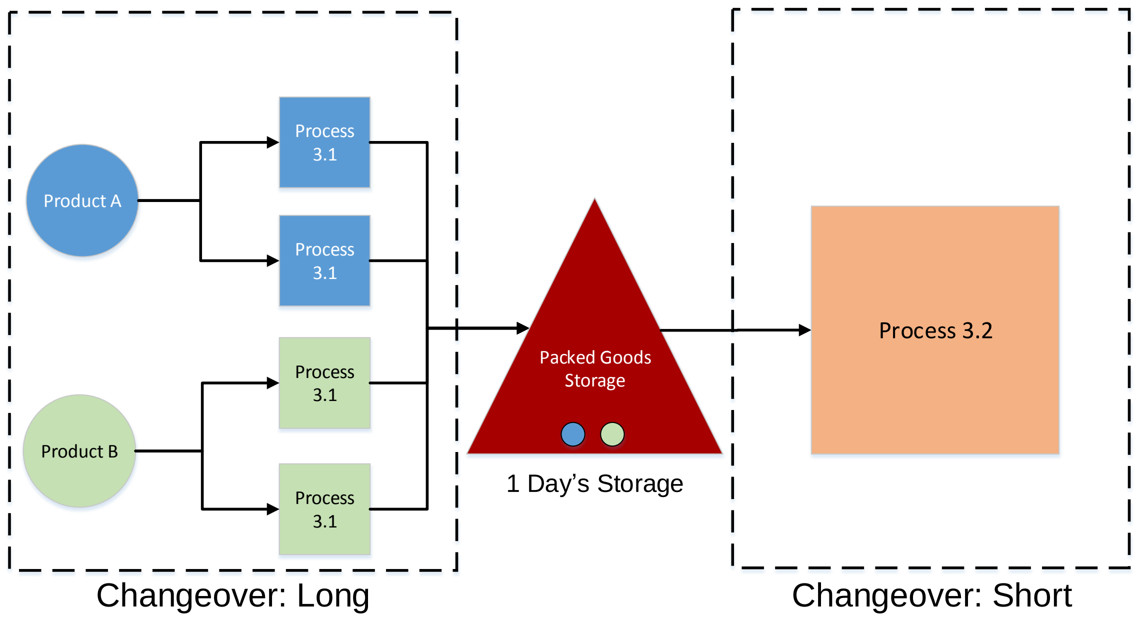

Figure 22. Experiment 1 visualized as splitting the product types over two "Process 3.1" and adding an intermediate buffer before "Process 3.2."

Department 3 - 1 Product Type per 1 Process

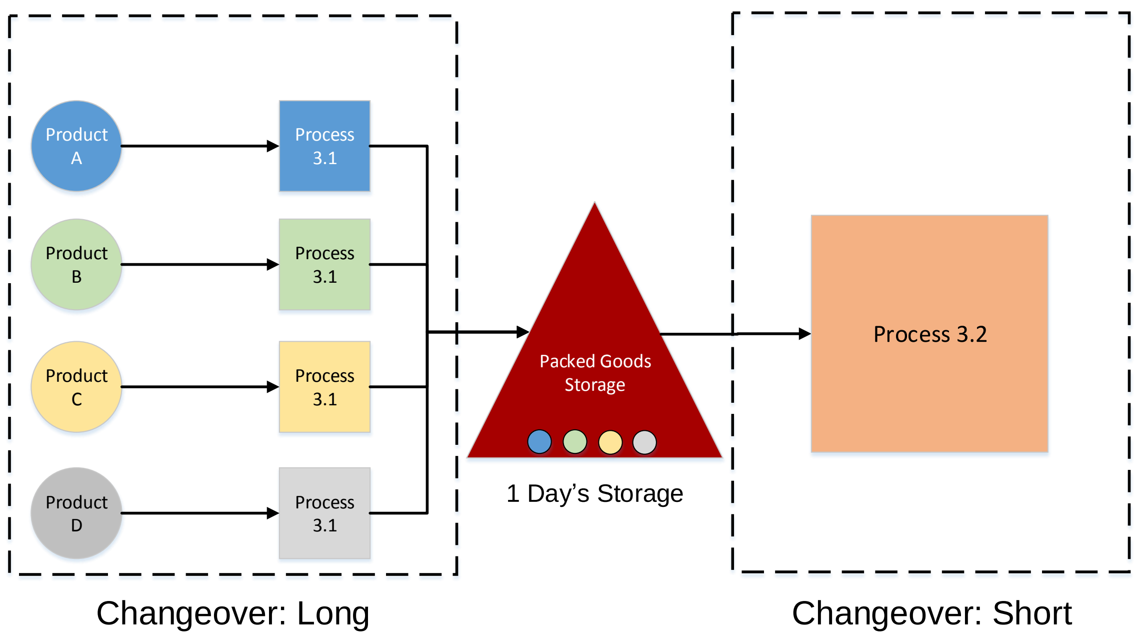

Figure 23. Experiment 2 visualized with one product type assigned per "Process 3.1," with an intermediate buffer before "Process 3.2."

The size of the packed goods storage was chosen to be large enough to contain products from a whole production day. The way the improved flow of materials works is that the processes "Processes 3.1" fill the buffer during one day which will the next day be sent over, product type by type, for further processing. The products are then sent forward to

"Process 3.2" while the processes "Processes 3.1" start to produce the next batch according to plan, in order to fill the buffers for production the day after. This was done to reduce the number of changeovers for the processes after "Processes 3.1." APPENDIX D illustrates how the simulation models were built, while Figure 24 and Figure 26 show the output result of the different simulation models in regards to number of product types produced per day. Figure 24 illustrates the production output when utilizing all production hours per day, while Figure 26 illustrates the production output when on average utilizing 12.8 production hours per day.

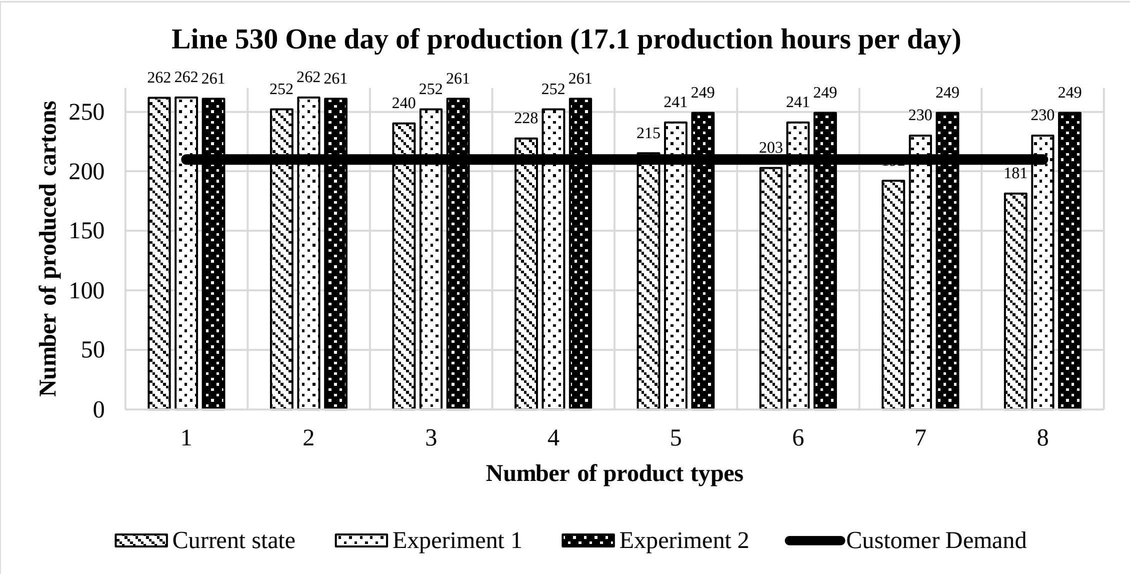

Figure 24. One day's production output per simulation model for a varying number of product types when utilizing all 17.1 production hours per day.

Table 6. The percentual increase in carton output is displayed with comparisons between the experiments and the current state production when utilizing 17.1 hours per day.

Utilization: 17.1h/Day	**Carton Output Per Day**				
Number of Product Types	**Current State**	**Experiment 1**	**Experiment 2**	**Percentual Increase Exp1 Vs. Current State**	**Percentual Increase Exp2 Vs. Current State**
1	262	262	261	0,00%	-0,38%
2	252	262	261	3,97%	3,57%
3	240	252	261	5,00%	8,75%
4	228	252	261	10,53%	14,47%
5	215	241	249	12,09%	15,81%
6	203	241	249	18,72%	22,66%
7	192	230	249	19,79%	29,69%
8	181	230	249	27,07%	37,57%

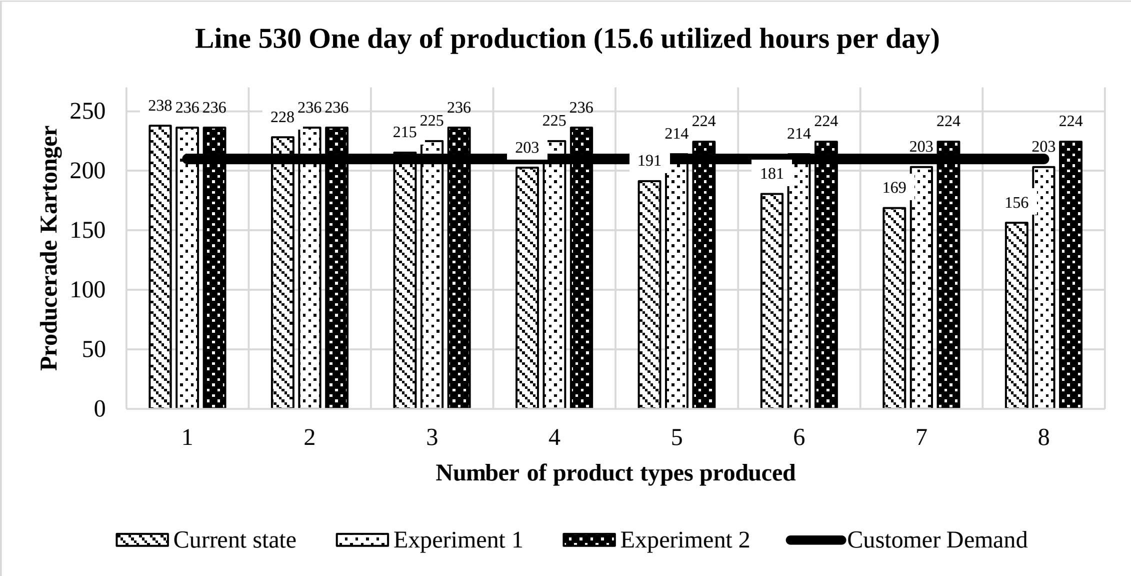

Figure 25. One day's production output per simulation model for a varying number of product types when utilizing only 15.6 production hours per day.

Table 7. The percentual increase in carton output is displayed with comparisons between the experiments and the current state production when utilizing 15.6 hours per day.

