Waste Analysis on a Production Line - A Case Study

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Abstract

This study aims to assist Swedish company Clemondo AB in reducing waste in production, where the goal is to determine where waste appears as well as make suggestions for potential improvements, which are presented as Key Performance Indices (KPIs) and minimized manufacturing costs. Citation chaining is used to retrieve extant literature, while other productions and process-related information are gathered through observations and discussions. The production and its value-creating activities are modeled through Environmental Value Stream Mapping (EVSM). Factors causing downtimes and other waste are identified via a Production Performance Matrix (PPM). The results show that actual production times differ from the planned times, which causes waste in terms of time consumption and energy consumption. Moreover, downtimes are present and are normally caused by the same factors. Wasted materials in terms of blend spillage and discarded packaging materials are also present in production. All waste ultimately increases the manufacturing cost, and it is concluded that the company spends approximately 13 000 SEK more on each batch production due to existing waste. In order to optimize production, and specifically to reduce waste, four KPI measurements are suggested for the company: (1) measuring all times in production including occurring downtimes, (2) frequently calculating OEE, (3) tracking material spillage, and (4) measuring energy consumption. Potential future studies include further investigating other areas in production where waste may be present, as well as continuously doing follow-ups to see how changes affect waste optimization.

Keywords: Sustainable manufacturing systems, Sustainable production, Lean production, Just in Time Production (JiT), Kanban, Waste, Environmental Value Stream Mapping (EVSM), Production Performance Matrix (PPM), Key Performance Index (KPI).

Sammanfattning

Denna studie har syftet att vägleda det svenska företaget Clemondo AB i att minska på avfall och annat slösande i deras produktion. Detta fullföljs genom att fastställa vart avfall och slösande uppkommer, samt genom att ge förslag på förbättringar, vilket presenteras i form av Key Performance Indices (KPIs) och i minskade produktionskostnader. Citation chaining används för att hämta befintlig litteratur, medan annan produktions- och process-relaterad information samlas in genom observationer och diskussioner. Produktionen och dess värdeskapande aktiviteter modelleras genom Environmental Value Stream Mapping (EVSM). Faktorer som orsakar stillestånd och annat slöseri identifieras via en Production Performance Matrix (PPM). Resultaten visar att faktiska produktionstider skiljer sig från de planerade tiderna, vilket orsakar slöseri i form av tids- och energiförbrukning. Dessutom finns driftstopp som normalt orsakas av samma faktorer. Avfallsmaterial i form av blandningsspill och slängt förpackningsmaterial förekommer också i produktionen. Allt avfall ökar tillverkningskostnaden, och slutsatsen dras att företaget spenderar cirka 13 000 SEK mer varje produktion på grund av befintligt avfall och annat slöseri. För att optimera produktionen, och specifikt för att minska avfallet, föreslås fyra KPI-mätningar för företaget: (1) mäta alla tider i produktionen inklusive förekommande stilleståndstider, (2) kontinuerligt beräkna OEE, (3) spåra materialspill och (4) mäta energiförbrukningen. Potentiella framtidsstudier inkluderar att ytterligare undersöka andra områden i produktionen där avfall kan förekomma, samt att kontinuerligt göra uppföljningar för att se hur förändringar påverkar avfallsoptimeringen.

Nyckelord: Hållbara tillverkningssystem, Hållbar produktion, Lean production, Just in Time Production (JiT), Kanban, Avfall, Environmental Value Stream Mapping (EVSM), Production Performance Matrix (PPM), Key Performance Index (KPI).

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1 Introduction

The manufacturing industry has been on a striking development path ever since its origin, with heavy impact from the changes and development of society [1]. One crucial area that nowadays is more frequently adapted within the industry is sustainable production. This is because manufacturing companies are becoming more cognizant of their influence on the environment and society [2, 3], and the interaction between manufacturing processes and the natural environment has become an essential issue in decision-making. Sustainable development is the belief that social, economic, and environmental concerns should be concurrently and holistically managed in the development process [4]. Specifically, sustainable production describes the development of goods and services using non-polluting methods and systems that conserve natural resources and energy, are economically viable, are sound and secure for personnel, communities, and customers, as well as being socially and intellectually rewarding for all employees [5].

Problems with mass production in the Western world arose after the Second World War which considerably affected the automotive industry. Mass production of cars and other highly demanded products was based on *Taylorism*, a philosophy developed by Frederick Winslow Taylor in the early 1900s that mainly focused on standardization. This standardized approach resulted in rapid mass production, but also showed weaknesses in flexible production. Moreover, a new market with demands for more customized products and variants grew significantly which called for adaptation in the product industry. The ways of Taylorism could not keep up with the transitioning market as the production became highly unstable when attempting customized products since it led to reduced party sizes and an increase in lead times. The strategies of mass production companies were therefore heavily affected by the new market, as changes in production were of need to meet the demands [6].

Resource-efficient production began trending in the Japanese automotive industry in the 1930s. This developed philosophy later became referred to as *Lean production* and was meant to face the challenges of demand and resource shortage. This production method originates in Toyota Motor Company, as Toyota is the first documented company to guide and maintain lean production. Typically synonymous with lean production is the Toyota Production System (TPS), developed by Taiichi Ohno with assistance from Eiji Toyoda which supports a system of flexible mass production. The core of lean production includes eliminating waste and the development and management of production should take place in the same organization [6]. Within lean production, a highly common approach is Just in Time (JiT) production. JiT refers to the effort to manufacture products precisely when they are needed, in the lowest amounts possible, and with the least amount of waste of human and natural resources [7, 8]. By implementing JiT within an organization, inventory levels and costs may be significantly reduced, and the turnover has the possibility of increasing drastically. To realize the JiT principle, the pull system was developed, in which the movement of materials along the supply chain is observed in reverse, from downstream to upstream [8]. An example of a pull system is the Kanban system, which serves as a Material Flow Control (MFC) mechanism invented by TPS. It regulates the quantity and timing of the manufacturing of essential products and has been frequently used globally within manufacturing systems. "Kanban" is the Japanese word for a card, the concept utilizes cards to manage the delivery and/or manufacturing of components, goods, or raw materials [9].

Minimizing waste is a highly important aspect when implementing lean production in manufacturing processes. Specifically, waste in production includes all activities, times, and resources that are not creating value for the final product that is produced. Within manufacturing systems, there are typically seven types of waste. These wastes include overproduction, waiting, transport, extra processing, inventory, motion, and defects [10, 11, 12].

1. Overproduction refers to when production continues even after the desired amount is produced. Generally, manufacturing companies aspire to produce more than demanded in order to have a safety margin if products end up not reaching the criteria, but overproducing may cause an excess of products and result in an unwanted increased inventory. It is therefore essential that the overproduction is limited.

2. Waiting involves inactivity in downstream processes due to an upstream activity not being delivered as planned. This can be described as queuing and often results in activities that do not add value to the production.

3. Transport includes motions or movements of materials that can be considered unnecessary since it does not specifically add value to the production. These movements can be identified as transporting unfinished products of one activity to another and could lead to handling damage of goods.

4. Extra processing refers to activities that involve additional operating of products, such as reprocessing, rework, and storage handling. The reason for this occurrence is usually due to products being incorrectly manufactured, i.e., defects, or excess inventory.

5. Inventory within waste includes all inventory that is not essential to specifically meet current customer demands. Raw materials, unfinished, and finished products are all inventories that fit into this category and need to be limited as increased inventory requires both increased handling and storage.

6. Motion involves any additional motion done by employees and equipment that does not actively favor efficient production. These motions are mainly a result of poor production layout, but also due to reprocessing or surplus inventory. The additional motion does not add value to the production and is only a time-consuming activity.

7. Defects refer to products that do not meet the standards in order to satisfy customer specifications. Defected products may have incorrect dimensions, visual flaws, or even incorrect material properties [11].

The wastes listed are all crucial to consider when developing an effective production system. As they do not add value to production, they are unnecessary activities that take up time and resources, and ultimately, do not favor sustainable production. It is therefore important for a company to implement lean production, as it is a cognitive approach with measures and procedures that have the potential to bring about a lean model, and thus, a highly competitive state in a business [13].

1.1 Clemondo AB

Swedish company Clemondo AB manufactures chemical products tailored to vehicle care, hygiene, and cleaning. The company was founded in 1952 and has since been a market leader in their field, with its own brands Lahega, Liv, and Strovels being highly coveted within industries of, among others, automotive and healthcare. Clemondo has embarked on a path to become a sustainability-focused business and now focuses primarily on total solutions as opposed to individual goods. This focus engenders a broader perspective, in which not only the sustainability of their own operations are considered, but also how the company can contribute to the sustainability efforts of their customers in general [14].

One crucial aspect of their path to a more sustainable company involves their production. They have expressed concerns about waste being heavily present in the current production system, and therefore have desires to minimize waste on their production lines. Moreover, since this company is exclusively dealing with chemicals, their material release becomes highly relevant in the matter of environmental waste.

1.2 Problem Formulation

The aim of this study is to assist Clemondo in reducing waste in their production. With a basis in lean and resource-efficient production theory, the goal is to analyze waste patterns on one production line, determine where waste appears as well as make suggestions for potential improvements and strategies. The results of this study may, later on, be implemented in the production planning of the company in order to reduce waste. Specifically, the potential improvements developed from the analysis can subsequently be applied to the remaining production lines.

1.3 Limitations

This case study does not involve practical testing, implying that the results from the study are not implemented into actual production practices. Furthermore, any other lean theories and approaches not mentioned throughout the study are not taken into account. Since the study is time-limited as well as deals with a highly flexible production system, the analysis and optimization are simplified into an average overview of the production. Certain products are chosen for the analysis that contributes to this overview. This is because of a complex system being present due to numerous different products being produced, making it significantly challenging to cover the whole production. Moreover, the analysis exclusively contains fictitious values.

2 Background

Similar to many other companies that produce their own products, Clemondo AB also receives deliveries of raw materials and other equipment before the actual production of their products can begin. In this chapter of the study, descriptions of the company's products are included along with an overview of the company's entire production as well as one particular production line.

The overall production planning of a company lays the foundation for how well a company maintains its goals and thus its prosperousness. Whether or not the company is able to employ strategies such as JiT is completely reliant and determined by a company's overall production planning [6]. How conscious line operators are of the impact of their work and how successfully a production is adapted to procedures like JiT, however, can be impacted by the design, shape, and follow-up of production lines [15], [16]. Production lines are used to streamline production and humans have been employing them since the 12th century [17], [18]. Furthermore, the level of automation versus the amount of manual work practiced on the production line has the ability to affect its effectiveness. It might seem as if having a highly automated production is solely beneficial due to the reduced labor costs, increased quality, and problem-solving. However, Thierry Allavena et al cover instances where this does not apply, cases regarding the enormous costs associated with automation as well as the different circumstances for various companies [19]. As explained earlier in the study; there are various ways to identify different wastes the production lines cause in order to further optimize them. A concrete example of this matter is addressed by A. M. Bonvik et al; where they used kanban and other expressions to make an analysis and improvement of a company's production line [20].

2.1 Product type

The type of products that Clemondo AB creates consists of a plastic bottle filled with some kind of chemical blend that is sealed with some type of plastic cap. The bottle also has a label on it that lists its contents. The type of chemical blend, the bottle cap, as well as the quantity of the product, differs between the different products that are being produced. This is due to the fact that they are producing blends that cover everything from vehicle care to hygiene etc and that some products need a cap that has the characteristics of a spray bottle, for example. Besides this, the company produces between 1-liter bottles and 1000-liter intermediate bulk containers (IBCs). When it comes to the bottle itself, due to these differences, the bottles also have to be carefully chosen. For instance, if a blend is highly chemical and corrosive, the bottle has to be made out of a material that can withstand this. In addition to this, only some types of bottles are compatible with certain types of caps. Some examples of products are added in figure 2.1.

Figure 2.1: Example of bottles used for some of Clemondos products. The first row of products (with blue labels) is the same product that appears in different formats, while the last row is another product that also includes a format of a spray bottle.

Clemondo has many more products than shown in the figure but these are considered to give an overall perspective. Furthermore, the company has introduced a new product line called Greenium in an effort to become more environmentally friendly. The blend of products from this product line is exclusively plant-based. It can therefore be stated that their production line is fairly flexible in order to be able to switch between recipes for the blend as well as the difference in a bottle, bottle caps, labels but also quantity of the product.

When dealing with chemical blends, it can become difficult to reassure the weight of the blend due to the change in density over temperature. When the temperature of the blend rises, so does the density, and in turn the weight of the blend increases. The density and weight of the blend increase in synchrony as the blend's temperature rises. This overall increase is linear, according to *Archimedes Principle* [21]. Therefore, in order for the finished products to maintain the correct weight, the density and temperature of the blend have to be regularly checked during the production process.

2.1.1 Product material

There are several guidelines that the company adheres to when it comes to the material of the products in their lines. These standards are either connected to the amount of recycled material in the bottle or the guidelines by Nordic Swan Ecolabel (svanenmärkt) [22]. PET, PP, PE, and HDPE are the plastic polymers used in the majority of Clemondo's products. The goal for Greenium products is to contain plastics that are 99 % recycled, while older packaging and certain suppliers use anything from 25 % to 90 % recycled material. Even if the company is seeking materials with high recyclability, it is not always the obvious choice. For instance, it is more difficult to locate recycled materials for larger bottles since it may disrupt the working environment around the bottle. Larger containers need to be specially engineered in order to be made from more recyclable materials, which makes it more difficult to pour liquid from the bottle. Additionally, some higher chemical blends have the ability to pass through bottles. Thus, materials with less recyclability might still be opted for when it comes to the size or the blend of the bottle. What the various materials are used for and their recyclability is summarized in table 2.1 below.

Table 2.1: Includes the usage areas and recyclability of the most used plastic materials in the company [23].

Plastic materials	**Used for**	**Recyclability**
PET	Bottles	Thick-walled bottles: reused Thin-walled bottles: recycled.
PP	Bottles & bottle caps	Thin-walled
PE	Bottles	Easy to recycle.
HDPE	Bottles	Easy to recycle.

It can be seen in the table that each material is recyclable on its own and when it comes to the recycling of their products, they are recyclable as long as it is possible to separate the different components. By separating the different materials, they are not contaminated during the recycling process. In order to be able to screw the cap on tightly while yet maintaining some other qualities, the majority of the caps are generally made out of a harder material (PP) than the bottle (PE). The components are separated before being sorted at the landfill in order to keep the different plastics in their pure form without contaminating them. Therefore, the cap has to be removable from the bottle and the label has to either be removable or made out of the same plastic material as the bottle. This is the case for most of the products that Clemondo offers. However, some of their products have safety locks or paper labels. These locks are made to prevent their users from drinking the highly chemical contents of some of their products but since they are difficult to remove from the bottle, it makes the recycling of these products more challenging. Bottle caps resembling pumps or sprayers also include a metal spring or other element inside them, making them more difficult to recycle. Paper labels are not as easy to remove as plastic labels since they break more easily, which can also contaminate the plastic during recycling.

Products made of white or transparent plastic are more desired for the aftermarket. This is because it is simpler to reuse these plastics for various purposes. Colored and darker plastics are harder to recolor but still hold the capability to be recycled. For some products, it may even be undesirable to be able to see the emptying rate of the products through the transparent bottles, hence colored bottles are still opted for. In Sweden, when items are recycled, plastic is scanned using an Infrared scanner and sorted according to its constituent materials [24]. The plastic is simply sorted into the flammable category if it is contaminated or contains an excessive amount of other forms of plastic. With the exception of carbon black-free containers, this IR scanner is unable to distinguish between different types of plastic when the container is black. Therefore, Clemondo only produces products that are carbon black-free when needing black items.

2.2 Overview of Entire Production

The overview of the entire production flow of the company consists of a few stations and initiates in receiving goods by suppliers in the goods reception. These goods include both packaging material (such as bottles, caps, labels, cardboard boxes, tape, and plastic wrap) as well as raw material in the form of chemical liquids, creams, or powders. The packaging material is distributed to the in-house storage via forklifts, while the chemical liquids are mostly transferred and stored in huge tanks outside of the facility if not stored in IBCs inside the facility. Additionally, the storage also contains purchased finished goods. The distribution of pallets in their storage space can be seen in the table 2.2 below.

Table 2.2: Shows how many pallets contain packaging material, raw material, purchased finished goods och finished products in the warehouse.

Packaging material [piece]	**Raw material** [piece]	**Purchased finished goods** [piece]	**Finished products** [piece]
881	934	935	4728

The next station in the production flow is the *blending* station. Here, the chemical liquids, powders, and creams are mixed into the right blend for their products according to prescription. The production line itself is the next station, where blends from the blending station come through either IBCs, which are transported by forklifts, or pipelines along the roof. The packaging materials needed for the product are transported from the warehouse with a forklift. Additionally, *bottling and packaging* take place in this station during the production process but are more specifically covered in the sub-chapter below (*2.3 Production Lines and Description of Specific Company Production Line*). Lastly, finished products from the production line are once more stored in the warehouse using forklifts before they are delivered to the customer.

2.3 Production Lines and Description of Specific Company Production Line

Clemondo AB has more than one production line, but only one of them is to be examined in this study. The products being produced on this line differ between the range of 1-5 liters. Before the actual production process can begin, blend and packaging materials must be transferred to the production line, as explained earlier, and the computer must be adjusted manually to the right program for the specific product. When this is done, the operator begins loading packaging materials onto their intended places on the manufacturing line before the blend is sent to the lab for quality control. Since the chemical blend is blended in-house, it is regularly checked to be able to maintain its quality. All of these things mentioned so far are included in the set-up time for the production line. The lines' set-up has to be approved by another operator before it is allowed to start. When these steps have been completed, the actual manufacturing process can begin. A schematic image of the specific production line is illustrated in the figure below.

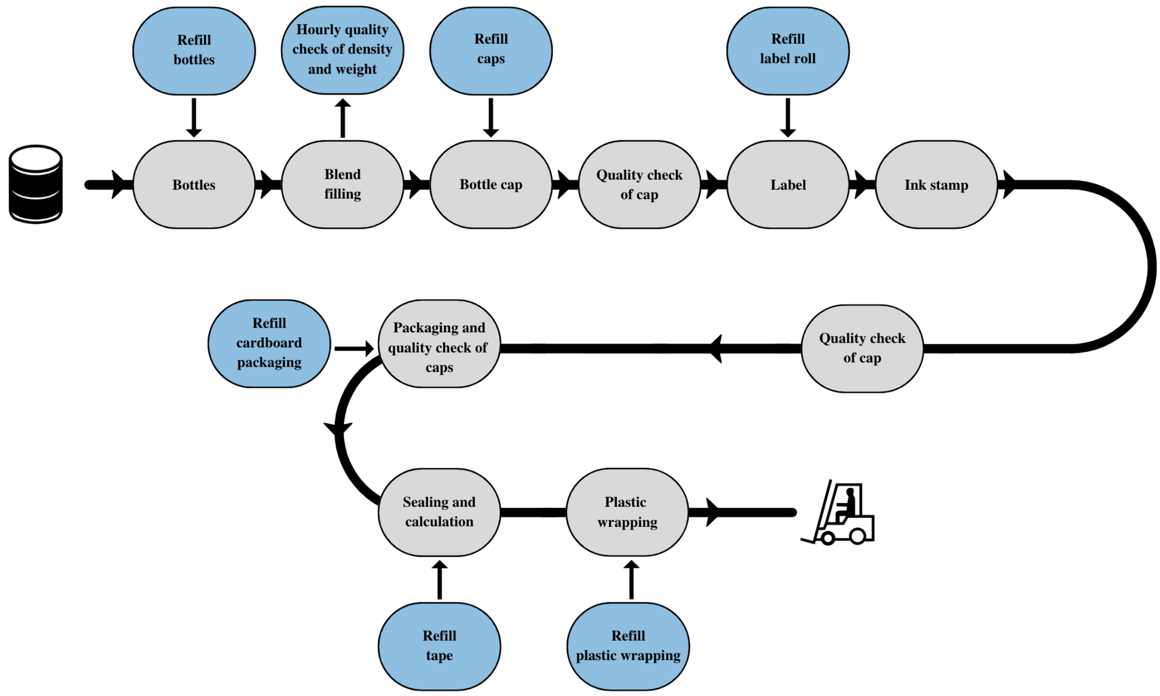

Figure 2.2: Schematic image including the different steps of the production process in the production line.