Utilization: 15.6h/Day	**Carton Output Per Day**				
Number of Product Types	**Current State**	**Experiment 1**	**Experiment 2**	**Percentual Increase Exp1 Vs. Current State**	**Percentual Increase Exp2 Vs. Current State**
1	238	236	236	-0,72%	-0,72%
2	228	236	236	3,52%	3,52%
3	215	225	236	4,49%	9,66%
4	203	225	236	11,07%	16,56%
5	191	214	224	11,87%	17,32%
6	181	214	224	18,53%	24,31%
7	169	203	224	20,27%	32,96%
8	156	203	224	29,89%	43,60%

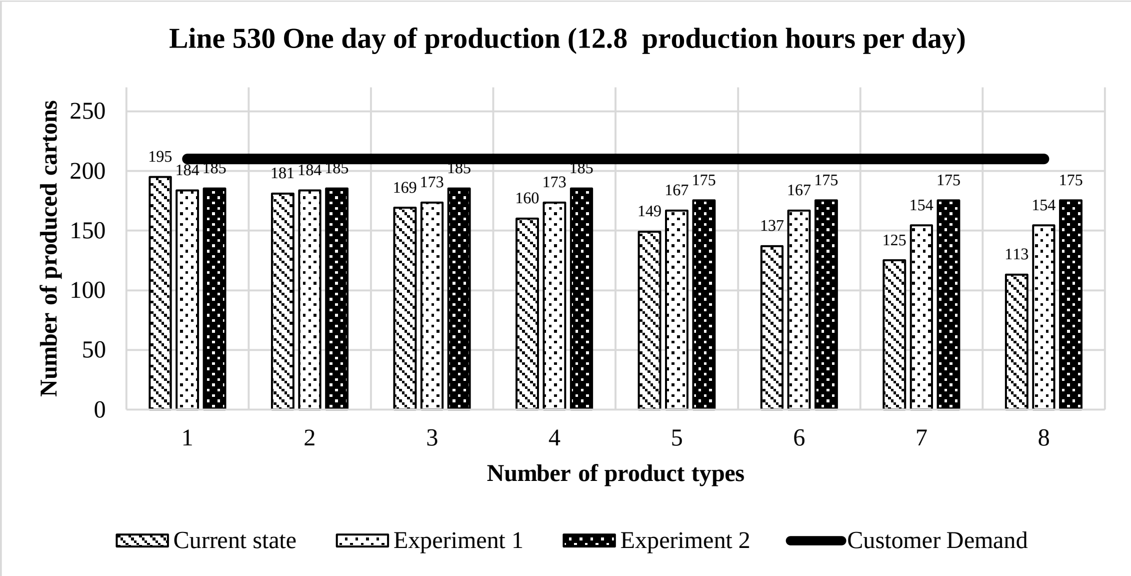

Figure 26. One day's production output per simulation model for a varying number of product types when utilizing only 12.8 production hours per day.

Table 8. The percentual increase in carton output is displayed with comparisons between the experiments and the current state production when utilizing 12.8 hours per day.

Utilization: 12.8h/Day	Carton Output Per Day				
Number of Product Types	**Current State**	**Experiment 1**	**Experiment 2**	**Percentual Increase Exp1 Vs. Current State**	**Percentual Increase Exp2 Vs. Current State**
1	195	184	185	-5,64%	-5,13%
2	181	184	185	1,66%	2,21%
3	169	173	185	2,37%	9,47%
4	160	173	185	8,13%	15,63%
5	149	167	175	12,08%	17,45%
6	137	167	175	21,90%	27,74%
7	125	154	175	23,20%	40,00%
8	113	154	175	36,28%	54,87%

5.8.2 Analysis of Output and Flexibility

A number of experiments have been performed in "Process 3.1's" simulation model to verify if the capacity of the machines in this process can be better utilized. Theoretical calculations on the number of cycles per minute of the machines and available working hours display a theoretical maximum number of cartons of snus that can be produced per day, which in turn shows an overcapacity of the machines. However, the number of available production hours are not fully utilized due to several reasons, such as "Department 2" running out of product to send to "Process 3.1," many machine failures and reaching the production plan prematurely.

All of this contributes to an inability of making a fair comparison between current production time and the theoretical calculations of max output. This could be a reason why “Processes 3.1” is regarded as the primary constraint, but may ultimately prove not to be if they were run during all available production hours. This has been shown in the results of the case study, proving that a layout change of the current production line is unnecessary in regards to production flexibility if all available production hours are utilized. Of course, “Processes 3.1” themselves are the slowest part of the production line, but the desired production flexibility is achievable once these processes are run during all available hours. Running the processes on a higher stroke per minute value increases quality defects, meaning that an investigation into if making the “Processes 3.1” faster may be beneficial for the company’s future plans.

To clarify the different available production hours presented, an explanation to the arrival of the respective times is needed. For the future state optimal model, 17.1 hours corresponds to all available production hours from the shift start in the morning to the decided shift end at night. 15.6 hours is the actual effective time the production uses today to produce, and is arrived to by taking the total time (17.1 hours) and subtracting time for breaks and lunch across shifts. The last amount of hours, 12.8, is arrived at by calculating the average amount of production hours utilized over the examined period. In this way, 17.1 hours describes the most optimal future state of production hours utilization, while 15.6 hours illustrates the possibility to improve solely based on the actual effective hours they have to utilize today. Lastly, 12.8 hours illustrates the current state of production hour utilization (see chapter “5.6.2 Analysis of Production Hours Utilization”).

From previous observations of historical production plans, the amount of products produced was observed to be inversely proportional to the amount of desired product types. The historical production plans showed that not more than two different product types per day were produced due to long changeover times, with very few exceptions. With the calculated production requirement of 210 cartons per day (see chapter “5.7 Customer Demand”), the current state production can according to Figure 24 produce a maximum of 5 product types per day assuming all 17.1 production hours are utilized, however if some leeway due to production variation is desired, the upper limit could be set to 4 product types per day. This enables all 14 product varieties to be produced in one working week of 5 days.

However, looking at Figure 25, it is evident that if the production line were to utilize the actual amount of production hours fully, it would be able to meet the customer demand by itself and produce up to 3 product types per day. On the contrary, Figure 26 shows that if the production were not to change its utilization of production hours, it would not meet up to the calculated requirement of 210 cartons per day. Of importance to note in this regard is that the utilization of production hours in the current state production is a calculated average over 16 months. This does not mean that the production utilizes the calculated 12.8 hours of production time every day, since this would mean that they do not meet customer demand with the current state production when in fact they do.

As a consequence, a calculated average of production hours may provide misleading results regarding meeting customer demand, however since the production line sometimes utilizes overtime and sometimes stops the production line prematurely, they manage to meet the customer demand with the chase-strategy they currently employ. Moreover, some products produced on the production line of study are also produced on other production lines in the factory, adding to the evidence that the production line of study does in fact meet its customer demand despite the results in Figure 26.

To increase the flexibility and be able to produce more product types, a new production layout is needed as well as a full utilization of all available production hours. Observing the bar chart in Figure 24, it is noticeable that at four product varieties the production line output between the current state production line (the bar with diagonal stripes) and the model representing one product variety per "Process 3.1" (the shaded bar) differ by about 33 cartons per day. Running the line with one variety per packer thus gives roughly 165 cartons more in output per week than the current production is capable of, or 39,600 more cans of snus per week. Considering the time savings, double the amount of varieties could be produced on the line effectively doubling the output in the same amount of time. Even at extreme cases of eight varieties produced per day, the difference in output of cartons becomes even more apparent.

By continuing to run the model through a genetic algorithm in an attempt to further optimize the model production planning-wise, the optimization resulted in a different order of products to produce, but with no significant improvements found in regards to total production time required. The tool will however probably give a better result if the batch sizes are decreased and the flexibility is increased.

From the case study's observations it is clear that almost an entire shift can be saved in production time per day by fully utilizing all available production hours. However, it is not possible to cut the production time down to one shift, since there is a risk that the desired number of varieties will not have time to be produced when factoring in failures for "Processes 3.1." The risk of not completing the number of varieties needed lies in the batch sizes of the varieties to be produced, but also in the underutilization of production hours. Running the simulation model with only one shift resulted in a simulation time of 12 days, compared to running two shifts with the same production plan which resulted in 8 days, a 4 day net profit of production time.

Therefore it is important to investigate where the extra production time is wasted and to minimize it as much as possible. The more the lost production time is minimized, the more flexible the line will become automatically due to its increased number of production hours to produce several product varieties.

5.9 Today's Production and Possible Improvements

The following chapter describes how the production works today and how it can be improved to be more efficient.

5.9.1 The Current Production Strategy

The interaction between "Department 2" and "Department 3" raises the possibility of a shifting bottleneck occurring. For example, sometimes "Processes 3.1" have to stop prematurely due to starvation, meaning that "Department 2" becomes the constraint since not enough products have been produced. When "Department 2" supplies the production line with adequate quantities of snus, the "Processes 3.1" become the constraint due to their slow speed. From the experiments that have been made in the simulation model (see Figure 24) it is shown that “Processes 3.1” are fast enough to meet the customer demand, however it also shows that all production hours need to be utilized to meet the demand if an increase in flexibility is desired. When “Department 2” doesn’t supply a sufficient amount of products it will therefore affect the utilization of production hours of “Processes 3.1.”

Furthermore, there is some cause of speculation if the production plan is faulty, since “Department 2” produces products according to the production plan. One reason for a faulty production plan could be that the production planners do not have any choice in their planning because of the capacity limitations of “Department 2.” It seems unreasonable to take it one step further and speculate if the forecast data from headquarters is faulty, but it could possibly be a point for future reflection when the forecasting data calculation can be examined.

Additionally, it is known since previous visits in “Department 2” that the working staff actively modify the production plan they receive from the production planners based on the instantaneous situation in the department regarding utilized capacity. This modification of the production plan can be questioned, since the production plan made by the production planners then becomes redundant. “Department 2” and the production planning department thus seem to have poor communication, while the production planners also do not seem to have enough information regarding the capacity and available materials of “Department 2,” further enforcing the fact that a faulty production plan is devised to begin with.

There is a reason to believe that the production plan sent to “Department 2” should from the beginning adopt the appearance that the staff of “Department 2” modify it to, in order to save the staff of conducting more work than necessary and save the production planners from creating redundant work. The staff of “Department 2“ thus perform their own production plan which seems odd considering their duties versus the production planners. In this regard the production planners should have knowledge about the instantaneous situation in “Department 2” and its current capacity in order to more effectively plan a more efficient production, while taking care to analyze the forecasting data received from the main headquarters.

5.9.2 Results from the Production Curve

The following graph shows the production plan for production line GB-530 from week 2 of 2014 until week 12 of 2015 (see Figure 27).