The steps that are in gray (on the line) in the figure refer to steps within the process that are automatic, while the blue bubbles (outside of the line) are steps that are manually made by the line operator. This production line only requires one operator during machine running and idling time. Because of this, the production line is expressed to be semi-manual.

The manufacturing process initiates with bottles being loaded onto the line and filled with the blend (bottling). When filled with the correct amount, bottle caps are mounted before the quality of this step is checked automatically. During this quality check, the height of the product is controlled. If the height exceeds a bar, the line will stop and this means that the cap has not been screwed on sufficiently. The operator, therefore, has to manually tighten the cap before the process can continue further. Moving forward, the label adheres to the bottle and this step also includes the products being fed between two soft rollers that make sure that the label is properly attached. Afterward, the bottle is ink stamped with its batch number, article number, and expiring date. After these two last steps, the products are visually checked, as they are fed on the line, for potential errors. If something is out of the ordinary, the production has to stop while the operator finds the cause and manually fixes it. Another quality check of the caps is later on made in the same manner as explained before. At this point, the product is essentially ready, but it still needs to be packaged in a cardboard box, sealed with tape, placed onto a pallet, wrapped in plastic film, and transported to the warehouse. Approximately 4-8 products are being placed in the cardboard box at once, depending on the product size. Here, the packing machine checks yet again if any caps are missing. This quality check is made automatically when the packing machine grabs the bottles. The amount of products that have been produced is calculated automatically on the production line before being stored on pallets. The pallet is lastly carried out to the warehouse by a forklift.

This concludes all the gray steps of the manufacturing line in figure 2.2. Most of the manual steps, however, are yet to be covered. During the production process, all types of packaging material have to manually be refilled whenever they seem to be low. This is done at different steps during the manufacturing process as seen in the figure. Moreover, since the density of the blend changes with the rise in temperature during manufacturing and affects the weight of the blend in the bottle, it is essential to make related quality checks regularly. These quality checks are made each production hour and include a density and temperature check of an existing bottle on the production line. A specific amount of the blend, in the bottle taken from the production line, is poured into a measuring cylinder. Inside this measuring cylinder, a thermometer is inserted to measure the temperature of the blend. After the temperature has been established, the thermometer is taken out before a hydrometer is inserted to measure the density of the blend with the help of Archimedes' principle. The density, weight, and temperature of the blend should increase accordingly to a chart that is made specifically for that product.

More specifically, this chart contains a target weight. The target weight includes the weight that the blend should be, but there is an upper and lower bound that this weight can assume before it is considered incorrect. These bounds are the minimum and maximum weight of the blend, which i.a. are recorded in a running protocol during production. Logically, a higher number of products can be filled if a minimum amount of the blend is used in production compared to the maximum amount being used. An example of this is added in the table 2.3 below.

Table 2.3: An example of an extraction of a running protocol from a product in the Greenium product line, containing the different weight bounds of the product.

Target weight [kg]	5.175		
Minimum weight [kg]	5.097		
Maximum weight [kg]	5.253		
Recorded weights each hour [kg]	5.178	5.180	5.184

If the density, weight, and temperature ratio are correct according to the chart, the blend is poured back into the bottle, which is placed back on the production line again. However, if an inaccuracy is discovered during this quality check, the production must stop while the blend is sent to the lab for examination. The production can continue once the blend is blended correctly. After production the production line has to be cleaned and equipment has to be washed. The washing time is the time it takes for the employee to wash equipment, such as tools on the line and IBCs, but also to clean the peripherals of the line before a new production run. The description of the production line is now completed and to identify wastes and ways to optimize the line, different methods may be applied, which is covered in the following chapter.

3 Methods

The introduction and background for the study have been established and the methods needed to move forward are included in this chapter. These methods either cover the gathering of information needed for the background or the execution itself, thus, this chapter is divided into two main sections. This study is a case study that takes a semi-inductive path in order to achieve reliability. This implies that the two steps included in an inductive path - data collection and description - are performed. The data collection and description are gathered and established through citation chaining of extant literature as well as through observations and discussions with employees at the company.

3.1 Information-Gathering Methods

The information-gathering methods are conducted in order to set a foundational base for the upcoming analysis. These methods include literature review in the form of citation chaining and practical information approaches of observations in the production and discussions with employees of the company.

3.1.1 Citation Chaining

In order to obtain as much information as feasible for this study, *citation chaining* is employed as one of the strategies. This technique entails locating an initial information source with a high degree of relevance to the phenomenon. This original source can subsequently be used for both *forwards and backward chaining*. Backward chaining is the retrieval of additional relevant sources from the source's references, whereas forwards chaining entails studying further articles that have cited the source. By utilizing this technique, the highly relevant source can be identified, hence creating a chain of relevant sources. Since this study covers various themes, original sources for each topic are unique. Using proper keywords for each issue enables the retrieval of relevant initial sources. The search engine Google Shoclar is used and for each topic, the keywords are as follows; Sustainable Production, Lean Production, Just in Time production (JiT), Kanban, Waste, Environmental Value Stream Mapping (EVSM), Production Performance Matrix (PPM), Key Performance Index (KPI) [25].

3.1.2 Observations and Discussions

When analyzing a phenomenon, it is highly valuable to observe the area and environment where it takes place. Both structured and unstructured observations are chosen as a method, where a structured approach implies choosing certain observation categories beforehand, and an unstructured approach implies that observations are noted as they happen and therefore keep continuous notations. Observations help with an objective view as the situation is seen without any subconscious opinions and thoughts that the surrounding employees may have. By observing operations in contact with the phenomena, various improvement possibilities can be identified. This helps uncover any problems and challenges with the current situation. Experts in the field, i.e., the employees of the company, are consulted as a second way to obtain useful information for the inquiry. Several specialists are consulted in order to encourage a strategy that considers a holistic view, with the purpose of identifying any occurring problems. The discussions are open interviews with open-ended questions to prevent respondents from being led to a certain perspective or response. By not asking overly specific questions, respondents are able to react on their own terms and based on their own experiences. Asking follow-up questions, such as why or how particular issues are formed, also contributes to the quality of replies [26].

3.2 Data-Gathering Methods

The data-gathering methods involve theories based on lean production and are the main driving contributors to the upcoming analysis and optimization. The methods include Environmental Value Stream Mapping (EVSM), Production Performance Matrix (PPM), Key Performance Index (KPI), and Calculations of Manufacturing Costs. These are based on and further build upon the information-gathering methods.

3.2.1 Environmental Value Stream Mapping

To favor sustainable production development, it is essential to use proven theories and approaches in a systematic way. Systematic Production Analysis (SPA) contains a collection of methods that all have the goal of systematically analyzing production systems. One method frequently used is Value Stream Mapping (VSM). A value stream consists of all activities necessary to transport a product through the essential production flows, including the flow from raw material to the customer as well as the design flow from concept to launched product. Mapping the value stream facilitates a holistic perspective of the process without requiring optimization of sub-activities [27]. The primary objective of a VSM is to determine the location of value creation and its distribution throughout the production process. The method provides a foundation for making judgments on priorities and activities in order to streamline the production flow. Typically, the activities are categorized into three groups: value-creating, necessary non-value-creating, and non-value-creating activities, which identifies as waste. Value-creating activities refer to activities essential for the product in order to create value from the customer's perspective, while essential non-value-creating activities are required based on the capacity for a specific production process but do not directly create value for the final product [6].

VSM mainly includes three steps that serve as the foundation for conducting necessary system modifications. The initial stage is to choose a single product or product family that requires improvement. The second phase involves observing the process in order to develop a map of the current production state. This stage aids in comprehending the foundation of the system as well as identifying its vulnerabilities. The third and last phase is to develop a map of the ideal production state, i.e., the state in which changes have been made and which, as a result, represents an optimal system. In the third step, efficiency-related concerns are identified where related questions are to be answered, and then methods that promote lean production are implemented [27]. An example of how a VSM can be performed within production systems is shown in 3.1.

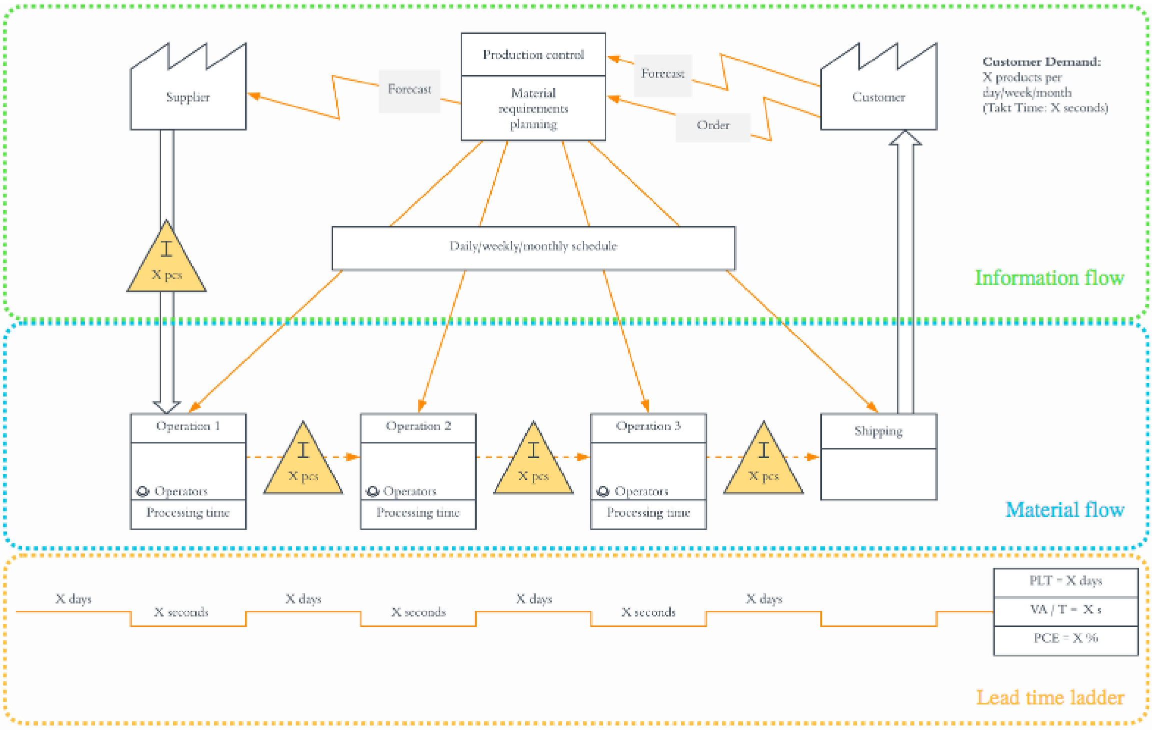

Figure 3.1: Example of a VSM for production purposes.

The mapping represents an overview of the manufacturing process, with the cycle containing production control, supplier, production operations, shipping, and customer. The green marks the information flow, where production control receives an order of a specific amount of products from the customer and sets the upcoming forecast of ordering materials from the supplier. *Takt time*, shown below customer demand, represents the maximum time production can spend on each product while still satisfying the demand. A specific amount of material pieces, shown in the triangle, are then transported to the production facility, in which the material flow, marked in blue, begins. The materials are passed through operations depending on how the goods must be processed in order for them to transform into final products. Within the operations, different information can be added depending on the goal of the mapping. In the example, the number of operators is presented as well as the processing time for each operation. The triangles between each operation represent how many pieces are carried through to the next operation, where information regarding how many pieces are discarded i.e., wasted products. The final products are lastly shipped to the customer, which concludes the mapping of the process. The orange mark represents the lead time ladder, which illustrates the value-adding time and non-value-adding time. The upper steps show the time of which material or products are waiting to be transported into the next stage in the process. This includes the time when ordered material waits in the production facility to be processed, the time in-between each operation, and the time when finished products are stored before being shipped. The lower steps show the actual production time, which identifies as the value-adding time. Depending on what needs to be established with the VSM, the resulting box shows value-creating activities in relation to the whole supply chain. Often presented are the production lead time (PLT), value-added time (VA/T), and process cycle efficiency (PCE) [28]. By creating a map of the supply chain, it becomes easier to track the activities that create value for the products and identify what processes should be optimized in order to develop an efficient production system.

The environmental aspect when executing a value-stream mapping means looking into both waste and energy consumption. Normally, even when machines are in the idling state, they require approximately 85 % of the total capacity. Specifically, when analyzing the environmental sustainability of a production system, it is highly relevant to investigate the causes of wasted material and increased energy consumption. [6].

3.2.2 Production Performance Matrix

To be able to analyze a production line, a *production performance matrix* (PPM) can be used. PPM is a matrix that can be used for structuring information after the execution of an EVSM, according to SPA. The PPM consists of columns and rows that represent *result parameters* from their respective *factor group*, an example is shown in table 3.1 below

Table 3.1: An example of a production performance matrix.

Factor groups A-G and H	**Quality parameters Q**	**Available parameters S**	**Production speed parameters P**	**Environmental and recycling parameters ER**	**Σ factors**
A. Tools					
B. Work material & workpiece					
C. Manufacturing process					
D. Personnel & organization					
E. Wear & maintenance					
F. Special process behaviors					
G. Peripherals					
H. Unknown factors					
Σ Result parameters					

It can be seen in table 3.1 that the different factor groups usually are *tools, work material and workpiece, manufacturing process, personnel and organization, wear and maintenance, special behaviors, peripherals*, and *unknown factors.* These factor groups are developed when imagining which parts of the production might lead to different causes and may therefore differ. The last mentioned factor group deals with causes that have not been linked to a specific factor or factor group. By inserting values in this factor group instead of wrongfully putting them into other factor groups, the relevance of the other factor groups is spared. However, it is not desired to have multiple registrations under this factor, the number of inserts in this factor group demonstrates a lack of knowledge in the production and calls for improvement. Moreover, the result parameters are *quality* (Q), *availability* (S), *production speed* (P), and *environmental and recycling parameters* (ER). The Q parameters form the basis when calculating the rejection ratio q_Q, which could entail the ratio of parts that are rejected in a batch of production. The standstill time q_S caused by a variety of disturbance-related problems is given by S parameters. Demands and desires for the production speed parameters are included in the P parameters and are used for calculating q_P. Within the ER parameters, the energy, waste, etc. are included. The last mentioned parameter gives the base for the material waste parameter q_B.

The usage of PPMs offers advantages such as the ability to; monitor and evaluate ongoing production to pinpoint areas that require improvement, gather knowledge for future designs of new production systems, and map the effects of decisions that can be connected to the factor groups [6]. The implementation of a production performance matrix, can therefore potentially help to standardize the work done in production lines [29]. According to Jan-Eric Ståhl and Christina Windmark, both a horizontal and vertical summation can be made on the matrix. A horizontal summation presents the cost of a given factor or factor group, while a vertical summation gives the cost of a given result parameter in a matter of discarding caused by either quality requirements or downtime disturbances. Additionally, competence or expertise is a key component in determining how accurately times are recorded against a certain factor or factor group - therefore subjective judgments must frequently be made. PPM generates calculations of different q-parameters (such as q_Q, q_S, q_P, and q_B) and in turn, financially related key performance index (KPI) can be identified. Furthermore, these economical-based KPIs have the potential to become the link between technology and the economy and result in reduced manufacturing costs. More about KPIs and manufacturing costs are going to be written in later chapters of the study.

Another benefit is connected to PPMs ability to establish a foundation for structured approaches for experience and competency documentation [6]. An example of this includes an analysis of a line made by Constantin Hofmann et al, where some of their findings imply that production metrics spread awareness to the operators and made lines more flexible with fewer break-downs [30]. The quality parameters Q are usually divided into Q_1, Q_2 ... Q_n, where the different Qs are related to the quality requirements that the company has - reasons why pieces are scrapped. The S parameters are commonly divided into S_1, and S_2, and stand for planned and unplanned downtime, while P parameters can be divided into P_1 if the production takes place at 1/4 of the intended production rate, P_2 if it's only 2/3 of the intended rate and so on. The ER parameters, on the other hand, might be difficult to assess and measure but can be divided into ER_1 and ER_2, where they refer to energy consumption in kWh and kilogram material waste.

When gathering the essential information for the PPM, it is common to make a production monitor protocol. This protocol is beneficially made by operators in the production line and includes a table that is similar to the PPM. In this table, it is possible to register individual downtimes according to their specific factor group. It is common to use complementary methods alongside PPM; to be able to distinguish specific factor groups for the matrix and monitor protocol, discussions with the employees can be made. It is therefore important that every disorder of the production is encouraged to be reported. The purpose of this protocol also includes increased consciousness regarding the production and the importance of machine learning [6].

3.2.3 Calculations of Manufacturing Costs

It is possible to base manufacturing costs and their improvement potential on PPM. Therefore, formulas leading to calculating this cost, based on the book "Sustainable Production Systems", are covered in this part of the study. The manufacturing cost for each produced part is ultimately calculated using equation 3.1 below [6].

$$\begin{aligned} k = &\frac{k_A}{N_0}\left[\frac{N_0}{1-q_Q}\right] + \frac{k_B}{N_0}\left[\frac{N_0}{(1-q_Q)\cdot(1-q_B)}\right] + \frac{k_{CP}}{60\cdot N_0}\left[\frac{t_0\cdot N_0}{(1-q_Q)\cdot(1-q_P)}\right] \\ &+ \frac{k_{CS}}{60\cdot N_0}\left[\frac{t_0\cdot N_0}{(1-q_Q)\cdot(1-q_P)}\cdot\frac{q_S}{(1-q_S)} + T_{SU} + \frac{1-U_{RP}}{U_{RP}}\cdot T_P\right] \\ &+ \frac{n_{op}\cdot k_D}{60\cdot N_0}\left[\frac{t_0\cdot N_0}{(1-q_Q)\cdot(1-q_P\cdot(1-q_S)} + T_{SU} + \frac{1-U_{RP}}{U_{RP}}\cdot T_P\right] \end{aligned} \tag{3.1}$$

To be able to determine this manufacturing cost, each term of this equation has to be solved. The first term refers to the tool cost (k_A) for a batch, while the second one deals with the material cost (k_B). The idling and running costs of the machines are covered in the next coming terms (k_{CP} and k_{CS}). Lastly, the personnel cost (k_D) is included, where the cost also depends on the number of operators (n_{op}) among all the other parameters. The other parameters include quality and time parameters as well as the nominal batch size (N_0) and utilization rate (U_{RP}). All parameters must be established in advance to use this equation. According to the book, the quality and time parameters can be distinguished after the execution of the EVSM and PPM. These parameters include the quality rejection ratio q_Q, production loss q_P, production downtime q_S, material loss q_B but also the cycle time t_0, set-up time T_{SU}, and the production time T_P.