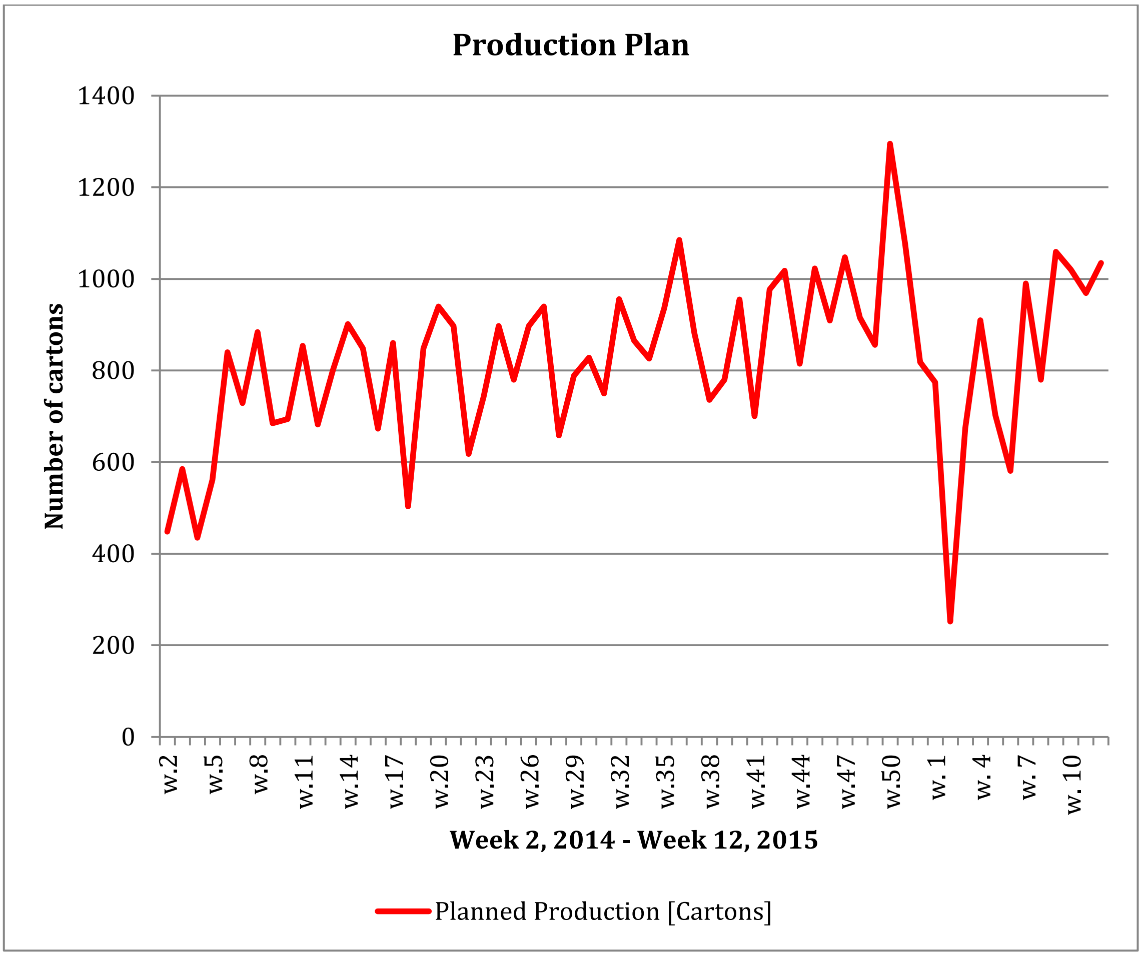

Figure 27. Illustrating the historical production plan curve of total number of cartons to produce on a weekly basis based on the incoming forecast.

5.9.3 Analysis of the Production Curve

From Figure 27 it is obvious that the demand curve is very uneven on a weekly basis, which is where most of the leveling needs to be done within the production plan. Since there is a desire to produce more product varieties per day, a leveled production plan on a weekly basis is crucial.

Leveled production comes at certain benefits but also certain costs. Large batch sizes coupled with a large amount of product types leads to large production spikes and troughs, causing uneven material flow. In the situation of the case company, the traditional manufacturing mantra of producing large batches with low varieties may have worked well previously, but in the light of budding competitors and the need for flexibility, the company has remained to produce their large batches while increasing the amount of product types. A truly leveled production as close to one-piece flow as possible requires a production line which is highly flexible and able to produce a large amount of product types in small batches. Hence, the choice to level production will ultimately force the company's production to adapt by minimizing batch sizes and reducing changeover times, thus meaning that changeover procedures and times need standardization - something not present in the case company today.

With the TPS in mind, the lean principle *heijunka* seems very relevant for the analysis of this area of time utilization and efficiency in the case company. Since the demand curve is so uneven, production leveling should be implemented to further make the production efficient, but this is not the case for the case company. The production strategy seems to chase the demand curve rather than even it out, which leads to days and weeks with a very low amount of utilized production hours and other days and weeks when the production has difficulty catching up. This therefore gives further support to the notion of improving the production planning aspect of the case company in order to level the production and provide a smoother product flow.

To achieve a more flexible production and simultaneously produce larger amount of products per day, a production plan where a production period is condensed in order to fully utilize that period's number of production hours is needed. For example, finishing a large batch prematurely at 16:30 on a Monday while another product variety of a very small batch is planned for Friday could be re-planned so that Monday's batch and Friday's batch both produce on the Monday in order to utilize as many hours of Monday's production as possible. This way of planning however further requires an investigation into the flexibility of the "Department 2" and how many product varieties it can produce and at what volumes.

5.9.4 Analysis of Customer Demand

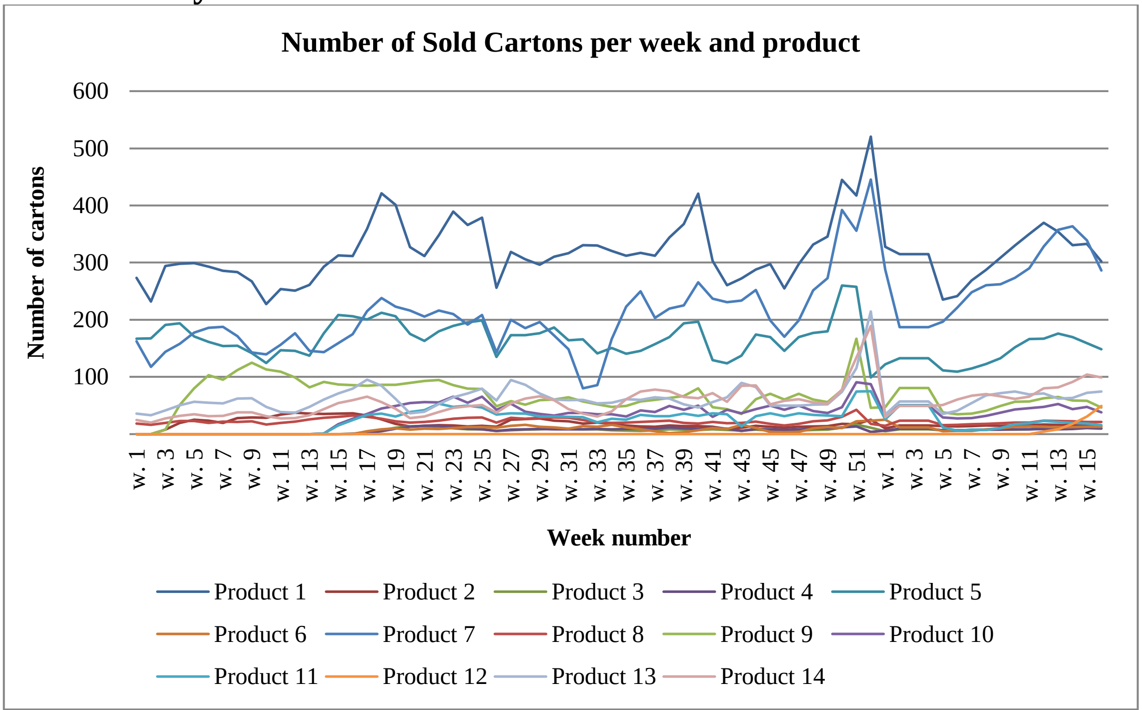

Figure 28. Customer demand in cartons sold, against production weeks illustrated with product types produced on the line.

From Figure 28 we see the customer demand (y-axis) quantified as the number of cartons against the week number of production (x-axis). Many product types are sold well below the current capacity of production, while there are 2-3 varieties that sell a lot of products per week, shown as the three main varieties (top lines). The remaining products are sold in little quantities but are produced in large quantities resulting in an unnecessarily large finished goods stock of those products.

With these observations in mind, the simulation model and data gathered over the overall customer demand proves that there is enough capacity on the production line to produce all 14 varieties, and that only a week's worth of finished goods stock of each variety is needed to meet customer demand. Although the calculation for coverage days in the finished goods stock is strictly calculated, there should be no major adjustment required more than a few days since the leveled production plan should help meet customer demand even during demand spikes and troughs.

However, a valid point to take note of is why should the production produce 210 boxes per day of a variety that sells a lot less? This problem could be resolved with a forecast adjusted toward a seasonal index. From past and future projected forecasts a factor may be derived that is multiplied with the minimum amount of products to be produced during a certain season, so as to adjust the forecast for high-volume and low-volume products to avoid overstocking and understocking of each respective product type.

Depending on how diverse the customer demand is for short periods (e.g. weekly), it may not prove useful to have a seasonal index for the poorly selling goods, since when customer demand increases it will instead be possible to ship from the finished goods stock. However this depends very much on how often the customers demand fluctuates for these product types, making the Assemble-To-Order strategy suitable for poorly selling products, while the Make-To-Stock strategy is suitable for highly sold products. It may be beneficial for the production planning department to review its Economic Order Quantity (EOQ) since the dilemma of safety stock and the amount of products to produce to forecast solves many problems at the case company today.

5.9.5 Production Leveling at Swedish Match

The production of large batches in order to mitigate changeover times is a relic from previous production strategies which is especially true for the case company studied.

Swedish Match today produce many of their products in a Make-To-Stock fashion, however from this case study the evidence suggests that the company should shift their production toward an Assembly-To-Order production strategy. Taking into account the varying levels of demand on a weekly basis, an Assembly-To-Order strategy may prove more useful for the company given its goals of short Time-To-Customer and high service levels with high product variety, however it does not fit in with the Toyota way of lean thinking and varying demand. In order for the company to successfully implement an Assembly-To-Order strategy, the production will need to be leveled, creating a production system utilizing a combination of an ATO production strategy and production leveling. Meier, D. and Liker, J. (2006b) and Liker, J. (2004) suggest that an ATO strategy fares well when using a leveled production plan, both in regards to the company producing and especially its suppliers.

Moreover, the bullwhip effect seems pronounced within the case company due to their large WIP and buffers further upstream from the customer. Since a large concern regarding shifting customer demand has been exclaimed, there has been an artificially grown need for large buffers in order to level the varying demand. However, the case company has not investigated underlying issues regarding uneven customer demand which could help in reducing large safety stocks and level the production in the long term, reducing the bullwhip effect observed within the production process itself and possibly toward outside stakeholders such as suppliers.

However, for the case company's situation, this hybrid production strategy approach may only work once the case company moves the CODP further down the production line (see chapter "5.3 Placement and Analysis of the CODP").

5.10 Production Management at Swedish Match

Despite the prominent advertising of company goals and performance indicator measurements of increments ranging from weeks to months posted on boards throughout company premises, there seem to be some noteworthy problems within the organization regarding the management of decisions and working approach permeating all levels of the company pertaining to the production process and its efficiency and flexibility.

5.10.1 The "Leanness" of Swedish Match and its Production System

As compared earlier, the SMPS and TPS share similarities within different organizational areas. From this it would thus seem reasonable to conclude that Swedish Match have taken steps to implement a lean-philosophy within their organization. While true to some extent, from observation the company seems not to have taken steps, and those steps they have taken have only been partially implemented. An example of a step implemented fairly well is 5S, where company offices are to be clean with all supplies being put in assigned places. However, in the scope of the production process, the nature of the production process does not require tools to be ready at a certain table or near a machine (with few exceptions in mind). Repairs and changeovers are often handled by production staff dedicated to the tuning and repair of machines, as well as other personnel such as electricians. The machines are otherwise operated by production floor staff which are knowledgeable in less complex changeover operations and overall operation of the machine.