Generally, the loss ratios are found when dividing the total amount of either quantity, downtime, or production loss with the recorded losses. For calculating the hourly cost for the machines while running and being idle, the following two equations (3.2 and 3.3) are used:

$$k_{CP} = \frac{a_f\cdot K_0\cdot(1+k_{0ren}\cdot N_{ren}) + A\cdot k_{area} + T_{plan}\cdot\left(\frac{k_{MHh}}{h_{MH}} + k_{ph}\right)}{T_{plan}} \tag{3.2}$$

$$k_{CS} = \frac{a_f\cdot K_0\cdot(1+k_{0ren}\cdot N_{ren}) + A\cdot k_{area}}{T_{plan}}. \tag{3.3}$$

In these two equations, a_f, K_0, k_{0ren}, and N_{ren} deal with the initial cost and renovation cost concerning the initial investment. Moreover, parameters A and k_{area} concern the premises cost and the area on which the machine stands. Lastly, k_{MHh}, h_{MH}, and k_{ph} in the machine running cost cover maintenance costs and running machine costs. This last term in the equation 3.2 is i.a. dependent on the energy consumption of a running machine. These two machine hourly costs can equal the same value if it is considered that the energy consumption between running machine hours and idling machine hours are small enough to be neglected. In such a case, the terms can be explained as

$$k_{CP} = k_{CS} = k_C. \tag{3.4}$$

Furthermore, the utilization rate is explained in equation 3.5 and is

$$U_{RP} = 1 - \frac{T_{free}}{T_{plan}}, \tag{3.5}$$

where T_{free} is the downtime that is free capacity. As can be seen in the equation, the rate that is obtained from this formula is the ratio between un-utilized time including downtime in contrast to the planned production time [6].

3.2.3.1 Additional Useful Calculations

To calculate the takt time, the planned production time is divided by the demanded products from customers as shown below.

To calculate the takt time, the planned production time is divided by the demanded products from customers as shown in equation 3.6 below

$$Takt = \frac{T_{plan}}{N_0}. \tag{3.6}$$

To calculate the cycle time, the production time is divided by the amount of produced products. The equation 3.7 shows this relationship

$$Cycletime = \frac{T_p}{N_0}. \tag{3.7}$$

The overall equipment effectiveness (OEE) is a key figure when calculating the efficiency of a manufacturing system concerning the occupancy shortage. It determined by the equation 3.8

$$OEE = \frac{t_0 \cdot N_0}{T_{SU} + \frac{t_0 \cdot N_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{pbfree}}. \tag{3.8}$$

where T_{pbfree} is the shortage of occupancy shared on the respective batch that is calculated as equation 3.9, [6]

$$T_{pbfree} = \frac{1 - U_{RP}}{U_{RP}} \cdot T_P. \tag{3.9}$$

3.2.4 Key Performance Index

Before KPIs, organizations considered only two aspects of work improvement and goal achievement: to plan creation and plan execution. It is the responsibility of the organization's leaders to determine whether or not the goals were accomplished and whether or not the work was enhanced. Whether the plan would be altered depends on the level to which the objectives were met. This process frequently blinds employees because a significant amount of effort is expended without the desired outcome, and by the time the leader realizes the situation, it is too late to alter the path. Peter Drucker developed the concept of performance indicators, which would provide organizations with a better understanding of employees' progress on key business goals regularly, as opposed to at the end of the year. After their rise to prominence, KPIs became highly popular and are now widely utilized by organizations [31].

KPIs are intended to improve the organization's work, and to accomplish this, they must be based on quantitative data. The data should be collectible and provide information about activities and processes within the organization that can be converted into knowledge for the employees. This is to gain a deeper understanding of the process and its cause-and-effect relationship. A thorough comprehension of the process's behavior not only improves the quality of the work but also allows for a more precise specification of the data that must be collected and managed to generate even more knowledge and insight [6].

When selecting a KPI, the organization must ensure that the KPI will help them aim in the right direction in order to achieve the goal. A poor selection of KPIs may affect the established strategy, causing the organization to deviate from its intended objective. In addition, it is essential to clearly define the KPI and ensure that everyone involved understands, analyzes, and applies it in the same manner. Moreover, it is crucial that the KPIs are not interdependent, as there is a risk that a change in one KPI may affect another, resulting in poor KPIs. The KPI should have a strong relationship with the company's objectives. Because companies have different objectives, using the same KPI in one company may not yield the same results as using it in another. It is also essential to collect rapid feedback from the measured data and provide it to the relevant employees to effectively manage system changes [6]. When organizations divide their KPIs into categories, it is possible to include multiple sustainable measurements within the category of sustainability and environment, for instance [32].

4 Case Study

This chapter involves the data gathering of the chosen methods. During the execution of this study, some essential remarks were noticed during observations and discussions. Therefore, these remarks are covered before going into the execution of Environmental Value Stream Mapping, Production Performance Matrix, Calculations of Manufacturing Costs, and Key Performance Index. In addition to this, each of these methods includes its own paragraph of *remarks from observations and discussions* since it laid the base for their execution as well.

4.1 Remarks from Observations and Discussions

The production line appeared to be reasonably flexible at first, but with closer inspection during observations and discussions, the complexity of this adaptability became apparent. The production managers know approximately how many products that are demanded by customers and produce up to this number each month to be able to have them in storage against upcoming orders. Due to their extensive partnerships and prior knowledge, they are able to estimate how much of these ”highly demanded” products to create each month. Beyond these products, Clemondo has “additional” products that are made in accordance with a precise amount of pieces and a direct order. They manufacture these exceptional goods as an outsourcing company because they have the capacity and ability to do so on their production line. In order to be able to keep up with both the ”highly demanded” and ”additional” products, the manufacturing planning needs to be reprioritized by the production managers every week. This reprioritization either adds or removes products from the manufacturing process depending on the change in customer demand. This is, for instance, in cases where the customer needs an order earlier than planned, the customer wants another amount or format of the product, or if unexpected orders appear that need to be prioritized.

The generated goods are stored in the warehouse until bought at the end of the month. However, the goods are only kept for a maximum of one year if they are unable to be sold. After this, goods are added to the obsolescence list and are processed accordingly. They might, for example, be sold at a cheaper price or re-bottled to smaller bottles, while yet retaining the same level of product quality. Fortunately for the company, this only happens a few times a year - approximately ten times a year. In addition to this, the number of times this occurs has decreased over the years as the company has worked on, for example, producing in smaller formats to be able to more easily deal with the sale of products that have been in stock for over a year. In contrast to this, if there is a shortage of goods in stock towards the end of the month, the company is compelled to manufacture the proper amount.

Products associated with soap, hygiene, and coolants (glycol) are produced on the production line alone. In addition to this, it is common for one blend to be adequate for multiple production runs. The formats of the products in these runs can range from 1-5 liters, thus it is possible that one blend is enough for several batches. During observations of the entire production, several waste factors are identified. The reasons behind these are later clarified during discussions with operators. For instance, when making a blend, all the raw materials are being fed through a 20-meter-long hose. This hose is not emptied of raw materials before the next raw material is filled. This causes an imbalance of raw materials in the blends and therefore, raw materials are "wasted" in order to adjust the blend correctly. It is also observed that waste occurs when bottling up the blend from blending tanks to IBCs and pipelines along the roof. This is due to the constant risk of the blend getting stuck in the hoses. As a result, the company has specialized pipelines for different blends as well as a system for when and how IBCs should be washed.

Furthermore, there is a chance for blends to be wasted when bottled IBCs are put on the line for production. This is due to the possibility that the blend could leak on the ground while changing the IBCs' hose. The spilled material flows into a drain in the ground that collects all blends to be disposed of in a tank. By placing any kind of bucket underneath the IBCs' opening, the amount of waste can be reduced before changing the hose. It is determined through discussions with staff members in charge of the blending station that; since this hose is cleaned before a new product is to be tapped from the tank to the IBC, residue of water and detergent may be left in the hose before the blend comes out. With each bottling, 10 to 25 liters of the blend are consequently wasted in order to get rid of the water and detergent residue in the hose. Moreover, between 25 and 50 liters may remain in the tank once bottling is complete, which is then simply washed out of the tank. Generally, soaps and products with thicker consistency have a higher possibility of remaining in the tank.

During observations on the production line, it was apparent that both blend and some packaging materials were thrown away during production. It has been observed that some packaging materials, such as tape and plastic wrap, do not become substantially wasted. As a result, the primary focus is not to assess waste on these, and they are thus removed from the category of packaging materials. Moreover, usually packaging material comes in plastic-sealed cardboard boxes and if the bottle caps from an unsealed box fall on the ground, it has to be discarded. This is due to the importance of maintaining the finished products clean, and if fallen on the ground, the product is considered to be contaminated and unusable. In addition to this, wasted material occurs during the replacement of label rolls. The design of label rolls leads to a certain number of labels being thrown away at the beginning of the roll when it is attached to the line. Labels are also thrown away after production when there are too few labels left on the roll to save for the next run. Despite this, for some production runs, the first labels are instead saved and put on bottles manually afterward. This is only done for products with a limited amount of labels where the company considers it beneficial.

Another reason why material might be discarded is due to the manual quality check of density and temperature. If, for example, a product consists of a viscous blend, it is going to be difficult to pour the blend back into the bottle and maintain the correct amount of product. This implies that the company is unable to sell the product. Therefore, the blend is instead poured back into the IBC tank, while the bottle is being discarded. Something else that was observed and clarified during discussions is that the company, in some cases, produces products in surplus to have a margin in storage. This is mainly due to the change in customer demand but also because of the difficulties in making a blend that covers the exact amount of demanded finished products. It is therefore common for the company to produce more products than initially planned if the amount of blend is enough for more bottles during production. However, during this overproduction, it sometimes happens that the number of bottles run out before the IBCs are emptied out of the blend. In these cases, the blend is either saved for later runs or wasted if it is under 5 liters. On the other hand, if the blend runs out before the packaging material does, they are always saved for later runs. Moreover, if only half a bottle is filled during overproduction, the bottle and its blend is discarded since it is considered unnecessary to save. Lastly, the weight of blends plays an important role and more products can be made if only the minimum amount of weight is used in them. This is therefore another reason why there might be more products produced than what is needed.

Each month, the material that is collected in the buckets put beneath the IBCs during hose changes and the excess material from overproduction are preserved and used for re-bottling. Re-bottling is a clever technique for the business to reduce its waste as the quality of the blend is not compromised since the company deals with highly chemical products. Yet, any blend that eventually could not be re-bottled is picked up by an external party. Presently, the number of pallets filled, rather than the quantity produced, is taken into account when measuring the amount of some products on the production line. Therefore, it's possible that the precise number of products produced is not counted. With all these observations, it becomes easier to understand the reason behind some working habits and therefore plan out the next-coming methods of this study.

4.2 Environmental Value Stream Mapping

This section presents the execution of Environmental Value Stream Mapping. The parts include the Identification of Activities, Remarks from Observations and Discussions, and Cases Investigated. The identification of activities and mapping only involves activities that are located within the production facility and do not take into account activities present outside of the facility, such as orders from suppliers or shipping of final products.

4.2.1 Identification of Activities

In order to identify the activities involved in the manufacturing process in the analyzed production line, the production flow is investigated. Based on observation of the flow of the production line, earlier presented in figure 2.2, activities are identified. Furthermore, additional activities not as obvious through observation are identified by discussions with operators on the line. Activities refer to actions or steps performed in the production process and are present each time a batch is produced. These include activities that are value-creating, essential but non-value creating and, non-value-creating. The value-creating activities refer to activities that directly create value for the final product, in perspective from the customer's view. This includes the blending, bottling, and other steps crucial for the final product to do its purpose. The division between activities are based on value creation, with the motive to distinguish what concrete activities provide direct value for the final product from the customer's perspective, what activities provide indirect value through essential steps, and what activities do not provide any value. By observing using the mind of a customer, the activities may be more easily distinguished. The value-creating activities either create the content of the product, finalize the product with appropriate information or make sure that the product can be carefully shipped to the customer. They are thereby creating direct value, which can be translated into what the customer is willing to pay for. Essential non-value-creating activities are chosen based on what steps are considered as creating indirect value for the final product, which includes all activities that prepare for production, maintain the quality of the product as well as prepare the production line for future batches. The non-value-creating activities refer to tasks that are visually observed at the production line and discussed with the operators that do not contribute to any value of the product. These are waste in terms of material spillage, time, and energy consumption and should therefore be minimized, or optimally, eliminated. Table 4.1 presents the activities identified in the manufacturing process on the production line.

Table 4.1: Activities identified in the manufacturing process of the production line.

Value-creating activities	Essential non-value-creating activities	Non-value-creating activities
Blending of the blend	Filling of raw materials	Disposal of packaging material
Bottling of the blend	Filling IBC with blend	Disposal of blend surplus
Caps screwed on product	Transport of packaging material	Downtime during production
Label added on product	Transport of IBC	Added production time
Ink stamp	Refill bottles and caps	
Products packed in cardboard box	Refill labels	
Cardboard box is taped	Refill tape	
Cardboard box gets label	Refill packaging	
	Change of IBC	
	Setup of computer	
	Setup of ink stamp	
	Setup of quality checks	
	Transport for laboratory check	
	Handover meeting	
	Control check before start	
	Density check	
	Quality check 1 of cap	
	Rollers pressing label	
	Quality check 2 of cap	
	Quality check 3 of cap	
	Package loaded onto pallet	
	Pallet gets plastic wrapped	
	Transport to storage	
	Washing of production line	
	Disposal of garbage	

The activities presented all require a certain amount of time in order to be performed. This implies that all activities not directly creating value for the product take up crucial production time that, instead, could have been used to directly create value for the product. It is therefore important to optimize activities to favor an effective production process. The identification of activities helps with determining what to essentially focus on in order to optimize the process. The activities can thereafter be mapped in the EVSM, where the time for each activity is taken into account.

4.2.2 Remarks from Observations and Discussions for EVSM

Due to the flexible production with a high variety of different products and formats, the time of delivery for customer orders differs significantly. When consulting with operators regarding lead time between stages in the process, i.e., the time when ordered material waits in the production facility to be processed, the time in-between each operation, and the time when finished products are stored before being shipped, it was discovered that the reason for the difference in lead time depends on the amount of raw materials needed, how easily the blend can be performed and current demand. How long the general lead time is when raw materials wait to be blended differs from a day up to several years, which depends on current demands and prioritized orders, but also what production resources are available at the moment. For example, for orders that the company forecast are recurring monthly or every other month, they keep a certain amount of raw materials in storage. Since the company knows that these certain raw materials will be used, they do not take up significant unnecessary space in storage. Some products include several raw materials and often only need a relatively small amount of each for the blend. This means that the company does not necessarily need to receive big formats of raw materials from the supplier, but due to it oftentimes being more economically worthwhile to do so, the big formats of raw materials are stored until needed for a new batch. Since only a small amount of each material is needed for each batch, the raw materials are stored for a relatively long time. The difference in products therefore heavily impacts the lead time.

The lead time between the completion of the blend, and the bottling of products also differs. Generally, the time span varies from a day up to a week depending on what orders are currently prioritized. The time when finished products are stored before being shipped to the customer, on the other hand, varies from a week up to a month. This is because the company might produce a surplus of products stored instead of producing the exact demanded amount.

4.2.3 Cases Investigated in EVSM

Due to the complexity of the production system, the analysis needs to be limited. Therefore the EVSM is performed in cases involving different products. In order to obtain as much information about the system as possible, four specific cases representing extreme cases and generalizability are chosen. The cases represent:

- Case 1: The least challenging and time-consuming product,
- Case 2: The most challenging and time-consuming product,
- Case 3: The most frequently produced product overall,
- Case 4: The most frequently produced product from the product line Greenium.

After consulting with the employees, it became apparent that the least challenging and time-consuming product is the same product that is most frequently produced. This limits the number of cases analyzed from four cases to three. The times presented for lead time, blending and bottling are established through documented data of previous production runs of the chosen products. To gain sustainable results, production runs involving the same batch size are chosen. For each investigated case, the manufacturing process is described from supplied raw materials to finished products. Moreover, any wasted blend during the process is examined through documented runs of the product. With the help from employees at the production and management sectors, the following products are chosen for further analysis.

4.2.3.1 Case 1: The least challenging and time-consuming product

The product that requires the least amount of different raw materials and the least challenging blending is a type of cooling glycol in a one-liter format. The materials needed for this blend are water and glycol, and since the facility has an unlimited water source, only glycol needs to be ordered from the supplier.

Process
The described process is based on a batch of *6400 finished units*, where the blend before bottling is *6400 liters*. The glycol is normally ordered once every week or every second week and is stored for about a week before it is moved to the blending station. The product is blended using two different tanks. The water travels through a hygiene room that analyzes the water by using a UV lamp to make sure that it is clean enough for the upcoming blending. To fill the blending tanks, the water takes approximately 4,5 h and the added glycol takes about 30 minutes. The actual blending process of water and glycol is estimated to be about one hour. Thereafter, the blend needs to be approved by a laboratory check in order to make sure that the product meets the requirements. After approval, the waiting time before being transported to bottling usually is about 24 hours.

To determine the bottling time, productions of the same batch size are examined through documented runs. Table 4.2 shows ten documented runs where values for set-up, washing of equipment, planned production, actual production, planned production speed, and actual production speed are presented.

Table 4.2: Documented runs of Case 1 for batches of 6400 products showing set-up time, washing time, planned production time, actual production time, planned production speed, and actual production speed.

Setup time [h]	Washing time [h]	Planned production time [h]	Actual production time [h]	Planned production speed [units/h]	Actual production speed [units/h]
4.2	1.3	9.2	13.7	699	467
2.7	1.2	9.9	14.7	650	436
2.6	1.4	9.9	10.9	650	584
1.6	0.9	9.9	8.0	650	787
1.4	0.9	9.9	8.3	650	770
0.9	0.8	9.9	11.8	650	545
1.4	0.7	9.9	10.8	650	593
1.9	1.0	9.9	8.8	650	725
4.3	1.6	9.9	10.8	650	594
2.3	1.0	9.9	9.3	650	691

What can be seen from the documented runs is that the times vary significantly. Set-up times vary from 0.9 up to 4.2 hours while washing times for equipment have more similar values. It can also be seen that the actual production times and actual production speeds differ from the planned times and speeds. Thus, one of the documented runs is chosen for further analysis. By viewing the table, it is noted that the most common set-up times vary from 1-2 hours. Furthermore, it can also be seen that there are two runs with the same set-up time of 1.4 hours, and may therefore be considered to be in the closest margin to the most occurring time. In order to also consider the lower production speeds, the run marked in the table is chosen. The chosen times for setup, washing of equipment, planned production, actual production, planned production speed, and actual production speed are presented in table 4.3.