On the other hand, there are several examples of lean principles which are both mentioned and not mentioned within company goals and performance indicator measurements. One such prominent principle is *Kaizen*, the principle of continuous improvement. The company claims to implement *Kaizen* proficiently throughout the organization, dedicating meetings to bringing forth ideas to improve upon current state production. However, from this case study's observations it is evident that the principle is applied but not executed efficiently. In this respect it is important to note that dedicating time to a lean principle does not automatically provide the company an additional point on the Lean-scale as has been stated by Liker, J. (2004). The effectiveness of *Kaizen*-meetings is crucial for the principle in itself to function. If a continuous improvement meeting is inefficient, it should be of priority to improve the *Kaizen*-meeting by implementing *Kaizen* on the meeting itself.

Evidence of the lack of efficiency when it comes to meetings and continuous improvement surfaces when comparing production improvement project results and the general cognizance among production improvement/development staff that a lot of improvements are implemented too inefficiently. Due to the apparent disengagement of production improvement staff and management leadership, it is evident that capacity losses of production lines as shown in the simulation results are of no surprise. On the other hand, the company has recently taken steps in order to investigate the plausibility of increasing flexibility of the production lines, however focus has clearly been on the wrong end of the spectrum when beginning a lean transformation, since problems with management have been ignored when in fact the problem lies within the utilization of available production time. Lean production focuses to efficiently make-do with resources currently available and build upon them when expanding, while production staff experience the company as investigating opportunities to invest themselves out of a problem rather than make the process more efficient and save on costs.

To conclude, Liker, J. (2004) recommends per the Toyota Production System, that the lean transformation should begin with upper management and work its way down. Without the support of upper management, a lean transformation is near impossible to perform and most implementations of principles remain inefficient or ignored as has been shown in the present case study.

5.10.2 The Need for Standardization

These points tie very tightly into the concept of standardizing work tasks and protocols. From the results of the simulation study and the underutilization of available production hours, it became evident that there was no standard regarding shift length. The premature shift length was however not of fault for the production line, but rather the production planning and lack of flexibility within “Department 2.” Naturally, once material supply to the production line had ended for the day, the line had to shut down long before the end of the day which resulted in a loss of many available production hours.

Fault detection, reporting and prevention are also areas which lack a prominent company standard. An abundantly large portion of data collected for the simulation study was incomplete, not reported, or had to be combined with irrelevant data in order to make educated guesses and calculations to retrieve data which should have been logged to begin with. For the company to continue *Kaizen* there is a requirement for study of the production processes, from which a simulation model and VSM are of great help, albeit with the caveat of receiving the correct and complete data. As has been previously mentioned, *Kaizen* is something which has been partly implemented but inefficiently executed, which this observation further provides support for. Without proper fault reporting, rectification and following up, there may be great difficulty in finding common ground to improve upon.

Not only have there been an underutilized amount of available production hours, a lot of the time lost has also been due to failures of machines and electrical peripherals. Many of these failures seem to repeat themselves across production weeks, which seems to indicate that *Jidoka* and Preventive Maintenance in general both need to be investigated in how they can be better and more efficiently implemented within the company. This is especially true when observing the way “Department 2” works and how the volumes of snus mixture to be mixed are decided. The department relies fully on a functioning scale, however this scale is said to differ with around 40Kg on batches of around

160Kg, causing large variations in volumes of product mixture. This affects the production line greatly as they expect to produce a certain amount of products using the expected volume of the mixture, but may end up being short of or overshooting the production plan goal, causing a premature closure of the production line or the false need for overtime.

This continues to management as the production manager receives reports on production status for the day. There is an indication that management must also improve and standardize their work tasks regarding the follow-up of errors and improvement in production, while basing their goals in the long term rather than the short term to resolve production problems.

6. DISCUSSION

6.1 Relating to Other Research

As per Helleno, A.L. et al. (2015), Abdulmalek, F.A. and Rajgopal, J. (2007) and Schmidtke, D., Heiser, U. and Hinrichsen, O. (2014), simulation and VSM have proven to show promise when combined, regarding result generation, presentation and analysis of data. Despite the articles utilizing a combination of simulation and VSM in a similar way to one another with the exception of Solding, P., and Gullander, P. (2009), none of the articles found have managed to utilize simulation and VSM as has been presented in this study.

For example, the articles mentioned have all produced a VSM and simulation model of the entire production of their studies, while Lovelle, J. (2001) also mentions that an external mapping of the VSM should be conducted before an internal mapping should be focused on. In this study, although the methodology by Lovelle, J. (2001) was followed, a full VSM was created but this negated the need for a complete simulation model due to the VSM pinpointing the problem area, saving very large amounts of time. Moreover, the analysis of the VSM was done only after its completion, meaning that a different approach to Lovelle, J.'s (2001) methodology could be used due to the study's satisfactory result generation.

6.2 Expectations

It is important to note that the results in themselves present the possibilities of a new way to combine VSM and simulation and in their quantitative nature prove this with their validity. The unique combinational use of the tools in this study proves that the methodology is valid for the type of organization and production of study, but may prove disadvantageous in other circumstances with differing conditions warranting different results.

The study had from the beginning no expectations of the quantitative form of the results. It was initially expected that the presented results would stem from production specific parameters such as buffer sizes, personnel, cycle times and other specific data. However, the study resulted in very interesting and quite unexpected results pertaining to the organization and managerial decisions regarding the company's production - something which was not expected to stem from a simulation model. In this way, the study proved that a tool of which static results are expected is possible to open an investigation into dynamic areas of a company not related to the tool used in the first place. It can be argued that a VSM would be more suitable to generate the organizationally- and managerially-related issues found in this study, however without a simulation model these problems would not surface given the detail required to uncover the base for the investigations that resulted in the presented issues.

6.3 Simulation Execution

Although the simulation model proved valid and provided relevant, accurate and satisfactory results, the method of constructing the simulation model and all it entailed contains points of discussion and further improvement.

6.3.1 Data Gathering

Great difficulties were had in gathering correct and reliable data when creating the VSM, but especially when creating the simulation model. Due to the company's logging software providing underwhelming data in regards to accuracy and reliability, a lot of data gathered was in qualitative form from relevant production staff. Qualitative data may prove just as useful as quantitative and concrete data, however in this situation the data had a large disparity in its reported integrity. For example, the changeover time for a certain machine could for one operator be interpreted as 10 minutes, while for another operator 45 minutes. The problem proved to lie in the definition of what a changeover is and the company's lack of standard regarding this matter.

Even the quantitative data collected through the company's logging software, among other sources, proved unreliable in many cases. The problem seemed not to lie in the logging software itself but rather the implementation of the logging software and how it was handled. Early on in the case study it was found that all the failure data was incorrect in regards to failure reasons, although it was possible to salvage the correct failure times. Despite salvaging the correct failure times and disregarding the failure reasons, changeover times were discovered not to have been separated from failure times in the logging software, ultimately discrediting the failure times used. Moreover, the failure data also incorrectly reported the number of failures for a specific failure type, as well as containing an "other" category of failure reasons, making it impossible to distinguish which of these times in the "other" column actually contributed to a real failure or just a warning signal in the software. This further perpetuated the notion of receiving grossly incorrect input data for a simulation study.

6.3.2 Verification and Validation

Investigations were made to validate production completion time for a static number of produced cans, but the variation in completion time was too great in the real data which did not yield trustworthy validation results. The phenomenon of a high variation of completion time to cans of snus produced is likely to depend on factors within the production environment outside the scope and control of this case study, which is therefore not included in the simulation model. To conclude, this validation method may have seemed sound at the time, however a new method was in need which resulted in the method reported in the validation results (see chapter "5.5.2 Results of the Validation").

The new validation method, although accurate to around 7% compared to real world data, provides an opportunity to further improve the model and raise the accuracy. In order to do this, special cases within the production environment would need to be taken into account, as well as a multitude of human decisions which by nature are exceptionally difficult to simulate. The method of validation pursued in this case study can be put up to scrutiny given the failure of the previous validation method, however given the starting conditions and the data as well as time available, the validation method proved effective given the accurate results of the simulation. This is especially true when taking into account (Sargent, R.G.'s (2013) Figure 11 illustrating model confidence versus cost (see chapter "2.7 Verification and Validation of a Simulation Model"), which in this case was the case study's time frame.

To conclude, the validation method which was settled for provides more reliable results since the normalization of real-world data of the previous validation method did not yield a fair result due to unsatisfactory "interpolation" of data to compensate for missing production data. Therefore, for the new method, the production data remained unchanged without the need for interpolation, and the validation was instead run for a fixed time which enabled the comparison of products produced in the simulation contra reality which ultimately proved to be the more accurate and fair validation method.

6.4 The Chosen Simulation Object

The VSM study was a good foundation for narrowing down the critical area in need of a simulation study, while Swedish Match guided the study to a more granular level regarding specific production lines. As such, the VSM could theoretically have delved into the granular level of identifying the most critical production line, however a VSM would then have to be made over all of the relevant production lines producing the product group of study which was not regarded as a task that could be completed with satisfactory results within the case study's time frame.

6.5 Bottleneck Detection

There were no specific bottleneck detections used as had been researched in the literature study due to the nature of the production and helpfulness of constructing a VSM and simulation model, however a combination of various observations were used helped in narrowing down in which department the bottleneck was present. The production was of such type that it was easy to identify the bottleneck without using any advanced methods or equations.

The bottleneck detection methods' "Arrow," "Longest queue" and "Waiting time," were used loosely. To explain, the exact data for each method was not necessary since it was enough to study the production with the bottleneck detection method concepts in mind. For example, it was easy to see that the buffer before the identified bottleneck was much larger than the buffer after, which by the definition of "Longest queue method" defines this as the bottleneck. Thus it was not necessary to count the exact buffer sizes to see this.

However, as described in "5.9.1 The Current Production Strategy," the production can be seen as having a shifting bottleneck since there are times when "Department 2" has not produced enough products to deliver to "Department 3." In these cases "Department 3" gets starved and "Department 2" is the bottleneck instead of "Department 3." In a way an adapted form of Bank's Methodology (Banks, J. (1998)) was used in combination with the conducted VSM and the simulation model as support to further investigate the issue on a granularity level in which the VSM and simple capacity calculations could not be as specific.

For the type of production studied and the type of data available for analysis, an overview of the VSM to identify an area to start further analysis felt most relevant, as the scope at that stage of the case study was too large to apply any of the researched bottleneck detection methods on. The process time for each department was calculated which led to the "Department 3" surfacing as the bottleneck in regards to product flexibility. From that point on, focus was moved from the VSM to the simulation model which provided a better and more detailed of where the bottleneck was exactly.

6.6 Delimitations

For the simulation model to have an adequate confidence while not investing too much time for diminishing returns, some delimitations had to be put in place. One such example is the failure data for the machines in “Department 3.” When a changeover happens in the simulation model, any failures present on the machines while a changeover is due will abort so that a changeover can begin. In a way this reflects how the process of changeover and failures overlapping would play out in real life, however it assumes that the machines are repaired instantly as soon as a changeover is due during their failure. This results in a skewing of Overall Equipment Efficiency (OEE) data for the machines since failures are artificially stopped for a changeover, however this skewing is regarded as negligible due to its low chance of occurring. For further improvement work, it is recommended that the case company employs a company-wide standard policy of reporting OEE data in order to more efficiently and clearly benchmark current performance against production goals.

Another delimitation is the stop times for the rest of the machines on the production line, downstream from the machines described in “Department 3.” This is due to the company’s lack of logging of stop times for these machines. An argument could be made to conduct a time study on these machines in order to construct a rough statistical distribution from manually collected stop data, however this was regarded to be outside the time frame for the case study and was thus abandoned. On the contrary, the machines downstream are capable of a capacity far larger than the previous machines, so stoppages on this part of the line could be seen as negligible. However, for as much accuracy as possible and for future improvements, it may be beneficial to collect stop data and include this in the simulation model.

Furthermore, there is a strong suspicion that changeover times for the machines described are blended into the stop times for the machines when observing historical failure rates. This affects the statistical time distributions put in place to simulate the machine’s failures considerably, since for best results it is recommended to divide the stop-times from the changeover times in the historical failure data. Since the stop reasons are not to be trusted due to the incorrect reporting of failure reasons by the operator, it is impossible to distinguish when a downtime relates to a changeover or failure. This fact clashes with the logic of the simulation model, since the model contains a special changeover routine which runs for a certain time depending on what product variety enters the production line.

With the suspicion that the statistical time distributions for the failures of the packing machines also contain changeover time, this results in that the programmed changeover routine contributes to an extra changeover time, effectively risking that the failure data for the packing machines could be as long as a changeover time. This may lead to an incorrect simulation completion time, changeover time and finally simulation output. From this, a delimitation has been appointed that defines the failure rates programmed to the packing machines as "true" failure rates, regardless of any suspected embedded changeover times. The question remains whether there is a suitable way to filter out the changeover times from the failure rates, but given the state of data logging in the case company this seems an impossible task until a categorization of stop times is properly implemented and new failure- and changeover data can be collected for future analysis.

Moreover, a simulation model of “Department 2” was built, however ultimately it was abandoned from the case study due to its difficulty to simulate. Many steps in the department rely on human interaction and unique decision making for one-time circumstances, making it increasingly difficult to simulate properly. In addition to this, the department also relies heavily on the large cold storage of partially completed mixtures of product. Since this cold storage interacts both with the delivery department of finished goods and “Department 2,” the complexity of the cold storage ultimately forced the case study to abandon the simulation of “Department 2.” For future study it would however be very beneficial to continue simulation on this department since it ties in so closely with the flexibility of “Department 3.”

Furthermore, the flexibility of “Department 2” with its assortment of machines could also be investigated in order to further optimize the flow of materials throughout the production process and also act as support for future improvements to the flexibility of the production line studied. To achieve a satisfactory simulation model of “Department 2,” the company would need to first thoroughly implement a set of work standards to how decisions are made and how work in the department takes place. An abolishment of human interaction is not recommended, however a standardization of the interaction is crucial in order to minimize the amount of variables to take into account for when constructing a simulation model.

6.7 Sustainability

Although it is possible to incorporate sustainability within a VSM and a simulation model as a possible investigative factor, it has not been done in this study. However based on the results of the study, it may be possible to demonstrate a future improvement of the company's efforts towards a more sustainable production within sustainability’s economic, social and environmental aspects.

6.7.1 Economy

To begin with, the economic aspects of the company’s sustainability could be improved based upon the results of the study regarding the utilization of production hours. By fully utilizing the production hours as has been mentioned in the study, substantial improvements to the following points can be made.

The production has substantial waste of processed product as a result of bad production- and capacity planning. This in turn means that a lot of the economic calculations that have been made to deliver raw material for the production is gone to waste, as well as any monetary investments made to pursue the processing and transportation of raw goods to the factory. In essence, a quantity equaling the ratio of waste within the production of the raw product which is bought could in theory be thrown away at the point of purchase. Since the production- and capacity planning is of an unsatisfactory standard, this leads to an underutilization of production hours and capacity leading to substantial waste of raw product.

Another economic aspect is the mindset of the company and its efforts to implement continuous improvement. As has been mentioned in the study, the company claims to implement continuous improvement, but tends to invest themselves out of problems rather than improve the current production in order to optimize and make the current state process more efficient. A lot of monetary assets are therefore prioritized for buying appliances and machines which carry an over capacity based on the current capacity and customer demand.

It is also evident that the evening shift is not as efficient as it could be, partly due to inadequate production- and capacity planning. As a result, the production hours are not fully utilized which means that the production lines usually stop long before the actual production time is over. This leads to the operators leaving to go home early, but get paid for the full shift.

6.7.2 Environment

Despite the economic issues mentioned, there is a possibility of better tackling the issues of a sustainable production's environmental aspect. One holistic idea is that a better production plan should yield a better utilization of available capacity and therefore help to rectify the following points.

To begin with the mentioned waste of raw material within the production, the machines used to sow the crops of tobacco plants can be seen as currently being over-utilized, causing unnecessary amounts of CO2 emissions. It can be questioned if pesticides are used for the cultivation of tobacco plants, and if they are, these pesticides would then be used unnecessarily causing further effects on the immediate environment around crops. However, the use of pesticides is undetermined.

Within the factory's production process, certain additives can also be seen as being used in a wasteful manner due to the processed material being thrown away due to the capacity planning issues mentioned earlier. These additives are also unnecessarily transported to the factory and bought in amounts that are not needed, causing even more CO_2 emissions that may be unnecessary and monetary assets used in vain.

The disposal of the processed product containing additives also raises the question whether this has an impact on the immediate environment, whether it is land, water or air. In any case, the waste product could be destroyed rather than filtered, but still raises the question of how much impact the CO_2-emissions of waste-transportation vehicles impacts the environment. The better the capacity utilization, the less waste is produced, and the less trucks need to transport the waste to dispose of.

Even the environment outside the factory can be affected. Waste water needs to be directed to the nearest water treatment plant which increases its capacity needs. The air around the immediate area around the factory can be affected by the odor of chemicals and tobacco, something which may not be appreciated by the public in immediate proximity of the factory. Given that the Gothenburg factory is situated in a central and densely populated area of the city, this could indeed affect the environment although maybe not to a substantial extent.

A final note can be made on the machinery and electrical efficiency of the factory. Old machines contribute to a lower efficiency rating both in production but also in energy efficiency. With a better production plan, there is a chance that machines could be run more efficiently depending on electricity prices. An investigation into agreements with wind-, solar and hydropower companies could be made in order to generate electricity from sustainable sources if it is not already done today.

6.7.3 Social Aspects

From a social point of view, the areas of the production discussed within this section could be amended by implementing better work standards, as mentioned earlier in this report, and possibly complementing these with various certifications appropriate for each area discussed.

It is possible to say that the production is very noisy, especially in the packing department, since most processes within this department function on pressurized air. An investigation into minimizing the amount of pneumatic processes and converting what can be converted into electrical power should be made in order to better the working environment for operators.

The internal logistics of the production also present some danger in the form of fork lifts which often transport materials for the assembly of products. The areas in which the fork lifts operate are the same as the operators walk, which urges caution when working in the production area. If possible, the separation of walkways from fork lifts would minimize the risk of injury and collision, although statistics of work related injuries and accidents are unknown.

The preparation department's involvement with additives of an explosive or corrosive nature also prompt some concerns regarding employee safety, with a strong emphasis on adhering to present safety standards. In addition to the handling of dangerous chemicals and materials, the smell of the department could be rectified by implementing a better ventilation system.

Moreover, in the milling department, the process of unpacking large cartons of raw tobacco presents immediate danger to the operator conducting the unboxing, due to their close proximity to the moving machinery of a crane, the handling of a sharp knife, and extremely heavy batches of tobacco falling 1-2 meters only 30-50 centimeters from their body. The department also conducts inspections of storage silos for raw product which presents immediate danger to the inspecting operator due to the lack of oxygen the lower down in the silo they choose rappel.

Lastly, in regards to the farmers caring for the cultivation of tobacco plants, by reducing the amount of raw product waste, farmers could more efficiently utilize their land either for other crops, or not have to work as long as they do due to the amount of product that is thrown away.

7. CONCLUSIONS

Whether simulation or VSM brings most value to a production improvement study is difficult to quantify given that both tools have their respective advantages and disadvantages. This study managed to show how simulation and VSM can support organizational improvements by combining both tools for successful result generation, however the specific benefit of each tool that was gained in relation to the frequency of their use is debatable. In this sense, the simulation model yielded the most value due to its detailed results and opportunity to open the study for deeper investigations into problem areas within the organization not pertaining to simulation per se.

With this in mind, the study has shown that the tools are very useful if they are to support organizational improvements. As an example, the VSM saved the study an enormous amount of time by proving itself tremendously helpful when narrowing down a problem area of the production to focus on. For this reason, it could help a company decrease its budgeted project costs when implementing a lean transformation due to the filtering of unnecessary project or process steps. A greater overview of the production and proposed improvements is also possible in order to garner the attention and confidence of management for further support regarding organizational improvements, meaning improvements can more swiftly be implemented with reduced cost.

A simulation model can not only provide concrete results regarding production parameters, but also point out improvements needed within the organization and its work procedures in order to successfully implement an improved future state simulation. Because of this, a lean transformation may prove easier for an organization to implement with a simulation model due to the theoretical evidence it can provide regarding if a proposed improvement will be useful. Both VSM and simulation can therefore support organizations on various levels of detail, whether it entails a general overview of a planned improvement, or a detailed simulation of what needs to be implemented before a project commences for optimal results.

The case study has come to the realization that there is no final conclusion whether one tool is better than the other; instead, compared to previous research, it provides evidence that the tools prove useful both used separately and in combination. It further proves that these usage scenarios also depend on the scope and detail, desired output, as well as other factors such as presentation and understanding of a conducted study.

The conclusions that could be drawn from the case study's production was that "Department 3" has the largest influence on the flexibility of the production because of its long changeover times. It could also be seen that "Department 2" impacts the flexibility, however not because of long setup times but because of large batches and a long processing time. Despite this, the full extent of "Department 2's" impact on the overall flexibility of the entire production process is unknown and warrants further investigation.

For "Department 3," a successful implementation of a leveled production schedule, coupled with a hybrid production- and suitable logistics and production planning strategy should yield a smoother production with decreased work in process and lowered finished goods stock with a major increase in flexibility. Moreover, "Department 2" should also benefit greatly from the employment of these methods in order to greatly increase the efficiency and capacity utilization of its machines, as well as reduce a very extensive amount of product waste.

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APPENDIX

APPENDIX A

Department Name					
	Ordering				Comments
Frequency					
Volume					
Electronic/Analogue					
	Deliveries				
Frequency					
Volume					
	Buffers				
Name					
Max Size					
Current Size					
Time in Buffer					
	Processes				
Name					
Nr. of Operators					
Shift					
Time per Shift					
Cycle Time					
Process Time					
Uptime					
Setup-Time					
Warm-up Time					
MTBF					
MTTF					
MTTR					

Figure I. A sample of the questionnaire used to gather data for the VSM.