Table 4.3: The chosen run with times for setup, washing, planned production, actual production, planned production speed, and actual production speed for a batch of 6400 units of Case 1.

Set-up time [h]	Washing time [h]	Planned production time [h]	Actual production time [h]	Planned production speed [units/h]	Actual production speed [units/h]
1.4	0.7	9.9	10.8	650	596

As seen in the table, preparing for the batch takes on average of 1.4 hours, and after production, 0.7 hours are on average used to wash any used equipment. The general planned time to produce all 6400 products is 9.9 hours but the actual used time to produce the whole batch is 10.8 hours. This indicates an increased production time of 0.9 hours. The planned production speed to reach the demanded products is thereby

650 finished products per hour, but in reality, approximately 593 finished products per hour are produced. After the bottling and packaging of the order are done, the finished products normally are put in storage for a week before being shipped to the customer.

Energy consumption

When looking at the energy consumption of the production line, the motors involved as well as other energy-consuming equipment should be taken into consideration. By consulting with shift coordinators, it becomes known that the production line includes 15 different energy-consuming equipment in total. When establishing the energy consumption, it is assumed that the equipment runs at maximum capacity. There are five motors that drive the line, where each motor consumes 0.1 kW, 2.2 kW, 0.2 kW, 0.4 kW, and 0.4 kW. For the label machine, four motors are required that each consuming 74 W, and for the machine that packages the products and tapes the box shut, two motors are required that each consuming 0.2 kW. Finally, to power the pumps to the bottling, three pump motors are used that each consume 0.8 kW as well as a so-called filling pump motor located by the filling pipes that consume 0.4 kW.

To calculate the energy consumption from the equipment, the efficiency of each motor is multiplied by the time of production. Case 1 includes 10.8 hours of actual production time, and by multiplying that by efficiency, the total energy consumption of the production line is achieved. As seen in table 4.3, production runs for longer than planned, more specifically 0.9 hours longer. In order to establish how much increased energy consumption is used compared to what was planned, the increased production time is multiplied by the efficiency. Table 4.4 shows the different motors involved in the production line, their efficiency, and the calculated total and increased energy consumption.

Table 4.4: The energy-consuming equipment on the production line for case 1, with their corresponding maximum capacity, as well as the total energy consumption and increased energy consumption.

Part in production	**Efficiency [kW]**	**Total energy consumption [kWh]**	**Increased energy consumption [kWh]**
Line motors	3.2	35	3.1
Label machine	0.3	3.2	0.3
Cardboard box/tape machine	0.4	3.9	0.3
Pump motors	2.4	24	2.1
Filling pump motor	0.2	4.0	0.4
Sum	6.5	70	6.2

The table shows that the total efficiency from the motors combined is 6.5 kW, and based on the production time, the total energy consumption for Case 1 is on average 70 kWh. Furthermore, within these 70 kWh, 6.2 kWh represents the increased energy consumption based on the increased production time.

Wasted blend
In order to establish how much blend is wasted during production, the runs are examined for how much blend was used at the beginning of the production and how many products were produced. Table 4.5 shows a documented run with the planned amount of produced products and how many were actually produced.

Table 4.5: A production run of Case 1, with the planned amount of products, actual amount of products, volume of initially used blend, amount of missing or extra products, as well as the resulting decrease or increase in products.

Planned amount of products [units]	Actual amount of products [units]	Volume of used blend [liters]	Amount of missing/extra products [units]	Decrease/ increase in products [-]
6400	6309	6400	-91	-1.4 %

Based on the resulting decrease in produced products, it can be determined that the company produces 1.4 % fewer products of Case 1 on the production line due to the blend being wasted. This translates to 91 wasted products per each batch of 6400 liters of blend used.

Takt time
To determine the maximum acceptable time to meet customer demand, the takt time for a 6400-unit batch size of this product is calculated. For Case 1, as seen in table 4.3, the planned production time is 9.9 hours which translates to 594 minutes. For a batch size of 6400 units, the takt time is calculated using equation 3.6 as shown below

$$Takt = \frac{594}{6400 \cdot 60} = 5.4 \quad \text{seconds}$$

This implies that production cannot exceed 5.4 seconds per part in order to keep up with customer demand.

Cycle time
Cycle time is calculated to determine if the defined takt time is achieved based on the actual production time. Case 1, as seen in table 4.3, has a longer production time than planned of 10.8 hours which translates to 648 minutes. The actual amount of produced products is 6309 units. Based on these values, the cycle time for Case 1 is calculated by using equation 3.7 as shown below.

$$Cycletime = \frac{648}{6309 \cdot 60} = 6 \quad \text{seconds}$$

This means that the time currently used for producing each product is 6 seconds.

4.2.3.2 Case 2: The most challenging and time-consuming product

The product involving the most amount of different raw materials and most challenging blending is soap in a five-liter format. This soap includes ten different raw materials which are all ordered from a supplier.

The process
The described process is based on a batch of 1000 finished units, where the blend before bottling is 5000 liters. The ten raw materials included in the product all have different times in storage before being processed. This is because of the difference in the amount needed for each raw material for the blend. Depending on the current demand, the raw materials are ordered from the supplier between two times a month up to once every other month. The raw materials are normally in storage for two weeks before being blended. The product is blended in three different tanks where the added water takes about two hours a tank and the rest of the raw materials take about one hour per tank. Blending all raw materials takes on average an hour. Thereafter a required laboratory check is done, taking approximately 30 minutes. Since the products involve a number of different raw materials, the correct blend can be challenging to achieve. Due to this, there is almost always an adjustment needed which takes from one to four hours. Once the blend is complete, IBCs are filled with the blend, taking approximately one hour. All hygiene products go through a bacteria test after being blended which takes four days to complete. Thereafter, an additional three days are planned for potential alterations in the blend. All in all, the lead time between blending and bottling is approximately a week.

To determine the bottling time, productions of the same batch size are examined through documented runs. Table 4.6 shows four documented runs where values for set-up, washing of equipment, planned production, actual production, planned production speed, and actual production speed are presented.

Table 4.6: Documented runs of Case 2 for batches of 1000 products showing set-up time, washing time, planned production time, actual production time, planned production speed, and actual production speed.

Set-up time [h]	Washing time [h]	Planned production time [h]	Actual production time [h]	Planned production speed [units/h]	Actual production speed [units/h]
1.0	1.0	5.0	4.3	200	232
0.1	1.0	5.0	4.8	200	202
1.3	1.0	5.0	4.2	200	240
1.1	1.0	5.0	3.0	200	262

The times are, for this case, more similar when comparing each run, but still differ. The values that stand out are the set-up time of 0.1 hours and the actual production time of 3 hours. These differ the most compared to the other documented runs and are therefore not chosen for the analysis. Thus, the runs with a set-up of 1 hour and 1.3 hours are concluded as being the most optimal ones to choose for a more generalized result. The third run has the biggest difference in set-up time compared to the others, and thus, the first run with a set-up of 1 hour is chosen. The chosen run and times are presented in table 4.7.

Table 4.7: The chosen run with times for setup, washing, planned production, actual production, planned production speed, and actual production speed for a batch of 1000 units of Case 2.

Set-up time [h]	**Washing time [h]**	**Planned production time [h]**	**Actual production time [h]**	**Planned production speed [units/h]**	**Actual production speed [units/h]**
1.0	1.0	5.0	4.3	200	232

As seen in the table, preparing for the batch takes on average 1 hour, and after production, 1 hour is on average used to wash any used equipment. The general planned time to produce all 1000 products is 5 hours but the actual used time to produce the whole batch is 4.3 hours. The planned production speed to reach the demanded products is thereby 200 finished products per hour, but in reality, approximately 232 finished products per hour are produced. After the bottling and packaging of the order are done, the finished products usually are put in storage for a week before being shipped to the customer.

Energy consumption

To calculate the energy consumption for Case 2, the efficiency from the ingoing motors on the production line is taken into consideration that are presented in Case 1. As seen in table 4.7, production durated for 4.3 hours. These hours are used to calculate the total energy consumption of production, by multiplying with the efficiency. Moreover, production runs faster than planned, which can be seen as 0.7 hours of saved time. Table 4.8 presents the energy consumption of all motors.

Table 4.8: The energy-consuming equipment on the production line for case 2, with their corresponding maximum capacity, as well as the total energy consumption and increased energy consumption.

Part in production	**Efficiency [kW]**	**Total energy consumption [kWh]**	**Increased energy consumption [kWh]**
Line motors	3.2	14	-2.3
Label machine	0.3	1.3	-0.2
Cardboard box/tape machine	0.4	1.5	-0.3
Pump motors	2.4	9.6	-1.6
Filling pump motor	0.2	1.6	-0.3
Sum	6.5	28	-4.7

As for all cases investigated, the total efficiency of the motors is 6.5 kW. The total energy consumption for Case 2 is 28 kWh and the saved energy consumption is 4.7 kWh.

Wasted blend
In order to establish how much blend is wasted during production, the runs are examined for how much blend was used at the beginning of the production and how many products were produced. Table 4.9 shows four different runs of batches where the columns represent how many products are to be produced, how many actually were produced, the amount of used blend, how many potential products are missing or how many extra were produced, and the resulting decreased or increased amount of products are produced in the percentage of the planned amount.

Table 4.9: Planned products, actual produced products, the volume of used blend, missing products, and decreased products in percentage for a batch of 1000 units of Case 2.

Planned amount of products [units]	Actual amount of products [units]	Volume of used blend [liters]	Amount of missing/extra products [units]	Decrease/ increase in products [-]
1000	980	5000	-20	-2.0 %
1000	965	5000	-35	-3.5 %
1025	924	5125	-101	-9.8 %
1000	955	5000	-45	-4.5 %

Based on the resulting decrease in produced products, it can be determined that, based on the median value, the company produces 4.0 % fewer products of Case 2 on the production line due to the blend being wasted. This converts to 40 wasted products per each batch of 5000 liters of blend used.

Takt time
As for Case 1, the takt time is calculated to determine the maximum acceptable time for production to meet customer demand for Case 2. For Case 2, as seen in table 4.7, the planned production time is 5 hours which translates to 300 minutes. For a customer demand of 1000 units, the takt time is calculated using equation 3.6 as shown below.

$$Takt = \frac{300}{1000 \cdot 60} = 18 \quad \text{seconds}$$

This implies that production cannot exceed 18 seconds when producing each product in order to keep up with customer demand.

Cycle time
The cycle time is calculated for Case 2, as for Case 1, in order to determine if the defined takt time is achievable based on the current actual production time. Case 2, as seen in table 4.7, has a shorter production time than planned of 4.3 hours which translates to 258 minutes. The actual amount of produced products, as seen from the documented runs, is 40 units less than customer demand. This means that 960

products are produced. Based on these values, the cycle time for Case 2 is calculated using equation 3.7 as follows.

$$Cycletime = \frac{258}{960 \cdot 60} = 16 \quad \text{seconds}$$

This means that the time currently used for producing each product is 16 seconds, which is shorter than the defined takt time.

4.2.3.3 Case 3: The most frequently produced Greenium product

Per request from the company, an analysis of a product from the Greenium product line is performed to investigate how well the process favors sustainability compared to its other products. The product chosen as the most frequently produced product from this line is in five-liter format. Seven raw materials are needed for this blend where the raw materials are ordered approximately every month.

The process
The described process is based on a batch of *600 finished units*, where the blend before bottling is *3000 liters*. The seven raw materials, much like the ones included in Case 2, have different times in storage before being transported to the blending station. The general planned lead time is a week for all raw materials, but established through documented lead times, they are stored for nearly three weeks. The blending process involves pumping in the water while adding the remaining raw materials. This, along with blending everything, takes approximately 45 minutes. The finished blend is then normally stored for a week before being moved to the bottling station.

To determine the bottling time, productions of the same batch size are examined through documented runs. Table 4.10 shows four documented runs where values for set-up, washing of equipment, planned production, actual production, planned production speed, and actual production speed are presented.

Table 4.10: Documented runs of Case 3 for batches of 600 products showing set-up time, washing time, planned production time, actual production time, planned production speed, and actual production speed.

Set-up time [h]	Washing time [h]	Planned production time [h]	Actual production time [h]	Planned production speed [units/h]	Actual production speed [units/h]
1.0	1.0	2.0	3.7	300	160
0.8	0.9	2.0	2.4	292	262
1.1	0.7	2.0	3.6	297	171
0.9	0.6	2.0	2.2	298	279

It is apparent that the times also vary in this case, but what can be seen is that they are more evenly distributed throughout the different runs. The first and third runs have similar values in terms of actual production time and actual production speed, and the second and fourth run have the same similar values. There is a significant difference between the slowest and fastest production speed of 160 and 279 units per hour, and in order to gain more generalized results, these are not chosen for the analysis. Out of the two remaining, it can be seen that there is a drastic difference between the actual production speeds. The third run has an actual speed loss of approximately 126 units each hour, which ultimately affects the production time. This is therefore considered as being an extreme case, and thus, the second run is chosen for further analysis. The chosen run and times are presented in table 4.11.

Table 4.11: The chosen times for setup, washing, planned production, actual production, planned production speed, and actual production speed for a batch of 600 units of Case 3.

Set-up time [h]	**Washing time [h]**	**Planned production time [h]**	**Actual production time [h]**	**Planned production speed [units/h]**	**Actual production speed [units/h]**
0.8	0.9	2.0	2.4	292	262

As seen in the table, preparing for the batch takes 0.8 hours, and after production, 0.9 hours are used to wash any used equipment. The general planned time to produce all 600 products is 2 hours but the actual used time to produce the whole batch is 2.4 hours. This implies an increased production time of 0.4 hours. The planned production speed to reach the demanded products is thereby 292 finished products per hour, but in reality, approximately 262 finished products per hour are produced. After the bottling and packaging of the order are done, the finished products usually are put in storage for two weeks before being shipped to the customer.

Energy consumption

As for Cases 1 and 2, the energy consumption for Case 3 is calculated accordingly. Case 3 involves an actual production time of 2.4 hours, as seen in table 4.11. To establish the increased energy consumption, the increased production time is used. The increased production time, based on planned and actual production time, is 0.4 hours which is multiplied by the efficiency of the motors. Table 4.12 shows the motors on the production line, their efficiency as well as their energy consumption in terms of the total for the entire production run and increased consumption resulting from increased production time.

Table 4.12: The energy-consuming equipment on the production line for case 3, with their corresponding maximum capacity, as well as the total energy consumption and increased energy consumption.

Part in production	Efficiency [kW]	Total energy consumption [kWh]	Increased energy consumption [kWh]
Line motors	3.2	7.4	1.6
Label machine	0.3	0.6	0.2
Cardboard box and tape machine	0.4	0.8	0.2
Pump motors	2.4	5.3	1.1
Filling pump motor	0.2	0.9	0.2
Sum	6.5	15	3.3

As for all investigated cases, the total efficiency of the motors is 6.5 kW. The production time of Case 3 leads to a total energy consumption of 15 kWh, where 3.3 kWh represents the increased energy consumption based on increased production time.

Wasted blend
Table 4.13 shows four different runs of batches where the columns represent how many products are to be produced, how many actually were produced, the amount of used blend, how many potential products are missing or how many extra were produced, and the resulting decreased or increased amount of products are produced in the percentage of the planned amount.

Table 4.13: Planned products, actual produced products, the volume of the used blend, missing products, and decreased products in percentage for a batch of 600 units of Case 3.

Planned amount of products [units]	Actual amount of products [units]	Volume of used blend [liters]	Amount of missing/extra products [units]	Decrease/ increase in products [-]
600	592	3000	-8	-0.3 %
610	597	3050	-13	-0.4 %
600	605	3000	+5	+0.8 %
600	604	3000	+4	+0.7 %

Based on the resulting products, it can be determined that, based on the median value, the company produces four more products of Case 3 on the production line, which translates to an increase of 0.7 %.

4.3 Production Performance Matrix

The aim of making a production performance matrix is to examine waste related to the production line, and the causes of these. In this way, any form of waste made in the blending station is excluded from the execution of this method. The term waste includes material waste (of both blend and packaging materials) but also parameters that affect the effectiveness and utilization of the production time such as downtimes. When initiating the execution of this method, an already existing matrix made and used by the company from earlier is given. The company uses this matrix to be able to gain an idea behind which causes of downtimes etc. are possible to link to documented parameters. Moreover, this matrix is used to gather information regarding *all* of their production lines and produced products. Despite this, only the products produced on the production line are looked at in this matrix.

The company matrix included, for instance, the planned and actual set-up time and production speed. However, this company matrix included limited data, and more parameters are needed for the upcoming analysis. Therefore, to be able to gather as much information as possible, a *shift protocol* is made. This protocol includes practices made on the production line that have i.a. been discovered during the identification of activities in EVSM. The company matrix and shift protocol is explained in detail in this part of the study.

4.3.1 Remarks from Observations and Discussions for PPM

During observation of the company matrix, it is noticed that the set-up time for the same product differed significantly. From discussions with employees, it is settled that this mostly depends on the order of the production set-up. The set-up time is shorter if similar products are produced one after the other. It is also noticed that the production speed differs a lot in the matrix. This parameter can be dependent on the operator's speed. If an operator is experienced and faster in their movements, downtimes and the production itself are going to go by faster and smoother. This factor - the human factor - can also be applied to the cause of the difference in set-up times. However, if the actual production speed is faster than the planned one, this is an indication that the cycle time for each part is too long. The ideal cycle time for a production run gives a production speed of 100 %, which results in the planned production time. If the actual production speed were to exceed this time, it would conclude that their planned cycle time is not ideal and probably too long. On the other hand, if the actual production speed is slower than the planned one, it could be due to downtimes, or otherwise the factors would be unknown.

Moreover, some parameters, such as the changeover time and the amount of discarded materials, are missing from this matrix. The changeover time includes the time it takes for technicians to calibrate the production line before the next-coming production run. This changeover is only made if necessary and is completely reliant on a technician and is therefore not carried out by line operators currently. This time also takes from the production time and can be seen as a waste in the production but has not previously been recorded. Another interesting observation is that the company does not have a planned time for how long the washing time approximately takes. These observations of the company matrix together with the observations made on the production line (explained in *4.1 Remarks from Observations and Discussion*) lay the base for the shift protocol.

4.3.2 Shift Protocol

The factors included in the company matrix were established by the production managers together with the line and shift operators. In addition to this, the company had already made a protocol that links the different parameters to factors causing a disturbance in the production time. However, these factors did not include any causes related to waste at all. Therefore, most of these factors are added to the new shift protocol, including a few more. In that way, the new shift protocol contains factors that are known to the workers from before together with a couple of new ones. This is important to keep in mind when creating these kinds of protocols that are distributed to employees - that they should be simple to grasp and not take more time than necessary. As mentioned earlier in the description of this method, one of the reasons behind this strategy is to bring awareness to employees. Thus, it is critical to retain a language and layout that workers comprehend and feel comfortable with in these protocols. The authors must consequently make assumptions in order to determine the fundamentals of some of the shift protocol factors that employees log. For instance, the reasons behind material being wasted must be resolved afterward. The shift protocols are applied to as many production runs as possible in order to collect as much data as feasible.