APPENDIX B

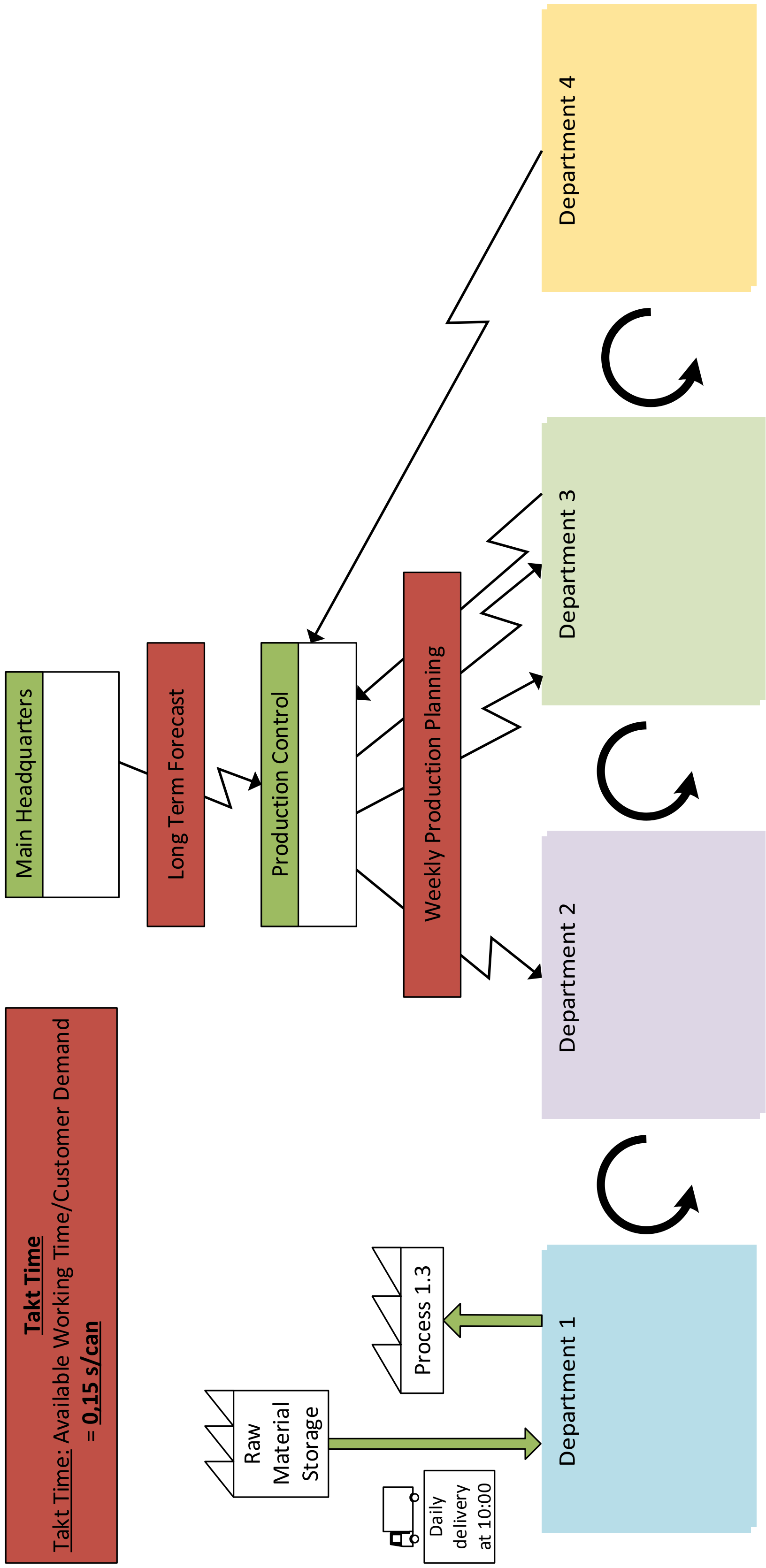

Figure II. A schematic illustration of how the departments interact in the VSM.

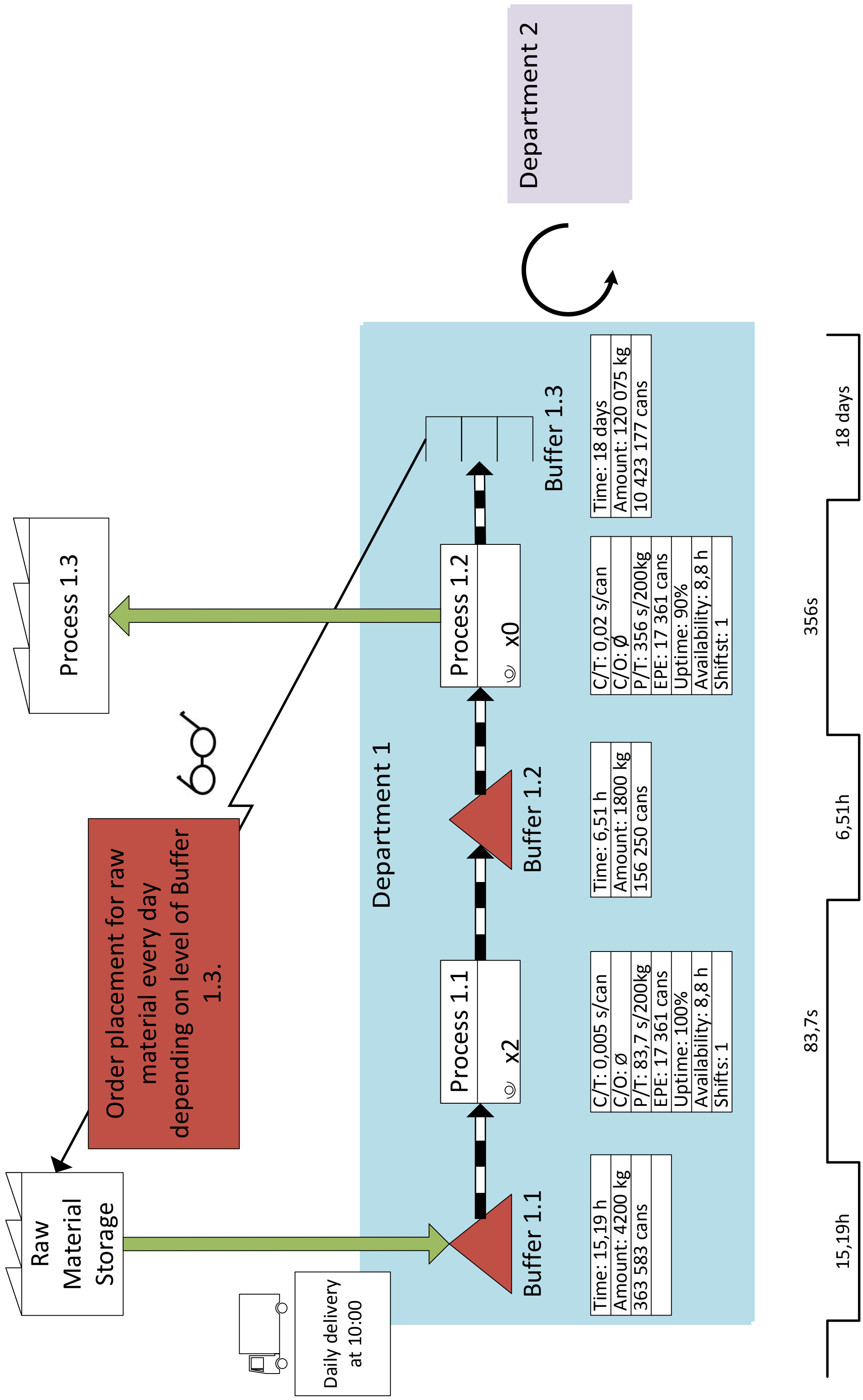

Figure III. The VSM of Department 1 in more detail.

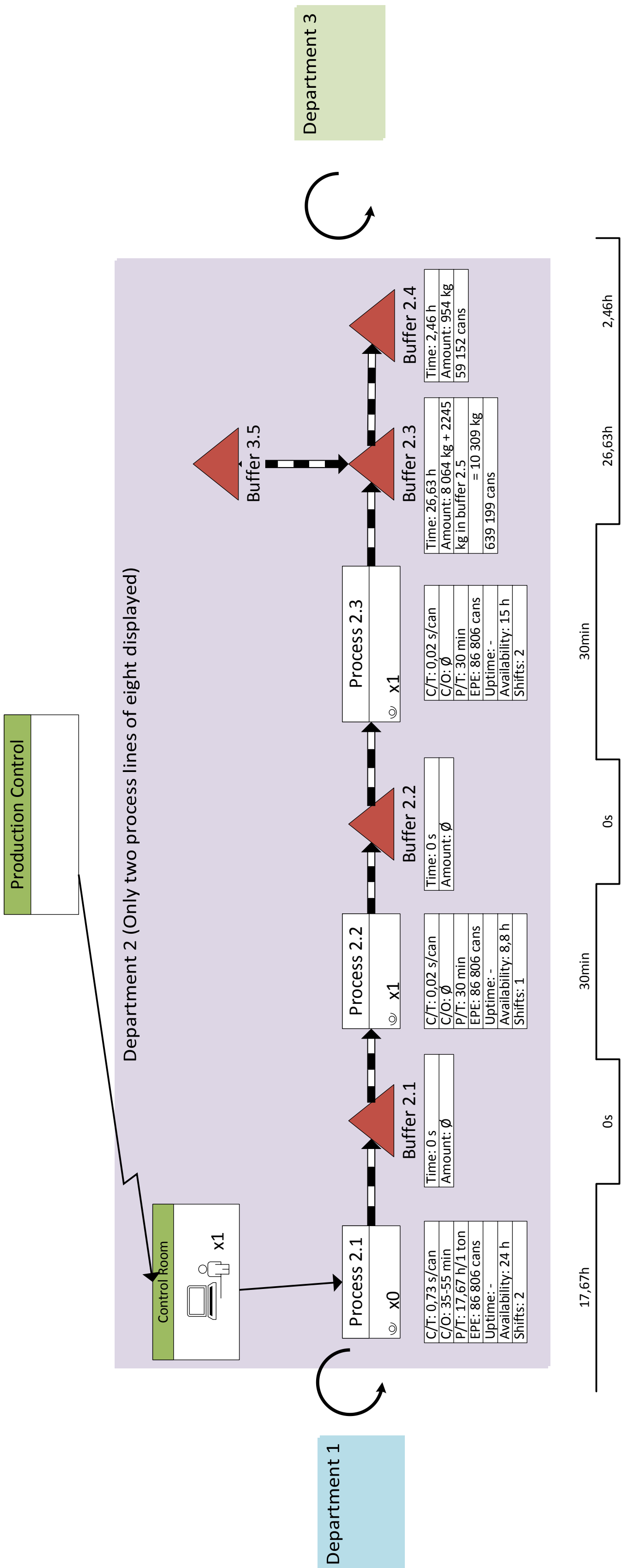

Figure IV. The VSM of Department 2 in more detail.

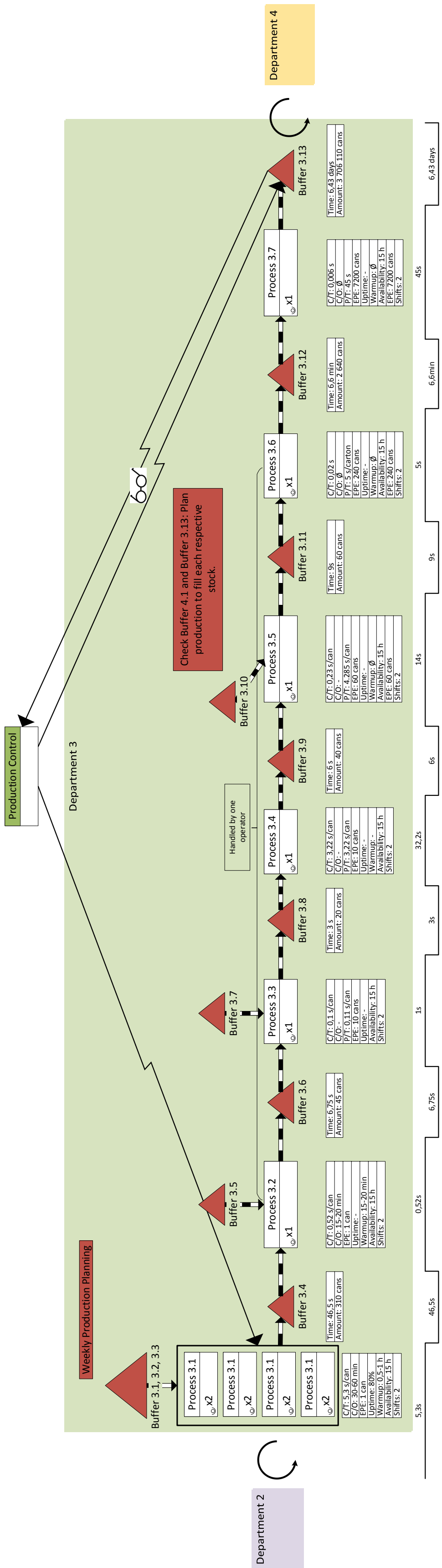

Figure V. The VSM of Department 3 in more detail.