Figure 4.1 and 4.2 below contain the shift protocol that is created for the personnel. The shift protocol is translated from English to Swedish before being distributed to the workers since this is their native language. Figure 4.1, shows the front page of the shift protocol where the date, time, and batch number of the product are desired. With this information, it is possible to compare the shift protocols with the values added to the company matrix. Further down on the page, two tables are added that cover the changeover time and material wastes that occur either before or after production. Figure 4.2, shows the backside of the shift protocol and includes all the imaginable causes for inefficiencies on the production line.

Date and time:

Batch number:

Before production

	Time [in min]
Changeover time (if necessary)	

After production

	Liter/pieces discarded
Discarded blend	
Discarded bottles	
Discarded caps	
Discarded labels	
Discarded cardboard boxes	

Comment:

Figure 4.1: The table on the front side of the shift protocol, including activities occurring before and after production as well as the time, date, and batch number of the shift.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels				
B3: Refill tape				
B4: Change IBC				
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line				
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues				
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure 4.2: The table on the backside of the shift protocol, providing examples of disturbance causes.

One of the tables at the front of the protocol makes it possible to record how many materials are discarded. This is done to be able to record how many materials are discarded due to quality matters and how many are simply wasted. Through discussions, the quality standards for the blend and each packaging material are established. Some of these standards have already been explained in *4.1 Remarks from Observations and Discussions*. Additional quality standards include if packaging material is broken in any way, for instance; if bottles are dented, caps are leaking, labels have deviations and if cardboard boxes are damaged. On the front page of the shift protocol, it is desirable to record the number of materials being discarded in total. On the backside of the shift protocol, the amount of downtime and/or discarded materials for each factor should be recorded.

In order to provide more clarity, some of the shift protocol's variables are explained in this paragraph. In figure 4.1, the discarded cardboard boxes refer to boxes used to pack the product and not the boxes that bottles and other packaging materials are delivered. Moving over to figure 4.2, it is thought that the first factor: *A1: Density-check (each hour)*, has the ability to cause waste in manners of both downtime and material waste. This is due to the chance of the bottle and/or the blend being discarded because of the viscosity of the blend, as explained earlier in *4.1 Remarks from Observation and Discussion*. Additionally, this density-check might lead to downtime if the production has to stop during the check itself. The same goes for factor *B4: Change IBC*, since this might lead to material waste as well as unplanned downtime. The factor *C3: Away from the production line* covers every reason behind employees being away from the production line and includes if anyone else needs help or if they are having a break, which might cause the production to stop for a while. Factor *C4: Take the blend to the lab for check (during production)* is made to be able to differentiate the different factors that have to do with the density of the blend. This factor specifically deals with occurred downtimes when the blend has to be taken to the lab, due to deviation of the blend, which is realized after the density-check. Under Wear and maintenance *D1: Technical causes*, refers to downtimes related to a technical problem in the machines that operators cannot fix without a technician. The causes behind these technical issues have been established earlier by the company but they differ a lot, this factor is, therefore, a combination of all of those reasons. Additionally, this factor has the ability to lead to both downtimes but also slower production speeds. Despite this, it is not noted in this table how much slower the production becomes. Moreover, *E2: Deviation in the blend*, deals with cases where some extra measure regarding the blend needs to be done to work in a production that leads to downtime (or slower production). Lastly, factor *E3: Deviation in packaging material* covers causes of material waste due to packaging material received from suppliers being unusable. *E4: Contaminated packaging materials* are a factor that covers packaging material being discarded due to falling on the ground.

4.4 Calculations of Manufacturing Costs

The costs that are covered in this section of the study consist of constant values that are given by the company. These values are ultimately used in order to calculate the manufacturing cost per part in equation 3.1 and are the tool cost, material cost, and machine cost. The tool cost (k_A) is neglected in this study since it is not applicable to this specific production line. This is established when observing the production line. The material cost (k_B) is divided into the general cost of the blend and packaging materials. The average product size in liters, out of all products produced on the production line is 3.4 liters. The different material costs can be seen in table 4.14 below.

Table 4.14: The costs for the blend and packaging materials.

The blend [SEK/product]	**Bottles [SEK/piece]**	**Bottle caps [SEK/piece]**	**Labels [SEK/piece]**	**Cardboard boxes [SEK/piece]**
41	8.0	0.40	2.6	5.0

By adding all of these costs together, the total material cost equals 56 SEK/part.

It is clarified during observations and discussions that the machine hour costs should consist of the same value in this study. Therefore, another simplification of the equations 3.2 and 3.3 is made before calculating this cost. The essential parts of the machine cost k_{CS} and k_{CP} is the initial cost (K_I), a renovation cost ratio (K_{0ren}), and area cost (K_A). The first cost covers everything regarding the initial investment and building of the machine, while the second cost includes preventive and remedial maintenance and the third deals with the local area that the machine constitutes. In addition to this, the renovation cost is a ratio between the price of total renovations divided by the initial cost. By simplifying the equation 3.2 and 3.3 and implementing equation 3.4, the following equation is obtained

$$k_C = \frac{K_1 \cdot (1 + K_{0ren}) + K_A}{T_{plan}}. \tag{4.1}$$

Moreover, when it comes to the actual cost of the machines, it is given by the company that employees were working for a total of 750 h to build the machine. Since the personnel cost is 350 SEK/h, this indicates that the initial cost equals 1 575 000 SEK. The maintenance cost is 100 000 SEK per year, which implies that the ratio is 0.063. The premise cost is 2200 SEK/m^2, while the area where the machine stands is approximately 150 m^2 and this gives an area cost of 330 000 SEK. This is therefore all the information that is possible to gather at this point of the study and more is covered in the chapter regarding results.

4.5 Key Performance Index

Defining KPIs is an important aspect when making efforts to reduce waste and optimize the handling of resources. As stated previously, optimal KPIs are measurable, do not depend on other KPIs, and are realistic to reach within the company. It is therefore crucial to define what is possible to measure and how it can improve current practices. Desired improvements should be clear and concrete to enable follow-ups and make sure that the path heads toward the company goals.

In order to determine KPIs that the company should implement for waste reduction and resource efficiency, current visions, strategies, and KPIs from the company are analyzed. The current strategies and targets at the company involve:

- Contributing to a sustainable future with the help of effective solutions, high service levels, and satisfied customers.
- Meet both current and future customer needs through conditions based on scalability in their production.
- Foster engagement and drive into sustaining healthy relationships with customers by helping employees become the best version of themselves.

What is gathered is that the company aspires to put heavy work into sustainably focused solutions and to maintain healthy customer relationships. This is done by having a flexible production system and proficient employees to be able to offer customer desires.

KPIs that are currently being measured in the company are under the categories of delivery precision, capacity, and cost efficiency. Under **delivery precision** they focus on two measurements. One of them is *On Time in Full* (OTIF), which is used to calculate the number of deliveries made on time in full in relation to the number of all deliveries made. This KPI helps the company estimate if orders are delivered as planned or if there are any fluctuations. The second measurement is in relation to the *re-planning of production*. Re-planning is done within two weeks in order to stay up to date with current deliveries and any other sudden deliveries.

Capacity efficiency is determined using two measurements. The first involves measuring produced liters of the blend, which can translate to finished products. This KPI is used to make sure that the demanded number of products is produced, but also to notice if production speeds are being held and productions are stable. Ultimately, measuring produced liters helps determine if their current capacity is optimal, or if alterations are needed. The second measurement for capacity is the number of adjustments in blends. These adjustments are, as stated previously if the current blend is incorrect and requires regulation. Measuring the number of adjustments helps with establishing if current preparations are optimal or if alterations are required to minimize possible adjustments.

Most KPIs are included in the category of **cost efficiency** and involve establishing direct costs. One of these measurements is to calculate profit in SEK/liter and the time used for creating each liter. This is to determine economic stability in the company and to see if current practices lead to the desired profit. Another measurement is checking tied-up capital and if it is currently at a suitable level. This is done because holding inventory is associated with an opportunity cost, and the money bound to products could be invested in other ways that yield a greater future profit. The final measurement of cost efficiency is calculating savings. By calculating savings, the company can determine if the current level of profit and losses is reasonable or if adjustments are required to achieve the desired state.

The KPIs currently applied are optimal for the current state of the company, but for future improvements, more KPIs are needed. The company uses suitable measurements to favor its presented strategies and visions, specifically in relation to delivery precision and capacity. However, in order to further optimize the strategies of minimizing climate impact and maintaining cost efficiency, waste in the manufacturing process is necessary to examine. Through finds and results from the chosen methods in the study, EVSM and PPM, appropriate and applicable KPIs can be distinguished. More measurements regarding waste may help the company with developing a more sustainable production planning and thereby improving the manufacturing process.

5 Results

This chapter presents the results achieved from each method used in the study. The sections include results from Environmental Value Stream Mapping with subsections of analyzed cases and the Production Performance Matrix with subsections regarding its content. Furthermore, the Calculations of the Manufacturing Cost are presented. The results are solely based on data from the chosen cases and documented runs and results thereby primarily representing these cases as they are specifically oriented towards these.

5.1 Environmental Value Stream Mapping

Based on the investigated cases in the data gathering, EVSMs of the current state are established. The activities and processes for each case lead to different lead times and processing times. As a result of this, the cases involve different values for value-creating time and non-value-creating time. The EVSMs illustrate the manufacturing process of each case, where all cases go through the same operations of blending, bottling, and packaging. The blending station includes information on the processing time (P/T) and the set-up time, while the bottling and packaging station includes information on processing time (P/T), cycle time (C/T), set-up time, and washing time. Furthermore, the EVSMs show information about waste in terms of energy consumption and wasted blend from the bottling and packaging station. The energy consumption is illustrated showing the planned consumption based on planned production time, as well as the actual energy consumption which is based on the actual production time. The EVSMs show how many liters of the blend is originally applied to the bottling and packaging station and how many liters are used for final products. The liters of the blend are also translated into the amount of products that should come out of the blend and how many products actually are produced. Lastly, what is illustrated is the lead time ladder, which shows the lead time between each operation and the value-adding times for the manufacturing process. These times are summed in the information box in the bottom right corner of the figures, which also includes the value-adding time to total manufacturing time ratio. The same structure of results is applied to the three investigated cases in the subsections below. Finally, a comparison of the cases is presented in a table at the end of the section.

5.1.1 EVSM of Case 1

The steps of the manufacturing process of Case 1 and their respective time-consumption are presented in table 5.1 where the times are divided into value-adding and non-value-adding.

Table 5.1: The manufacturing process of Case 1 including steps, value-adding time, and non-value-adding time.

Step in the process	Value-adding time	Non-value-adding time
Lead time before blending		7 days
Blending	60 minutes	
Lead time before bottling and packaging		1 day
Bottling and packaging	648 minutes	
Lead time before being shipped		7 days

An overview of the manufacturing process of Case 1, including the steps, corresponding times, material input and output, and energy consumption, is illustrated in the EVSM in figure 5.1.

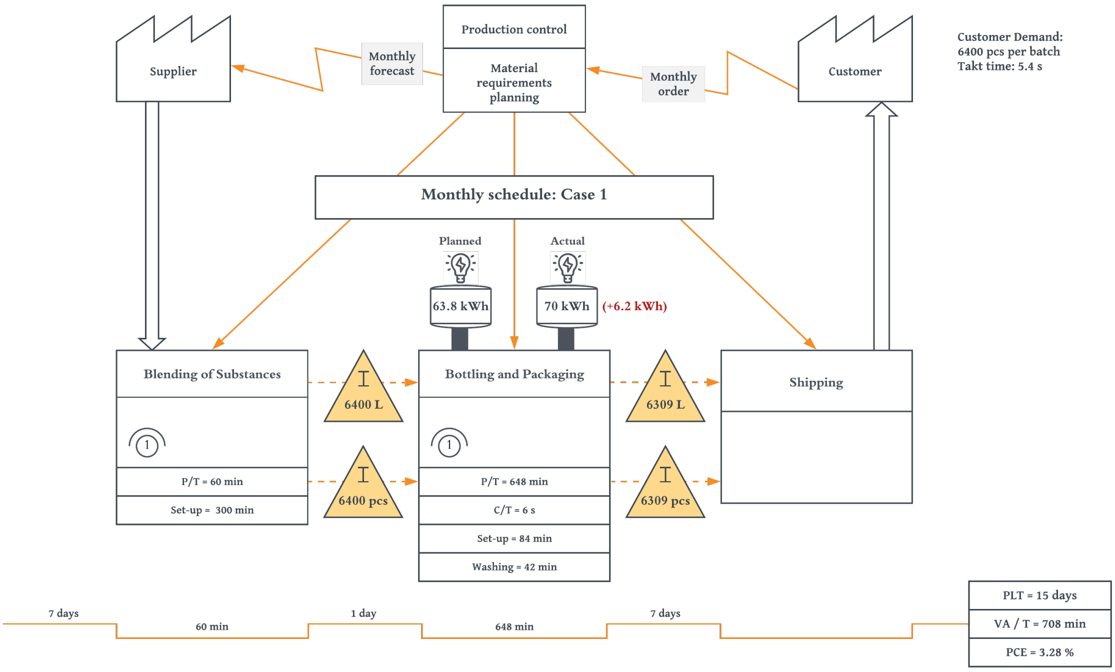

Figure 5.1: EVSM showing the manufacturing process of Case 1.

The map shows the steps in the manufacturing process with a focus on the ones occurring at the facility, including blending as well as bottling and packaging of products. The processing time of the bottling station is 60 minutes where an additional 300 minutes are needed for preparing the blend. In the bottling and packaging station, 648 minutes are used for processing time and an additional total of 126 minutes are required for set-up and washing of equipment. The takt time for production is 5.4 seconds to keep up with customer demand, and the current cycle time for production is 6 seconds. What can be seen in the mapping is that the total production lead time is 15 days, which represents how much time the materials and products are stored before moving on to the next stage in production. In contrast, activities that create value for the product, i.e., blending and production take a total of 708 minutes. Thus, the value-adding activities only represent 3.28 % of the total time used for manufacturing Case 1. Based on the planned production time, the total energy consumption for Case 1 would be 63.8 kWh. However, since production takes longer than planned, the actual energy consumption is 6.2 kWh larger than planned, this leads to a total energy consumption of 70 kWh. Moreover, the figure illustrates that from a blend of 6400 liters, 6309 liters are used for bottling of products. This translates to 6400 possible products that became 6309 finished products. To sum up, current practices lead to 91 wasted products during production per 6400 products produced.

5.1.2 EVSM of Case 2

The same structure used for Case 1 is used to present the results of Case 2. The steps of the manufacturing process of Case 2 and their respective time-consumption are presented in table 5.2 where the times are divided into value-adding and non-value-adding.

Table 5.2: The manufacturing process of Case 2 including steps, value-adding time, and non-value-adding time.

Step in the process	Value-adding time	Non-value-adding time
Lead time before blending		14 days
Blending	60 minutes	
Lead time before bottling and packaging		7 days
Bottling and packaging	258 minutes	
Lead time before being shipped		7 days

An overview of the manufacturing process of Case 2, including the ingoing steps, corresponding times, material input and output, and energy consumption, is illustrated in the EVSM in figure 5.2.

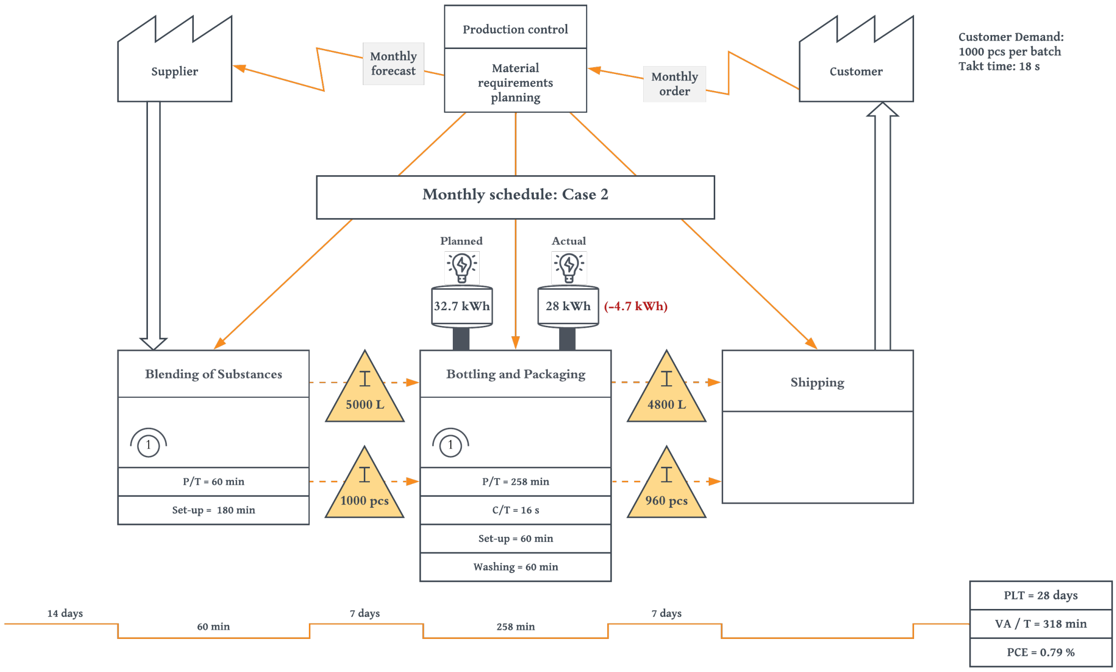

Figure 5.2: EVSM showing the manufacturing process of Case 2.

The steps in the manufacturing process are the same as for Case 1 but involve different times and resource handling. The blending station involves a processing time of 60 minutes with an additional 180 minutes needed for preparing the blend. The processing time for the bottling and packaging station is 258 minutes where an additional total of 120 minutes are required for set-up and washing of equipment. The takt time for Case 2 during production is 18 seconds to keep up with customer demand and the cycle time currently applied is 16 seconds per product. Seen in the mapping is that the total production lead time is 28 days, while activities that create value for the product take 318 minutes in total. The value-adding activities thereby represent 0.79 % of the total time used for manufacturing of Case 2. The energy consumption based on the planned production time is 32.7 kWh, but in reality, based on the actual production time, the actual energy consumption is 4.7 kWh less, resulting in 28 kWh. Besides this, the figure illustrates that from a blend of 5000 liters, the amount of liters that is used for bottling is 4800 liters. The 5000 liters to 4800 liters translates to 1000 possible products that only became 960 finished products. This implies that current practices lead to 40 wasted products during production per 1000 products produced.

5.1.3 EVSM of Case 3

The steps of the manufacturing process of Case 3 and their respective time-consumption are presented in table 5.3 where the times are divided into value-adding and non-value-adding.

Table 5.3: The manufacturing process of Case 3 including steps, value-adding time, and non-value-adding time.

Step in the process	Value-adding time	Non-value-adding time
Lead time before blending		7 days
Blending	45 minutes	
Lead time before bottling and packaging		7 days
Bottling and packaging	144 minutes	
Lead time before being shipped		14 days

An overview of the manufacturing process of Case 3, including the steps, corresponding times, material input and output, and energy consumption, is illustrated in the EVSM in figure 5.3.

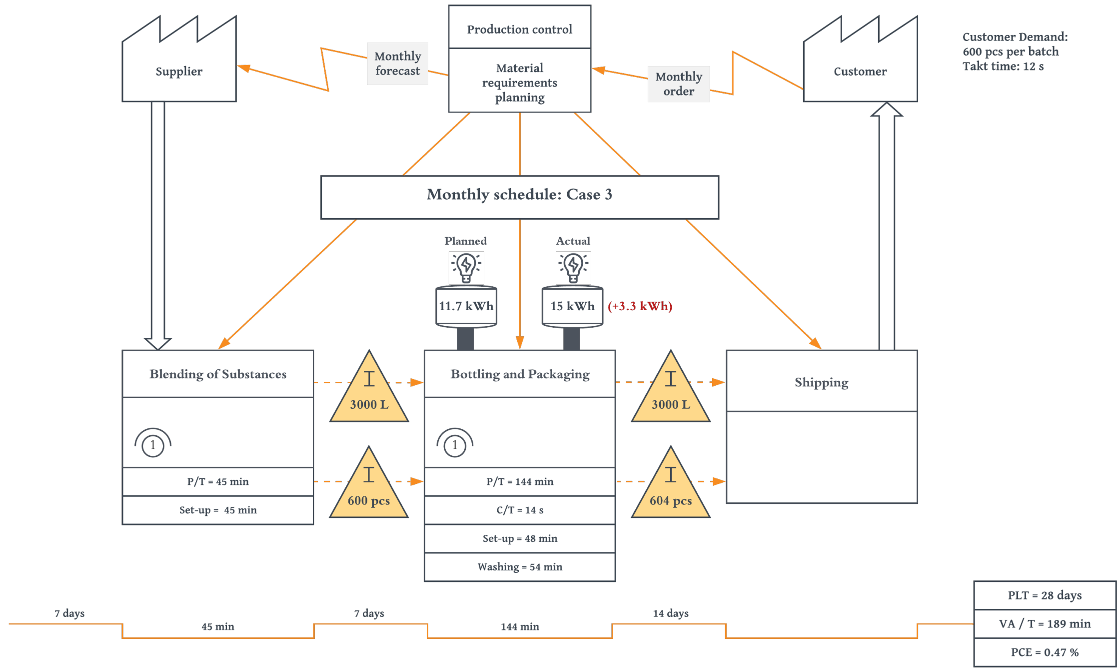

Figure 5.3: EVSM showing the manufacturing process of Case 3.

The steps shown in the mapping include the same steps as for Case 1 and Case 2 but with different durations and resource handling. The processing time of the bottling station is 45 minutes where preparing the blend is accounted for. 144 minutes are used for processing time in the bottling and packaging station where an additional total of 102 minutes are required for set-up and washing of equipment. The takt time for Case 3 to handle customer demand is 12 seconds and, for comparison, the current applied cycle time is 14 seconds per product. The mapping shows that the total production lead time is 28 days. Contrary to the lead time, value-creating activities take a total of 189 minutes. Therefore, the value-adding activities only represent 0.47 % of the total time used for manufacturing Case 3. The planned production time would lead to an energy consumption of 11.7 kWh, but due to an increased production time, the actual energy consumption is 3.3 kWh larger, indicating an energy consumption of 15 kWh. Furthermore, a blend of 3000 liters is needed to produce 600 products. However, as shown from the documented runs, an additional four products were produced from the blend. The reason for this occurrence is discussed in the next chapter.

5.1.4 Waste comparison

For all three investigated cases, different types of waste are present. This can be seen in the figures of the EVSMs where wasted resources are illustrated in terms of time, material, and energy consumption. To be able to compare the results, the cases and their resulting waste is presented in a table. Table 5.4 shows the investigated cases and their respective value-adding time to lead time ratio, amount of blend wasted in liters, wasted finished products as well as increased energy consumption.

Table 5.4: Investigated cases and their corresponding VA/T ratio, amount of blend wasted, wasted finished products, and increased energy consumption.

	Case 1	**Case 2**	**Case 3**
VA/T ratio	3.28 %	0.79 %	0.47 %
Blend wasted	91 liters	200 liters	-
Amount of finished products	-91 pcs (-1.4 %)	-40 pcs (-4.0 %)	+4 pcs (+0.7 %)
Increased energy consumption	6.2 kWh	-	3.3 kWh

What can be seen is that all three cases involve non-value-adding activities that take up the majority of the manufacturing process. This can be said because value-adding activities are shown to take 0.47-3.28 % of the total time in the facility. Although, it should be mentioned that the non-value-adding time also involves activities that need to be executed in order to create value for the products. Besides wasted time, the blend is wasted along the process as seen in the mappings for two of the three cases. Case 1 and Case 2 involve spillage of 91-200 liters of the blend which corresponds to 40-91 finished products that could have been produced. Documented runs of Case 3 instead show that more products were produced than what was planned. Moreover, a waste that is present in two cases is increased energy consumption. Planned production time and actual production time differed in all cases which led to an increased or a decreased machine time. Since the production line requires 6.5 kW, these increased machine times correspond to 3.3-6.2 kWh.

5.2 Production Performance Matrix

The PPM presented in this chapter is a complete version that includes all the factors reported by the shift operators in the shift protocols related to its parameter and sub-parameter. For this study, the parameters (and sub-parameters) are *Downtime S (Planned S_1 and Unplanned S_2), Production Speed P, Environmental and Recycling ER (Energy consumption ER_1, Wasted material in liter ER_2* and *Wasted material in* *pieces ER_3).* Since the focus area of this study puts emphasis on waste factors of the production line, parameters associated with quality standards are embedded in the ER parameters. The quality standards of the company include deviations in either packaging material or the blend and are therefore assumed to be more fitting in the ER parameters rather than having their own column in the complete PPM. Furthermore, there are a total of eight shift protocols documented by the personnel during the data gathering of this method. It is possible to find all of these shift protocols in Appendix A. It turns out that the manufacturing runs of these protocols are made on relatively easily flowing products that are neither soaps nor creams. Therefore, these products are more similar to Cases 1 and 3 in the EVSM compared to Case 2. Before presenting the actual PPM, the results from each of the parameters are presented in their own subsection.

5.2.1 Downtime (S)

There is nothing dividing planned and unplanned downtimes in the shift protocol. Whether a documented time is perceived as planned or unplanned downtime in the completed PPM is distinguished and assumed through discussions with employees. Moreover, the time distributed to setting up the production has been planned by the production managers beforehand. Despite this, sometimes the set-up takes longer than planned and therefore, the set-up time can either be planned or unplanned. The set-up time transitions to an unplanned time when it starts taking longer than planned. When it comes to washing and changeover time, they are thought of as planned downtime in the PPM as they are essential during production hours. The table below includes the production time and the unplanned downtime for each of the eight protocols. The *prod. time* in the table refers to the actual production of bottling, including downtimes. Additionally, table 5.5 below includes a column showing the percentage of downtime in the production time.

Table 5.5: Planned and unplanned downtimes during production.

Shift Protocol #	Prod. time [min]	Downtime (s.p)* [min]	Percentage [-]
1	141	25	18 %
2	123	28	28 %
3	1018	144	12 %
4	340	30	9 %
5	749	87	12 %
6	766	160	18 %
7	350	87	25 %
8	62	6	9 %
Sum	**3549**	**567**	**16 %**

** "(s.p)" deals with values from the shift protocol and the remaining data comes from the company matrix.*

Table 5.6 below includes a compilation of all the planned and unplanned times from the eight manufacturing runs, showing numbers documented in both the shift protocol and the company matrix. Some of the shift protocols did not include a filled-out changeover time and are therefore marked with "-". The *total prod. time* deals with the overall production time - including prod. time, actual set-up time, washing, and changeover time. For those cases where there is no changeover time value recorded, it is not counted in the total prod. time.

Table 5.6: Planned downtime before or after production.

Shift Protocol #	Planned Set-up time [min]	Actual Set-up time [min]	Washing time [min]	C/O time (s.p)* [min]	Total Actual Prod. time [min]
1	120	59	23	100	323
2	120	126	15	120	384
3	120	211	41	-	1270
4	120	68	60	95	563
5	120	178	91	-	1018
6	120	125	65	-	956
7	105	49	87	-	486
8	105	65	210	90	427
Sum	**930**	**881**	**592**	**405**	**5427**

** "(s.p)" deals with values from the shift protocol and the remaining data comes from the company matrix.*

Based on this table, the actual set-up time is lower than the planned one during some of the shift protocols. The total planned set-up time is 656 min while the unplanned set-up time equals 160 min. This indicates that 20 % of the total 816 min set-up time is unplanned. The total washing and the changeover time is 382 and 315 min. This is approximately 8 and 6 % of the total production time which is not currently recorded.

5.2.2 Production Speed (P)

The reduced production speed is found when comparing the planned production time with the actual production time of that run. These numbers are not recorded in the shift protocol and are therefore found in the company matrix. Table 5.7 below includes quantity and speed rates of all the documented shift protocols and the difference between the actual production rate without downtime and the planned production rate in percentage. These values are recorded in parts produced per hour.

Table 5.7: Includes quantity and speed rates of all the documented shift protocols and the difference between the actual production rate without downtime and planned production rate in percentage.

Shift Protocol #	**Planned prod. quantity** [pieces]	**Actual prod. quantity** [pieces]	**Planned prod. rate** [parts/h]	**Actual prod. rate** [parts/h]	**Actual prod. rate, without downtime** [parts/h]	**Percentage** [-]
1	400	389	250	166	201	**80 %**
2	588	588	200	287	371	**186 %**
3	5000	4836	300	287	295	**98 %**
4	1992	1961	275	346	380	**138 %**
5	6400	6400	650	513	580	**89 %**
6	7680	7680	650	602	760	**117 %**
7	972	988	197	169	225	**115 %**
8	300	276	175	267	296	**167 %**

The table above shows that five out of eight (5/8) cases had a faster production rate than the planned one without downtime. These cases are colored in yellow in the table. Since the actual production rate, without downtime, is faster than the planned production rate, the complete PPM does not include a column with production speed as there are no disturbances in the production rate.

5.2.3 Environmental and Recycling (ER)

The environmental and recycling parameters cover everything waste-related on the production line, such as energy consumption and wasted material. The first subsection of this parameter - ER1- includes the energy consumption of the production line. The energy is calculated in a similar manner as before in the EVSM. It is done by multiplying the total efficiency (6.5 kW) by the amount of producing hours. The energy consumption that is calculated in this study covers the additionally increased production time that machines are running. These additional actual running times are found when removing the actual production time without downtime from the planned production time. Since the production run consists of both downtimes and additional actual production times, the efficiency differs. The efficiency is thought to be at maximal capacity during running times and 85 % during downtime. The total energy consumption is therefore the summation of the energy consumption of prod. time without the downtime and energy consumption of downtime. The energy consumption is calculated and presented in table 5.8 below.

Table 5.8: Including the actual, planned, and increased production time with their resulting energy consumption.

Shift protocol #	Actual prod. time w/o dt [h]	Planned prod. time [h]	Increased prod. time w/o dt [h]	Energy consum. of prod. time w/o dt [kWh]	Energy consum. of dt [kWh]	Total energy consum. [kWh]
1	1.9	1.6	0.3	2.1	2.3	4.4
2	1.6	2.9	-1.4	-8.8	2.6	-6.3
3	15	17	-2.1	-14	13	-0.4
4	5.0	7.2	-2.1	-13	2.8	-11
5	11	9.9	1.2	7.7	8.0	16
6	10	12	-1.7	-11	15	4.0
7	4.4	5.0	-0.6	-3.6	8.0	4.4
8	0.9	1.7	-0.8	-5.1	0.6	-4.5
Sum	**50**	**57**	**-7.0**	**-46**	**52**	**6.6**

What can be seen in the table above is that the actual production time without downtime is shorter than the planned one for some shift protocols and thus, the increased production time becomes negative. As a result of this, the total energy consumption of prod. time without downtime also becomes negative for these cases. However, the energy consumption during downtime is positive and the total energy consumption therefore also lands on a positive number. The total increased energy consumption, with downtime, is 6.6 kWh.

The sub-parameter ER_2 contains the amount of blend in liters that is discarded during a production run. The reasons behind the blend being discarded have been covered before and are due to:

- Deviation in the blend,
- Material spillage from IBC/hose,
- If there are less than 5 liters left in an IBC at the end of production.

Sub-parameter ER_3, is, however, divided into additional four sub-parameters. These contain causes why each of the different packaging materials are being discarded and the causes are summarized in the list below.

$ER_{3.1}$ **Bottles are discarded if**:

- Fallen on the ground and become contaminated
- Not filled completely
- Blend is too viscous during density check
- Dented/leaking or having a slanted label
- There is a deviation in the blend

$ER_{3.2}$ **Bottle caps are discarded if**:

- Fallen on the ground and become contaminated
- Broken (leaking, not screwing sufficiently or has holes)

$ER_{3.3}$ **Labels are discarded if**:

- The design of the label rolls makes it necessary to remove labels at the beginning of each roll
- Broken (wrong color, damaged etc.)

$ER_{3.4}$ **Cardboard boxes are discarded if**:

- Broken from the beginning
- Broken during the production

5.2.4 Complete PPM

Despite the complete PPM having new parameters and sub-parameters, the factor groups and factors are more or less identical to the shift protocol. The only added factors in the factor group E. Peripherals are set-up, washing, and changeover time. The factor group F. Unknown factors are additionally inserted in the complete PPM to be able to register energy consumption. The complete production performance matrix is made as a compilation out of all the eight shift protocols and has therefore a total production time of 5427 minutes, including the production time with downtimes, set-up, washing, and changeover times. The complete PPM is added in figure 5.4 below.

Factor groups A-E	Available parameters S		Environmental and recycling parameters ER						Σ factors
	S1 Planned downtime [min]	S2 Unplanned downtime [min]	ER1 Increased energy consumption [kWh]	ER2 Wasted material [Liter]	ER3 Wasted material [Pieces]				
					ER3.1	ER3.2	ER3.3	ER3.4	
A. Work material									0
A1 Density-check (each hour)		5			2				7
B. Production process									0
B1 Refill of bottles and/or bottle caps									0
B2 Refill labels		99					233		332
B3 Refill tape		17							17
B4 Change IBC		139		15					154
C. Personnel and organization									0
C1 Planned meeting	25								25
C2 Unplanned meeting									0
C3 Away from production line		80							80
C4 Take blend to lab for check		10							10
D. Wear and maintenance									0
D1 Technical issues		157							157
E. Peripherals									0
E1 Wait for the blend									0
E2 Deviation in the blend									0
E3 Deviation in packaging materials		15			43	5		27	90
E4 Contaminated packing materials						2			2
E5 Emptying of garbage can		20							20
E6 Set-up time	881	160							1041
E7 Washing time	592			53			90		735
E8 Changeover time	405								405
F. Unknown factors			6.6						6.6
Σ Result parameters	1903	702	6.6	68	45	7	323	27	3081.6

Figure 5.4: The complete PPM.

According to the complete PPM, the longest unplanned downtimes during production are caused by factors *B2 Refill labels*, *B4 Change IBC*, and D1 Technical issues. These factors were also the most frequently documented in all of the shift protocols (according to the shift protocols added in Appendix A). However, the longest unplanned downtime of the total production time is found under *E6 Set-up time*, which is before production. The distribution of all downtimes can be also found in figure 5.6 below.

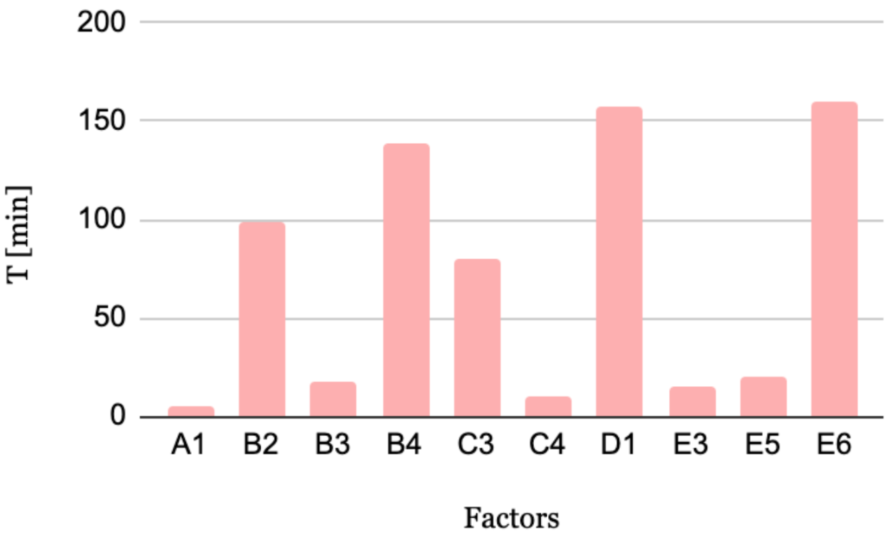

Figure 5.5: Unplanned downtime and their factors.

There is a total of 17 % of the unplanned time (including downtime and unplanned set-up time) during total production time. The factors that have the greatest unplanned downtimes are B4, D1, and E6. The distribution of planned downtime is added in figure 5.6 below.

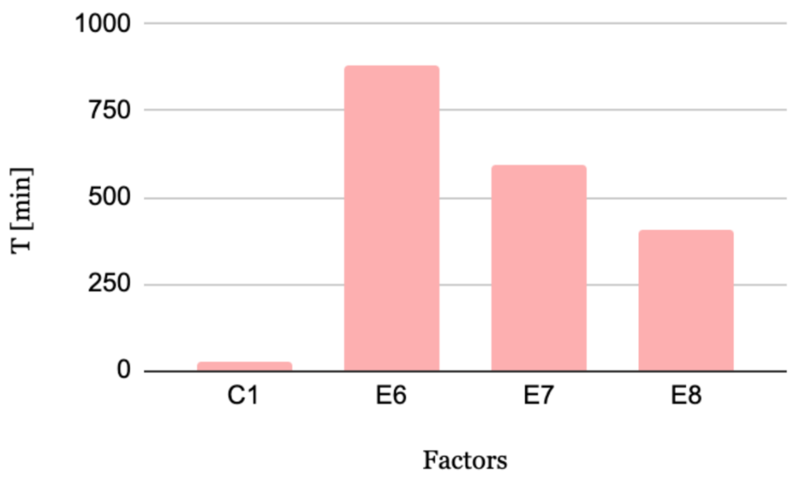

Figure 5.6: Planned downtime and their factors.

The total production time consists of 35 % planned downtime, including planned downtime during production runs as well as set-up, washing, and recorded changeover time. For planned downtime, the most significant contributing factor is E6. Moreover, what can be seen in regard to the ER parameters is that most labels are wasted compared to all packaging materials. This can also be seen in figure 5.7 below.