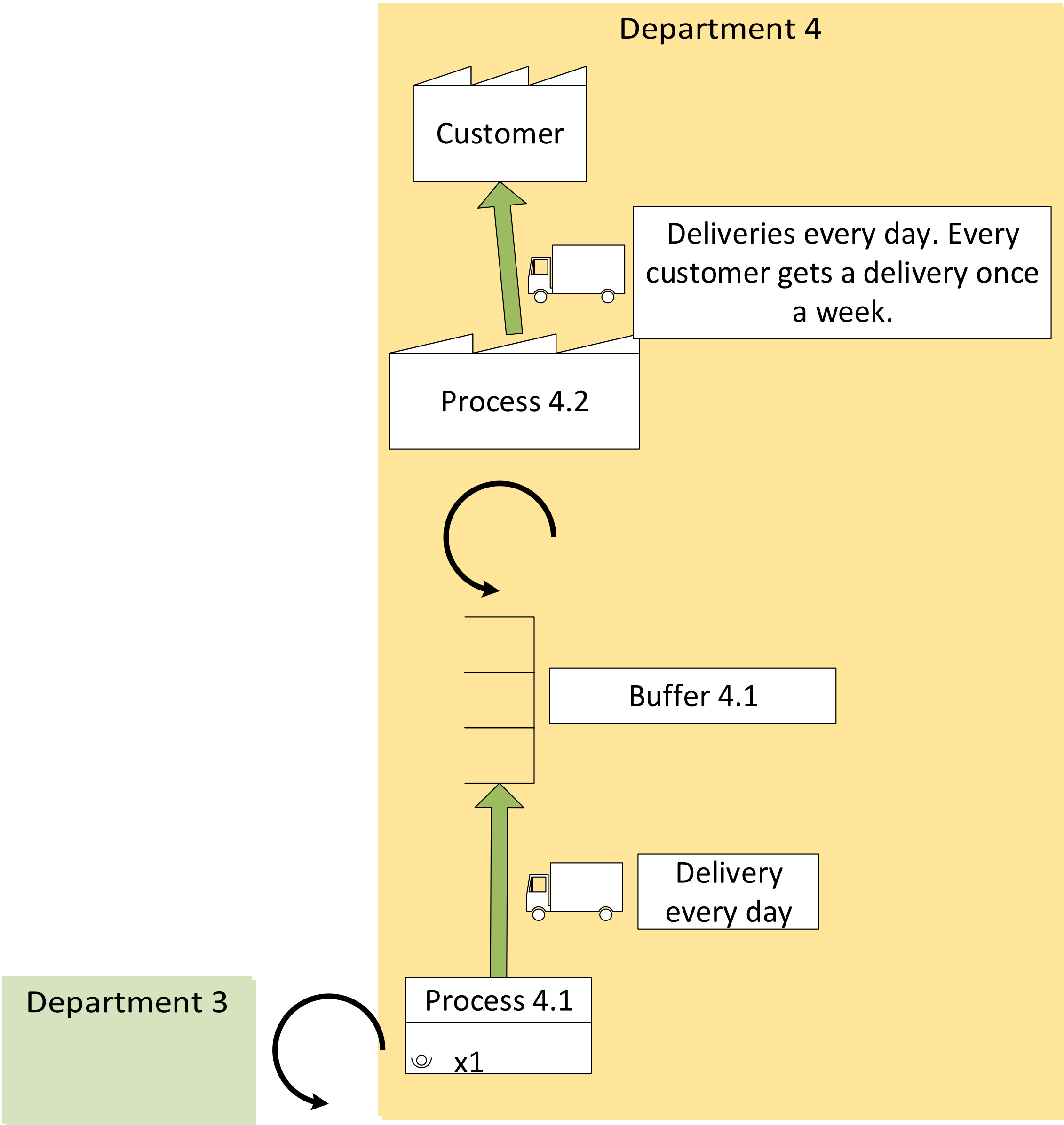

Figure VI. The VSM of Department 4 in more detail.

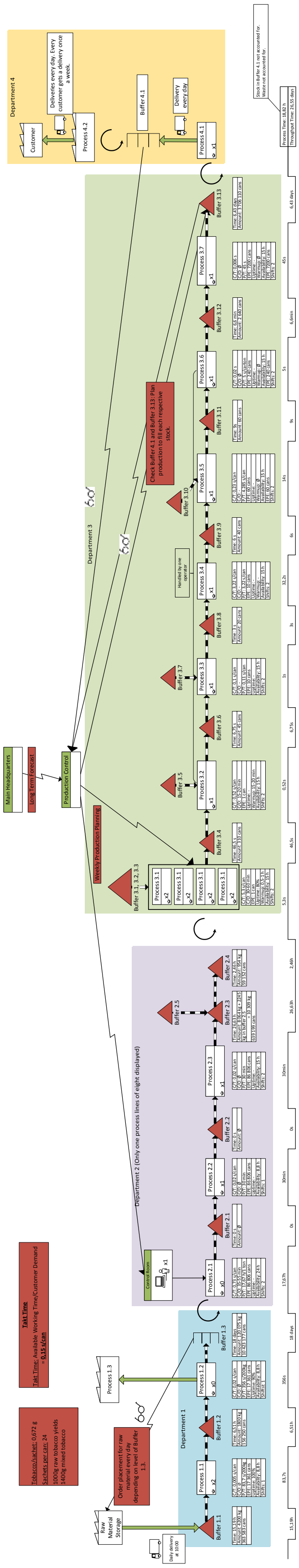

Figure VII. The current state VSM shown as a whole.

APPENDIX C

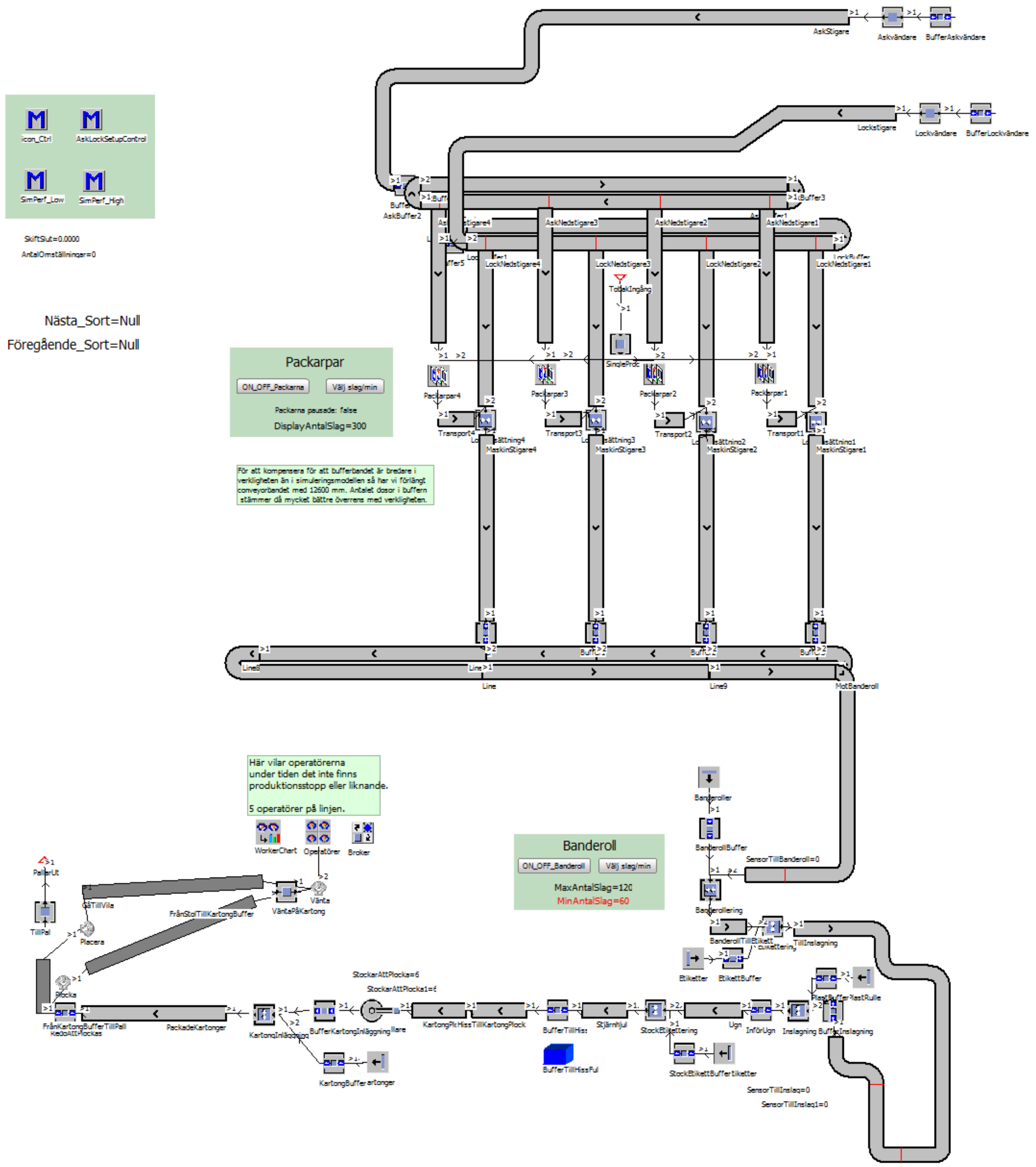

Figure VIII. The simulation model illustrating the current state production.

APPENDIX D

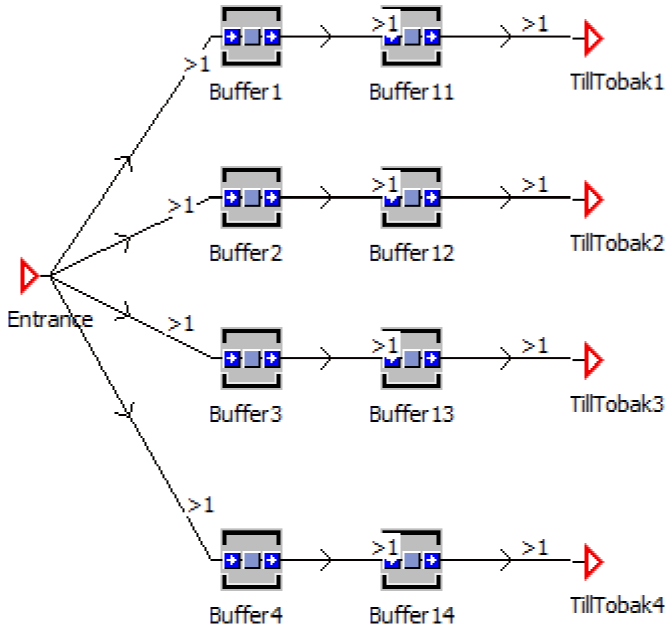

Figure IX. The simulation model's underlying logic for Experiment 1.