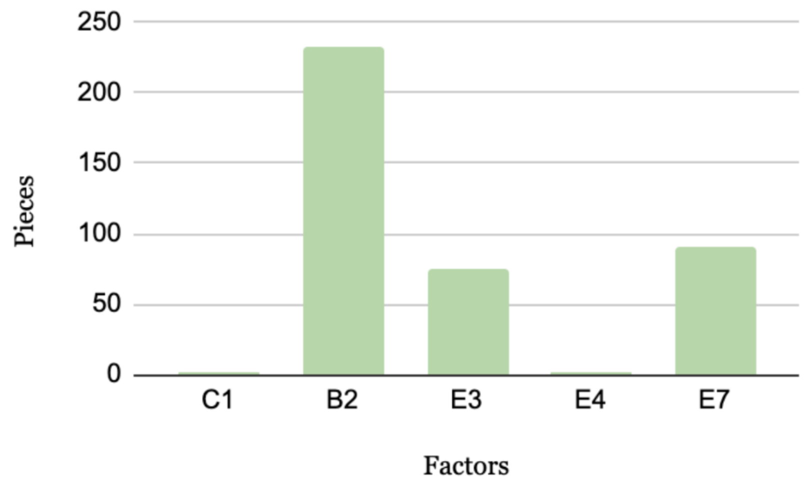

Figure 5.7: Wasted packaging materials and their factors.

Up to 81 % of all the packaging materials that are being discarded are labels and the cause behind this is mostly due to the refilling stage of the label rolls. Despite this, most packaging materials are thrown away due to the quality standard and factor *E3 Deviation in packaging materials* during production. The only product material that is thrown during *E7 Washing time* are labels.

5.3 Updated EVSM of Case 1

The runs analyzed in the PPM include a run, i.e., production run #5, of the same product and batch size as for Case 1, containing data of downtimes, i.e., non-value-adding time, during production. This data is used for implementation in an updated EVSM. This additionally takes into account total minutes of downtime as well as uptime of the process, which is a percentage of how much of the total available production the machines are running. The downtime, as seen in table 5.5, is a total of 87 minutes, which contributes to an uptime of 87 %. This leaves 561 minutes of actual production time. The downtime also affects energy consumption, as energy is consumed during idling machine time. Idling machine time consumes about 85 % of the total capacity and results in energy consumption of 8 kWh during downtime. The remaining time of 561 minutes uses the full capacity of the motors, resulting in an energy consumption of 61 kWh. The total energy consumption, based on both running and idling machine time, is thereby 69 kWh. Moreover, the cycle time is affected by the downtime. The cycle time is calculated using equation 3.7 as shown below.

$$Cycletime = \frac{251}{6309 \cdot 60} = 5.4 \quad \text{seconds}$$

Since the other two cases investigated in the previous EVSMs are not being manufactured in the duration of the study, any data on downtimes for these cases are not retrieved. Figure 5.8 shows the updated EVSM of Case 1 where downtime is taken into account.

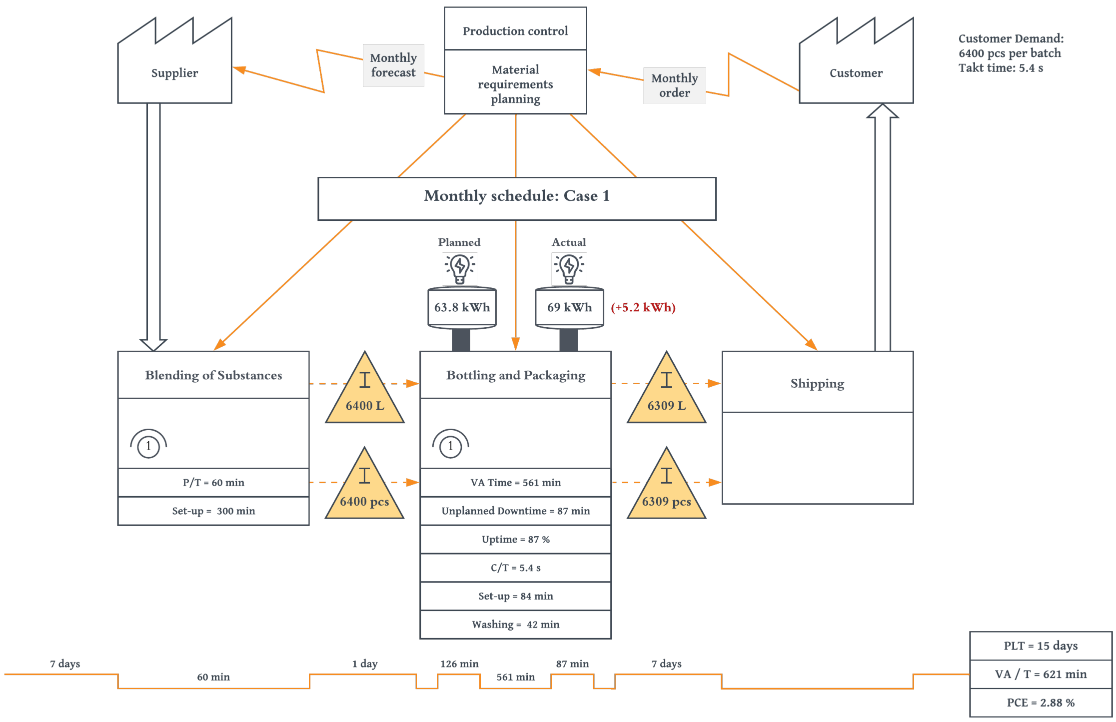

Figure 5.8: Updated EVSM of Case 1

The updated EVSM shows how downtime affects the value-adding time in the bottling and packaging station. Due to a downtime of 87 minutes, only 561 minutes remain which represents the value-adding time. This implies that, of the 648 minutes that are designated for production, 561 minutes create value for the product and the remaining 87 minutes is wasted time. Moreover, the updated mapping shows that the cycle time, when taking downtime into account, is lower with a value of 5.4 seconds. The downtime also affects energy consumption, where the running and idling machine time results in a total increased energy consumption of 5.2 kWh. The updated EVSM shows a more realistic overview of production than the previous EVSM for Case 1 since the bottling and packaging station contains more information about machine uptime and downtime. The information that is received through the updated EVSM can thereby be taken into account when making conclusions of the production station and the manufacturing process as a whole.

5.4 Calculations of Manufacturing Costs

The manufacturing cost is calculated during both an ideal case and an actual case that includes the identified wastes. Thus, this section of the study is divided into two sections. The ideal cost is based on planned production times excluding downtimes or diverse wastes, while the actual cost includes actual production times with wastes and downtimes. In order to further simplify the calculations of the complex production, an average of all the products registered in the eight shift protocols is made. In addition to this, parameters regarding cycle time and production time are based on either the EVSM or PPM.

The only thing that is needed to establish the machine's hourly cost is the planned production time. This time is found in table 5.8, before it is divided by eight to obtain an average value on all the production runs. The different components of the machine cost are summarized in the table below.

Table 5.9: Compliation of the costs needed to calculate the machine's hourly cost.

Initial cost K_0 **[SEK]**	**Maintenance cost ratio** K_{ren} **[-]**	**Area cost** K_A **[SEK]**	**Planned prod. time** T_{plan} **[min]**
1 575 000	0.063	330 000	428

By using the equation 4.1 the machine costs k_{CS} and k_{CP} is 4707 SEK. All the general costs that stay constant for both of these cases are presented in the table below. These values are established in *5.4 Calculations of Manufacturing Cost*, except for the machine hourly cost, and are summarized in table 5.10 below.

Table 5.10: Compilation of the different constant costs needed to calculate the ultimate part per cost.

Material cost k_B **[SEK/part]**	**Machine hour cost** k_C **[SEK/h]**	**Personnel cost** k_D **[SEK/h]**
56	4707 SEK/h	350 SEK/h

With this information, it is possible to look more closely into the two cost cases of this chapter.

5.4.1 Ideal Cost

The cycle time of this case is calculated using equation 3.7, where the planned production time and quantity are used. In addition to this, the planned production time is without any downtime and is found by adding all the production times from the protocols and dividing it by eight to gain an average value. The remaining parameters are also found in the values in the PPM. All of the values needed to calculate the ideal cost are summarized in table 5.11 below.

Table 5.11: Description and values for the parameters needed to calculate the ideal cost.

Description	**Parameter**	**Value**	**Unit**
Planned nominal batch size	N_0	2917	[pieces]
Cycle time	t_0	0.15	[min]
Production time without downtime	T_p	373	[min]
Planned set-up time	T_{SU}	116	[min]
Utilization rate	U_{RP}	1	[-]

The utilization rate for the ideal case equals 1 since it is considered that 100 % of the production time is utilized, and the loss ratios (q) are zero. This assumption is made even though it is not entirely realistic, since an ideal case is calculated. By using the final equation 3.1, the manufacturing cost per part k_{ideal} equals 72 SEK per part, which results in 210 024 SEK per batch.

5.4.2 Actual Cost

The parameters for this case are found the same way as in the earlier case. Despite this, some additional parameters are needed. For instance, the time for free capacity T_{free} is needed for the utilization rate, which is the downtime. When it comes to the loss parameters, both the quality loss parameter q_Q and the production loss parameter q_P are assumed to be zero. The quality loss parameter includes finished products that are discarded due to deviation and in this study, this scenario does not occur. In addition to this, the results of the production speed indicate a negative production speed loss since their actual production rate is overall faster than their planned one and, thus, this parameter is also put to zero. However, when it comes to the downtime loss ratio q_S, it is found when dividing the unplanned downtime from the total actual production time with downtime. The material loss ratio is a combination of wastes for both blend and packaging material. By using the same calculation method as for the downtime ratio, these values are therefore 0.20 and 0.018. Furthermore, the utilization rate is

$$U_{RP} = 1 - \frac{71}{428} = 0.83...83\%$$

Table 5.12 below includes all values needed for the actual manufacturing cost per part.

Table 5.12: Description and values for the parameters needed to calculate the actual cost.

Description	**Parameter**	**Value**	**Unit**
Actual nominal batch size	N_0	2893	[pieces]
Quality loss ratio	q_Q	0	[-]
Downtime loss ratio	q_S	0.20	[-]
Production loss ratio	q_P	0	[-]
Material loss ratio	q_B	0.018	[-]
Cycle time	t_0	0.13	[min]
Actual production time with downtime	T_p	444	[min]
Actual set-up time	T_{SU}	110	[min]
Downtime	T_{free}	71	[min]
Utilization rate	U_{RP}	0.83	[-]

The manufacturing cost per part k_{actual} equals 77 SEK per part, which results in 222 761 SEK per batch. The difference between the cost per batch for the ideal and actual case is therefore 12 737 SEK, which is approximately 13 000 SEK.

5.4.3 Overall Equipment Efficiency (OEE)

The overall equipment efficiency is calculated in this subsection. To calculate the OEE, the unutilized time during production per batch, T_{pbfree}, is needed. To establish this, the actual production time with downtime is used, which is 444 min per batch. This implies that the T_{pbfree} is

$$T_{pbfree} = \frac{1 - 0.83}{0.83} \cdot 444 = 88.6 \quad \text{min.}$$

In turn, by using equation 3.8, the overall equipment efficiency is 56 %.

6 Analysis and Discussion

This chapter involves analysis and discussion of chosen methods and the results. The chapter is divided into discussions of certain topics, including *Use of Methods, Environmental Value Stream Mapping, Packaging Material, Production Performance Matrix, Updated EVSM of Case 1, Increase of the Production Capacity, Calculations of Manufacturing Costs* and lastly suggestions for measurements and other improvements in *KPIs and Production Improvements.*

6.1 Use of Methods

Before the discussion regarding the results of the study begins, the used methods are validated and their reliability is discussed. Since, the methods are divided into *Information-Gathering Methods* and *Data-Gathering Methods* early on, the same division is made in this section.

6.1.1 Information-Gathering Methods

The information-gathering methods consisted of citation chaining as well as observations and discussions. The use of citation chaining was a suitable method in order to gain knowledge about sustainable and resource-efficient production in general, but also about the methods that were performed. The information that was collected is concluded as being relevant and from reliable sources as they either were found through the search engines Google Scholar or through published books.

The observations and discussions used were in the form of an open interview and only executed when needed. This implies that the discussions have not been strictly documented whereas no structural questions were used, but instead, direct questions were asked. Besides this, some of the information gathered through discussions involve confidential information, which results in the discussions not being presentable, since sensitive information cannot be leaked. Although the discussions were conducted with multiple employees in different departments, not all operators were consoled, which can raise questions about certain biases. However, overall, the methods used for information gathering are concluded as being reliable approaches for the study, since they have set a profound foundation of information that helped guide the execution towards the goal of the study.

6.1.2 Data-Gathering Methods

The method of EVSM is overall an approach that gives suitable information about which activities in production give value and which do not. It is a valuable method for mapping the manufacturing process as a whole and seeing the relationship between value and non-value-adding tasks. One limitation that it provides, however, is that for highly flexible manufacturing systems it is challenging to gain general results as products differ from one another. EVSMs are therefore more useful for manufacturing systems that are more standardized to produce the same type of products with similar lead times and production times. For the defined goal of the study, it is an appropriate method as waste can be distinguished. Moreover, it indicates what tasks and activities that should be further analyzed in order to reduce and optimize waste-related practices.

PPM is a suitable continuation method on EVSM for this study. During the execution of PPM, factors causing diverse wastes and downtimes on the production line are distinguished. By basing the different factors on the identified activities in the EVSM, the PPM becomes an analysis that is made in greater depth. In order to find patterns between downtimes and wastes and their causing factors, a hefty amount of shift protocols have to be examined. The more shift protocols, the better foundation for a pattern from which a conclusion can be made. However, it is concluded as a suitable method to reach the goal of this study. The calculation of manufacturing costs in this study is solely and entirely based on one source. This could therefore question the reliability of the method since it only takes one perspective into account. Despite this, the book that is used for this source is purely based on sustainable production systems, made for educational purposes and is considered valid. Furthermore, in the study, the calculation of manufacturing costs per part is used exclusively to gain a figure on how much waste affects the final price of a part. To make it more reliable, the method could have been compared with other ways of calculating the manufacturing cost but that is more relevant if that was the main purpose of the study.

The use of KPIs to improve a production system is highly relevant since it provides measurable goals to work towards. In this study, the existing KPIs at the company were examined to see what was currently being measured. To develop measurements based on the visions of the company, KPIs related to waste are based on the results of the execution. The results are evaluated throughout this chapter and lead to suggestions for KPIs and production improvements that are presented at the end of this chapter.

6.2 Environmental Value Stream Mapping

The main target when executing an EVSM is to distinguish waste-related problems in the manufacturing process, which has been shown to be achieved in this study. This section presents analysis and discussion based on the method of EVSM and is divided into *Identification of Activities, Production Planning* and *Analysis of Investigated Cases.*

6.2.1 Identification of Activities

The first step was to divide the activities into value-creating, essential non-value-creating, and strictly non-value-creating activities. This made it possible to see what steps actually gave value to the final product and determine what steps should be optimized or even completely removed. The division set the base for the upcoming mapping and PPM and thereby was the most crucial step in the execution. The division had to be carefully executed in order to gain desired results based on the goal of the study. The activities presented in table 4.1 were chosen based on observations on the production line as well as from insight from operators and production planners of the company. This gave a profound background to the upcoming division since some steps may be noticeable just by observing the process, while some need to be explained by experts in the process, i.e., the employees. Based on this, the chosen activities can be concluded as being relevant to the investigated cases as well as the downtime factors chosen for the PPM. The non-value-adding activities, as stated before, are considered as waste and should be removed. Although it can be challenging to completely remove these from the process, it is important to identify waste to create awareness of what needs to be further looked into in order to optimize the waste.

6.2.2 Production Planning

Production planning differs between each product, but the overall manufacturing process is more or less the same since the same activities are being performed. There is an apparent difference in lead time, which depends on how many raw materials are used for the blend, how challenging the blend is to achieve the correct mixture as well as how highly the product is demanded. These factors affect the waiting time between each operation, and therefore decisions in planning are chosen based on the product. As of now, the company normally plans production a month ahead but for some prioritized orders, they can alternate production in order to complete the prioritized batches first. For orders that the company knows are recurring, raw and packaging materials are stored, which does not affect the inventory space relatively much since it will be used within a month or two. Furthermore, it is not an apparent issue with raw materials taking up large space in storage since the company does not necessarily order big formats of raw materials if it is not required to produce the blend. Although, in some cases, bigger formats can be ordered from the suppliers if it is more economically beneficial, which creates the problem of inventory space. However, in the current state, this is not a significant issue and is therefore something that is not perforated to optimize. A difference is also found in the lead time between the blending and the bottling and packaging station, as the time can be shorter for some products and longer for others. Generally, hygiene products have a longer waiting time since they have to go through the bacteria test of three days, while other products only go through the laboratory check to evaluate the density and other properties. This is something that is necessary to perform, and thus, this time is required in order to create value for the product. However, it is important to measure the actual time needed for checks and potential alterations to see if there is room for decreasing the time planned for these tasks. The lead time when production is finished until the products are shipped to the customer has a high dependency on the customer demand. The company does not always produce based on orders but produces a surplus to keep in storage, which is why lead times can reach up to a month. This means that the company does not strictly follow JiT production, which could help in avoiding tied-up capital to finished products.

6.2.3 Analysis on Investigated Cases

The investigated cases used to create EVSMs were chosen based on how applicable the mapping could be used in general production. As stated previously, the chosen cases represent the least challenging, time-consuming, and most frequently produced product, the most challenging and time-consuming product, as well as the most frequently produced product from the Greenium line. Both Case 1 and Case 2 were chosen based on what results would help in determining generalized improvements, which is why the least challenging product is chosen as well as the most challenging one. What further supports the decision of these cases is the fact that Case 1 is the most frequently produced product in production, which makes the possible improvements from the analysis more applicable to the company. Case 3 was chosen per request from the company with the purpose to compare their more sustainable product line with the regular product lines. By adding another case to investigate, a more generalized discussion can be made since more data is analyzed. Although the chosen cases were meant to contribute to generalized results, the results do not fully represent a generalized manufacturing process. This is because of the highly flexible production system with significant differences in lead time and value-adding time. However, in order to execute the analysis during the present time frame, simplifications had to be made to be able to achieve an overview of the manufacturing process.

6.2.3.1 Manufacturing Process

What was first examined in the analysis of the cases is the manufacturing process as a whole. All three cases went through more or less the same steps in order to become finished products. The biggest difference between the cases is the lead time between each operation, which is highly affected by the blend that is to be produced. Products with more raw materials generally have a longer lead time before being moved to the blending station since more raw materials need to be delivered from a supplier. This can result in a relatively long lead time as opposed to products that only require a few raw materials. This could be seen when examining Case 2, which included the most raw materials out of all the investigated cases. Due to the difference in delivery times from the supplier, raw materials normally are stored for 14 days before being processed. This is a significant difference compared to Cases 1 and 3 which normally had a lead time of seven days, and both had fewer raw materials. This implies that the number of different raw materials included in a blend has an impact on the lead time before being processed. The time required for preparing the blend for the cases varied from 45 to 300 minutes. This is due to the amount of blend needed to produce the batches, where for smaller batches less time is needed to add the raw materials, and thereby for larger batches more time is needed. The results of set-up time for blending of the different cases, therefore, are realistic and are concluded as being at a required expenditure of time.