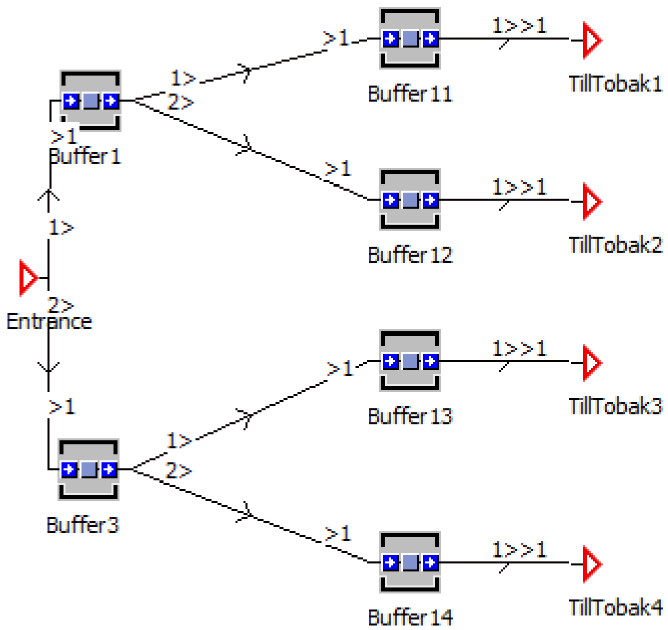

Figure X. The simulation model's underlying logic for Experiment 2.

APPENDIX E

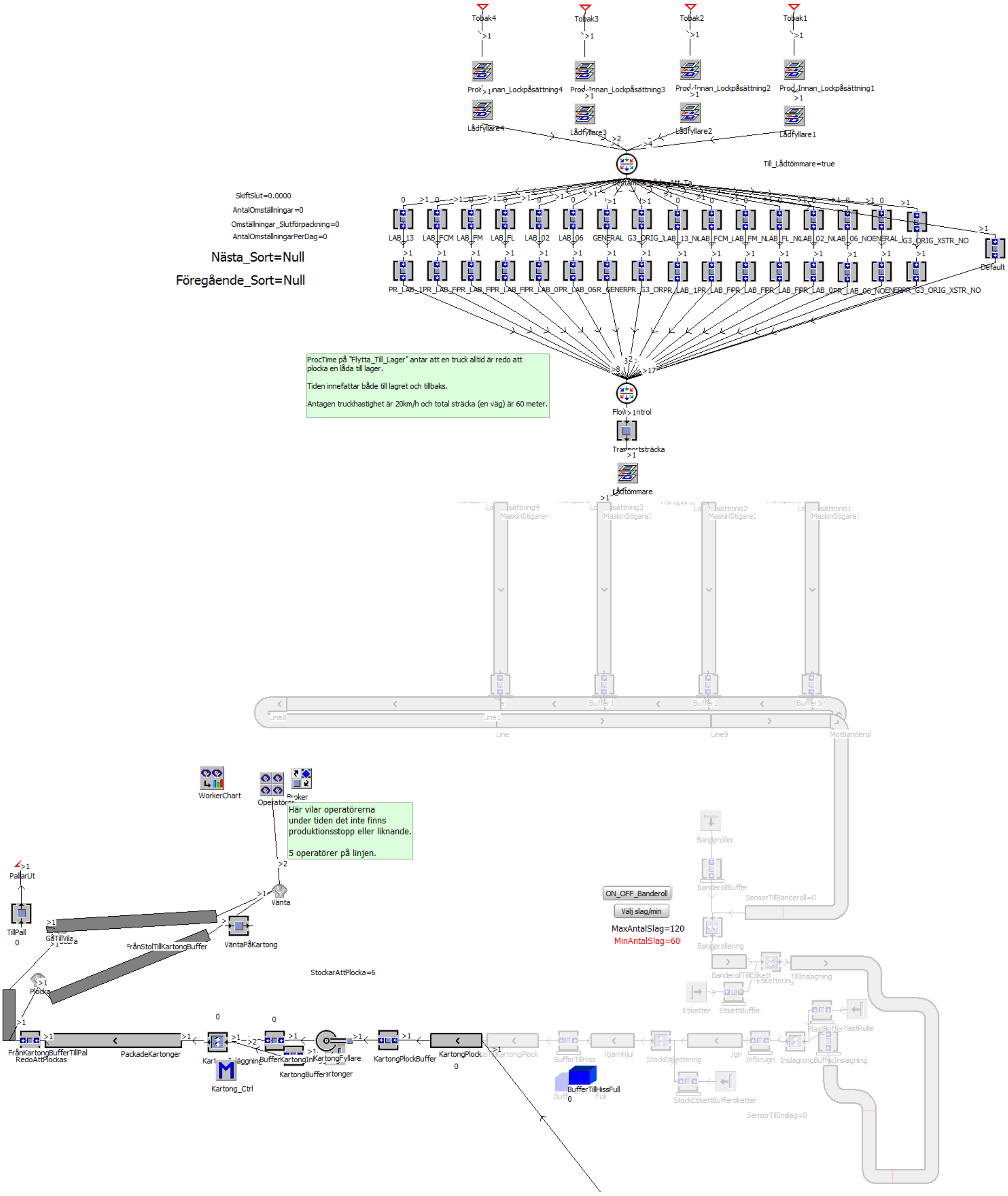

Figure XI. The simulation model of the future state production with suggested improvements, in combination with Figures IX and X.

APPENDIX F

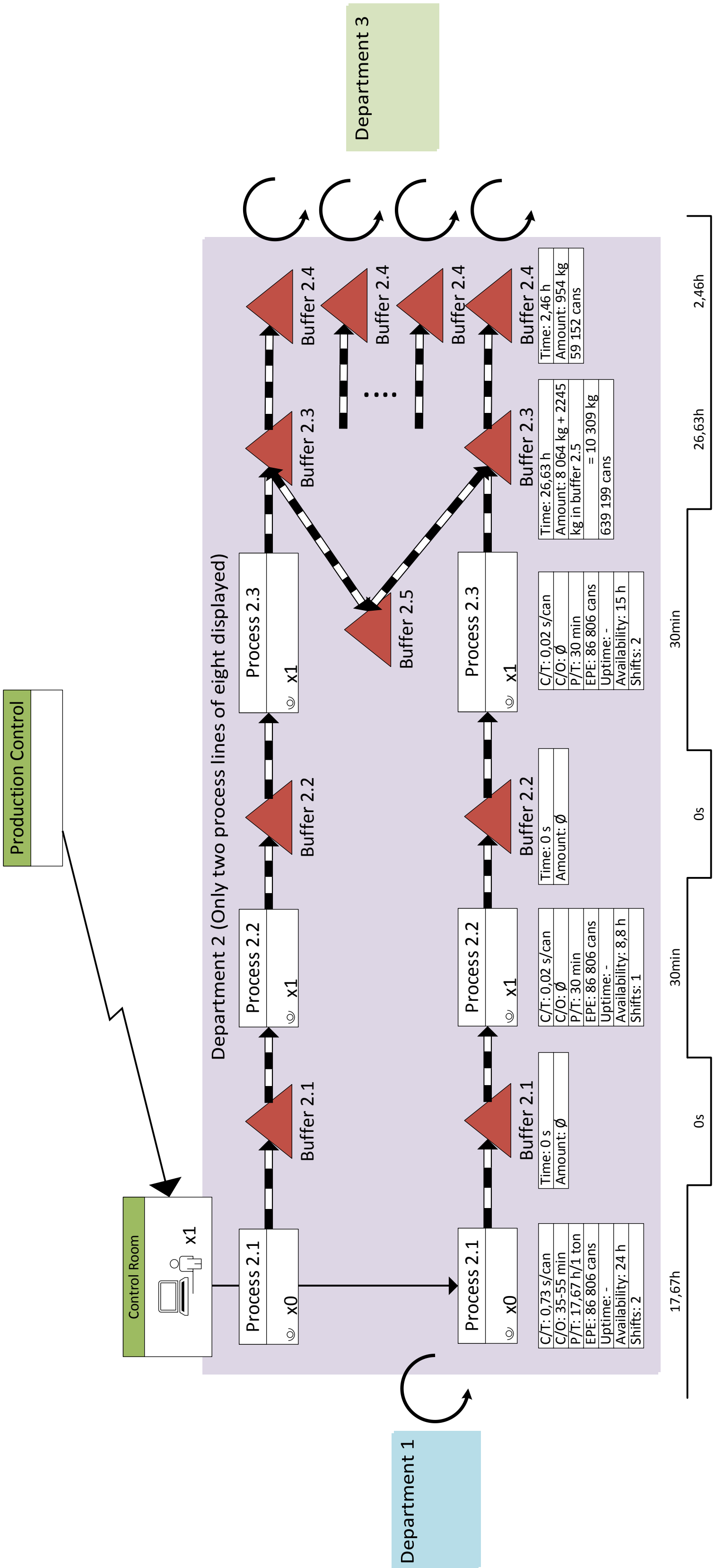

Figure XII. A more detailed view of the future state VSM of Department 2.

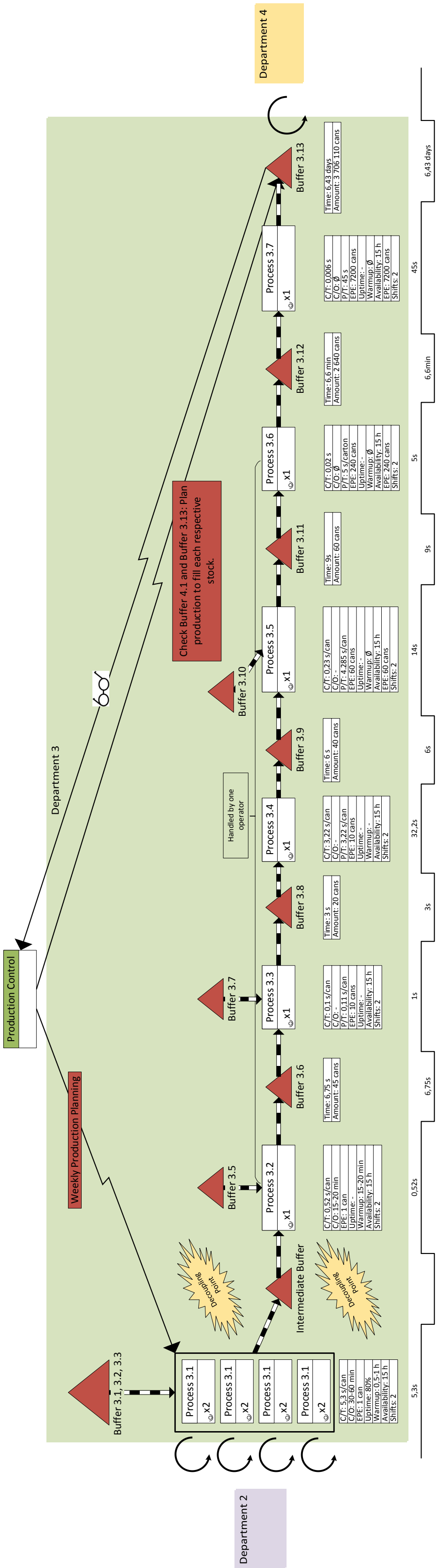

Figure XIII. A more detailed view of the future state VSM of Department 3.