6.2.3.2 Production Time and Speed

The production time for all cases differed, in which the batch size was the main contributor to a longer duration. Case 3 had the lowest batch size of 600 units, and therefore had the shortest processing time, whereas Case 1 with the highest batch size of 6400 units had the longest. A higher batch size generally increases the risk of downtime, since the same activities have to be performed more times. This includes changing of IBCs to bottle more products, refill of packaging material as well as waiting for the transport of goods. This is why the processing time for the investigated cases differs. What can be seen from different runs of the same product, however, is that the planned times for set-up and production are not normally achieved, as shown in tables 4.2, 4.6 and 4.10. The primary difference is in the set-up time, which could vary by multiple hours difference. One reason for this occurrence is presumed to do with differentiation in working habits among the operators. An operator with more experience on the specific production line will ultimately finish the set-up quicker than a relatively new operator due to familiarity. Another factor that has an impact on the set-up time is what kind of product is produced on the line prior to the new batch. If the previous batch involves products that are similar to the new one, the set-up time can be shorter than if a drastically different product is produced. This is because the machines need to be calibrated to fit the new batch along with adjusted quality checking equipment and packaging material. Furthermore, another theory on what can affect the set-up time is the viscosity of the blend being bottled. A more viscous product may be more challenging to prepare since the blend is more prone to stick to pumps, hoses or pipes, which ultimately will affect how quickly the blend can be transferred into bottles. This, however, did not show in the results from the investigated cases since the set-up time for Case 2, which is a more viscous blend, and Case 3, a more easy-flowing blend, is nearly the same. Although this theory could not be proven with the chosen methods of EVSM and PPM, it is realistically a present reason for extended set-up time in production as was noted during observation.

In all cases, production either ran for longer or shorter than planned. The increased production time directly affects the production speed since a longer production time implies a slower production speed. This is why the defined takt time did not match with the actual cycle time for all cases. Case 1 had a planned production time of 9.9 hours but ended up being produced for 10.8 hours. This implies an increased production time of 0.9 hours that was needed in order to produce the demanded amount of products. However, based on the actual production time and speed in table 4.3, the resulting amount of produced products is less than what was originally planned. This, although, can be discussed as there may be extra produced products already in storage, which supports the decision of not producing the planned amount. On the other hand, the results of already having extra products in storage can induce confusion of exactly how many products are needed in the specific production run. This calls for the need to alternate the planning of batch sizes to avoid any confusion. Case 2 instead showed that production ran for a shorter time than planned, indicating a time of 0.7 hours shorter. Even though this time can be seen as saved time, the planned amount of produced products was not reached. Furthermore, a shorter production time may cause production standstill, if the remaining planned time is not used for other production. Case 3, like the other cases, indicated an increased production time which durated for 0.4 hours. What differentiates Case 3 from the other two cases is that the planned amount of produced products actually was achieved with a margin of four extra finished products. The reason for being able to produce more products than planned may have to do with the added amount of blend in each product. As stated previously in this study, the amount of blend filled in each product has a margin of a few milliliters below and over the planned amount. This can result in the filling of more bottles if the amount of blend is lower than planned. Another reason why more products than planned are produced can be that the initial blend used for production contains more than what is needed. This implies that more raw materials are used for the blend than what is required in order to produce the demanded amount of products, which does not favor the sustainable use of raw materials. Although it is remarkably more efficient to produce more products rather than less of the planned batch size, consequences can arise. Overproducing leads to an overstock of products in storage, which can create issues in storage planning. The space needed to store the surplus of products could have been used to store other products that may be present in prioritized customer orders. Another complication that results from increased production time is that the operators are required to be present by the line for a longer time than planned. Not only does it affect the operators as they may be exposed to more manual work, but production is not executed according to plan. This is because the increased production time consumes resources in terms of the workforce that could have been used for other tasks, as well as may contribute to additional labor and facility costs.

Moreover, as a result of the increased production times in Cases 1 and 3, more energy is consumed than what was initially planned. The machines run for longer, which, as presented in the EVSMs in figure 5.1 and 5.3, resulted in increased energy consumption of 6.2 kWh and 3.3 kWh. Consequently, this does not favor sustainable production from not only an environmental standpoint but also an economic standpoint as, besides consuming more energy, the cost of machine time increases. Ultimately, although increased production time may contribute to producing more products, it has significant effects on energy consumption and resource allocation.

6.2.3.3 Spillage of Blend

Blend spillage has been shown to be present in two cases. The EVSMs in figure 5.1 and 5.2 show that from the initial blend, several liters are wasted during production. Looking at Case 1, the initial blend of 6400 liters was meant to be used for the production of 6400 products since each product should contain one liter of the blend. However, only 6309 products were the outcome after production was finished, which indicates that 91 liters of the blend were wasted along the process. This implies that the company produces 1.4 % fewer products of Case 1 than what is planned. It should be noted that this statement is only an assumption as only one production run could be examined. Wasted blend is present for Case 2 as well, as it involves a spillage of 200 liters of blend that occurred during production and an indication that the company produced 4.0 % fewer products of Case 2 than planned. As for Case 1, this is only an assumption that is based on a few production runs. The batch size for Case 1 was nearly six times bigger than that of Case 2. However, almost three times more wasted blends occurred in Case 2 than in Case 1.

The most significant factor as to why more spillage transpired for Case 2 is assumed to deal with the viscosity of the blend. Thicker blends generally are more challenging to retrieve from the IBCs as they are more prone to sticking to the sides of the container, but what also challenges the bottling of products with higher viscosity is that the blend also has an increased risk of getting stuck in hoses and pipes. Although the viscosity has a significant impact on the material spillage, it is not impossible to reduce the waste. Certain changes in practices can have an effect on how much material is ultimately wasted. For example, the amount of raw materials used for preparing the blend should be more precisely added, so that the correct amount is added. This will help in avoiding preparing too much blend which then is more likely to be discarded. These are only assumptions based on the EVSMs as they could not offer reasons as to why material is discarded during production. More specific reasons are presented and discussed below 6.3.3 Environmental and Recycling that are based on the production runs analyzed using PPM.

Case 3 differed from the other two investigated cases, as no material was wasted, based on the used production data. In contrast, four more products were produced than the planned amount. This is assumed to be a result of poor documentation of runs, as it implies that more blend is added in products than what was initially made. One reason for this occurrence could be the result of the minimum amount of blend being added to the products, which essentially means that more bottles can be filled using the same blend. Another reason for the extra produced products is that the initial blend was incorrectly documented. This can be said since the amount of blend may have been higher than what was planned, resulting in more products.

6.2.3.4 Types of Waste Present in Production

The analyzed cases all indicate that different types of waste are present in production. The waste illustrated in the EVSMs is divided into the seven types of waste mentioned in *Chapter 1 Introduction.*

Overproduction
Cases 1 and 2 do not indicate overproduction, as the planned amount was not achieved. Case 3, on the other hand, included overproduction of four products. Although overproduction is indicated in this case, it can be said that the company does not necessarily overproduce products in general. Instead, it is apparent that they underproduce for the most part. This can be supported by the EVSMs in figure 5.1 and figure 5.2. For both Case 1 and 2, the resulting finished products indicate blend spillage along the way. For Case 3, on the other hand, the resulting products indicate more careful handling of the blend since more products are produced than planned. Waste in terms of overproduction should therefore not be of focus to optimize.

Waiting
The waiting time is, for all three analyzed cases, the main contributor to wasted time in the production process. Waiting time involves the lead time in which raw materials, blend,s or finished products are on hold before each operation can begin. Compared to the value-adding times, waiting in between processes consumes a significant amount of

time that could be used for creating value for the product. The primary reason for the long waiting times is because of production planning, where factors such as different delivery times for raw materials and laboratory check-ups are taken into account. Some of the total waiting time is necessary, such as adding raw materials to the blend, the laboratory bacteria test for hygiene products, the laboratory density check for all products, filling of IBCs, and transportation of goods between each station. However, more waiting time is planned in the current process in order to have a margin if unforeseen deviations in the blend are found. This involves the lead time between the finished blend and the bottling of products may begin, which is a time that should be optimized. Moreover, the time when raw materials are stored before being moved to the blending station differs due to several orders from different suppliers with different arrival times. This leads to a relatively long lead time before manufacturing may even begin, which is why order planning also should be optimized.

Transport
Raw materials, packaging materials, blends, and finished products are transported several times during the manufacturing process. Transport is needed to get raw materials to the blending station, retrieving IBCs for the blend, move the blend for laboratory check-ups, move the finished blend to the bottling station, get packaging materials for the products, and lastly move finished products to storage. These are all necessary in order to ultimately ship the products to the customer. However, other transports may occur when the blend needs to be altered due to found flaws. Scenarios, where this occurs, are, as stated before, more common for hygiene products. This results in the blend being moved between the blending station and the laboratory more times than if the blend was to be correct in the first place. It should therefore be of interest to improve the waste in terms of transportation.

Extra processing
Extra processing in the analyzed cases can be challenging to determine and distinguish from necessary operations. Production of blends, and especially hygiene products, needs to involve processes that preserve the raw material. This is why the products require careful handling during the whole manufacturing process since they must not under any circumstances become contaminated. Observation and investigation of the input that is currently being used in the facility has led to the conclusion that current practices, that can fall under extra processing, are necessary.

Inventory
As stated under overproduction, it can be assumed that the company does not have an overload of the same product in storage. Although, as products are stored for an estimated 7-14 days after finished production, inventory is wasted that could have been used for other products. The time frame from which products are finished until they are shipped to the customer should therefore be reduced in order to avoid wasted inventory. Furthermore, inventory of raw materials and empty packaging materials take up more space in storage in comparison to finished products. For cases that require several different raw materials, this becomes even more apparent. More inventory space is needed if greater demands are ordered from customers, which is why the time when goods are in inventory should be minimized.

Motion
Waste in terms of motion refers, in the investigated cases, to the time when workers manually move the blend, product, or packaging material. This includes moving samples of the blend to the laboratory check-up as well as retrieving and refilling packaging materials such as bottles, bottle caps, labels, and cardboard boxes, (tape, and plastic wrap). Most motions currently present in the facility are assumed to be necessary but have the potential of being optimized. This is to gain more time for other value-adding activities.

Defects
Lastly investigated is waste in the form of defects. Packaging materials are ordered from suppliers and may sometimes have deviations when arriving at the manufacturing facility, which is thereby considered defects. Defects also refer to deviations in the blend, which is crucial to minimize when handling hygiene products. Although, since laboratory check-ups are frequently implemented before the blend is transported to the blending station, this does not often occur on the actual production line. Within defects, the wasted blend is considered. As seen from the EVSMs of Case 1 and 2 in figure 5.1 and 5.2, several liters of the blend is wasted during production.

As stated before, the investigated cases involve products that are highly different from one another. It is therefore challenging to state the exact issues of production in general, but assumptions can be made.

6.3 Packaging Materials

Currently, the company addresses the recycling matter by having products that can be separated to facilitate their recyclability. The new product line Greenium, that the company launched, takes the issue to the next step by increasing the recyclability and the percentage of recycled materials in the product itself. Furthermore, the company is overall opting for materials with higher recyclability that do not interfere with the working environment around the bottle and are adept to withstand highly chemical blends. For example, only thin-walled PET bottles are used in contrast to thick-walled PET bottles as the latter mentioned cannot be recycled. Despite this, there are difficulties when it comes to the recycling of some of their products. The biggest difficulties they encounter have to do with either the different materials involved in the product or the indiscernibility of the lid or label of some of their products. They are in the process of finding new materials, of harder plastic, which can be used as a spring in the spray bottles, for example. The idea is to substitute metals for plastics that can be recycled at the same time. Another improvement could be to have all their labels in plastic instead of having some on paper. The paper labels are cheaper but it might increase the value of the product if it can be fully recycled. In addition to this, to check further on the environmental impact of materials, the company can conduct a life cycle analysis (LCA) on the materials and the product to see recycling possibilities in a future study. In that case, this study would have given the company a better understanding of how the product is recycled but also where the product ends up after use.

6.4 Production Performance Matrix

The analyzed manufacturing line covered in this study is fairly flexible and it has therefore been difficult to cover the whole reality behind the line. The whole line is attempted to be covered in the execution of the PPM since the protocol was aimed for every production run the company had. However, only eight protocols are examined in this study in order to identify downtimes and waste factors. This is unfortunate since the study covers more than two months of data gathering of the company, which implies that at least seven shift protocols could have been received for each of these weeks. The reason behind the low amount of received shift protocols could be due to difficulties in keeping up both production and recording of the protocols at the same time since there is only one operator at the line. It could also be due to information being left out during the handover of the shift protocols to the operators.

Moreover, by looking at the values in table 5.5 it is possible to see that two values stand out. The actual set-up time for shift protocol #3 and the washing time for shift protocol #8 is much greater than the remaining values. The reason why these times are longer can either be because the changeover time was also taken into account, that the operator forgot to stop the time during counting, or that it simply took longer that particular time.

In addition to the company having a flexible manufacturing line, it is important to mention that each and every operator is working in their own way and it has therefore also been challenging to provide an overall homogenous image of the production. Despite this, the received shift protocols covered enough information to gain a perspective of the factors behind downtimes and where the production planning could possibly be improved. These perspectives could afterward be scaled up to match the entire production and make it more applicable in a real scenario. For example, there are some factors in the PPM that are completely empty while others have been registered several times. This gives an indication of which factors are the actual causes behind downtimes and waste and should therefore be examined in greater depth. The different factors are discussed in this subchapter of the study where optimization prerequisites are mentioned.

6.4.1 Downtime

Generally, when looking at the complete PPM from the results it can be seen that only a few factors have been recorded during these eight shift protocols. This may be due to the fact that some factors do not occur during some production runs. However, since the shift protocols cover eight different production runs, it could also imply that a pattern is found. There are only 10 out of a total of 15 factors that cause downtime during the examined runs. These factors are *A1, B1, B3, B4, C1, C3, D1, E3, E4* and *E5*. The factors that stand out of these are the *B2 Refill label, B4 Change IBC*, and *D1 Technical issues* since they cover 56 % of disturbances during downtime.

The production is able to still running while some packaging materials are added. If, for instance, there was a downtime when refilling bottles and caps, this downtime would be considered superfluous. However, refilling labels is a practice on the line where production has to stop. This factor has been recorded for half of the received shift protocols and might be due to the size of the label roller for that run. The label rolls are different in size and, thus, if a batch is smaller than the number of labels on the roll, a refill of labels is unnecessary. Additionally, the production has to stop during the change of IBC and is therefore also a necessary downtime that is recorded for every shift protocol, except for three of them. Again, if the quantity of the production does not exceed the capacity of the IBC, a change is not needed. Even though these last two mentioned factors are considered necessary downtimes, there are ways to optimize them. One considerable improvement includes a planned downtime by the company when there is a need for a change of either label roll or IBC, for example. In addition to this, by improving the working method around them and standardizing these working methods, an accurate time span for these necessary downtimes can be implemented in the planning as well.

Moreover, technical issues are a redundant downtime, which was also recorded in every shift protocol except for three. The reason behind technical issues is not specified in this study, as it was not desired by the company. The company already has an existing protocol for its technical issues and is handling this issue separately from this study. However, when looking into optimizations of technical issues, a few can be found. For instance, when a technical issue occurs, the line operator has to wait for a technician. If the factors behind the technical issues are clarified, operators could be educated on this matter. This would exclude waiting for an external employee and therefore minimize this downtime. Since downtimes in regards to this factor happened several times in the shift protocols, it could also be possible that the machines need renewal or maintenance. This, however, calls for a new basic investment of a machine and brings up new questions regarding, i.a. level of automation and is therefore not considered as an option at the time of writing.

Sometimes the set-up time takes either longer or shorter time than planned. The reason behind this is most likely because of the order of the production set-up as explained earlier in *4.3.1 Remarks from Observations and Discussion for PPM*. Despite this, it could also be due to the working methods of each employee - an imaginable improvement, is thus, to standardize this as well. Washing and changeover times are also necessary times during production hours and working shifts. There is no planned time for the washing or changeover time and only the washing time is currently recorded by the company. A possible optimization could therefore be to start documenting the changeover time and leave a planned time for both of them. This would need an approximation of how long the washing and changeover take. When finding these times, causes for unplanned downtimes in regard to these factors can be distinguished as well. For instance, the techniques for washing could be standardized and if it takes additional time, it is considered as a downtime. Since a changeover is only made when required, when and how long this take could be found accordingly with the order of the production set-up. By doing this, improvements such as assuring and streamlining the overall planning of the production site could be made. Lastly, changeover time is set-up time performed by technicians and a possible way to go around this would be to educate line operators to execute it themselves. This would in turn minimize the wait for a technician and yet again streamline the production line.

In summation, there are some types of necessary downtimes that happen in approximately more than half of their runs and are currently not added to the production time. By identifying and separating their necessary and redundant downtimes, the overall planning of the production managers would be more efficient, and in turn, it would be easier to pinpoint additional waste. Additionally, it is important for the company to include downtimes in their planning while still being able to distinguish planned time in a well-functioning process. If the line operators were informed on how to solve technical issues and changeovers, these could possibly lead to less downtime. Additionally, if working methods were more standardized, in regards to setting up, washing, and other executions during the production itself, some downtimes could be minimized. Above all, it is important that the company starts documenting more of its production times since it is significant and affects the total production time and working shifts. These documentations could take inspiration from the Kanban methods.

6.4.2 Production Speed

According to the results, most of the production runs exceed their planned production speed. This is the reason behind the production speed not being added to the complete PPM. Due to this result, it can be established that the defined cycle time is too long for five of the examined runs. It is necessary to recalculate these cases' cycle times in order to define an accurate cycle time that may be used in future planning decisions. In order to avoid this problem going forward, it is essential for the company to differentiate between cycle time and takt time (pace). However, due to the results, it is presumed that the company has the ability to handle a higher capacity than currently utilized.

Furthermore, the third case is the closest to its production speed and cycle time since it has a speed that is 98 % of the planned one. The ideal scenario is that each production speed equals more or less their planned production speed once the downtimes have been removed. The reasons why the remaining two runs have a lower pace without downtime are unknown factors. These unknown factors could be that production speed has been recorded insufficiently, or it is most likely that employees have not recorded additional actual downtimes. In addition to this, it could be imaginable that the cycle time is too short for these cases, which also occurred in the investigated cases of the EVSM. It is not inconceivable that the company encountered this problem of cycle times on their flexible manufacturing line. Possible factors behind the slower pace can be discussed but never assured in this study. Thus, it is essential for the company to make a follow-up of this study and determine both well-defined cycle times but also unknown factors. Lastly, if there would be an overall production speed loss in this analysis, its value would have been registered in F. Unknown factors in the complete PPM.

6.4.3 Environmental and Recycling

In the complete PPM of this study, the quality and ER parameters were merged together. This is done since the study emphasizes the waste parameters of the company. This limits the overflow of different result parameters and thus, if a different approach is needed, this should be avoided. Despite this, the merging resulted in an insight into the amount of wasted materials and the quality factors behind these.

The first subsection of ER parameters covers the energy consumption of the production line. To begin with; the value of energy consumption added in the PPM is based on somewhat unrealistic values. This is due to the fact that this number does not take peripherals into account. For example, the heating and light system is not covered in this study. Additionally, simply because a motor has a certain capacity does not imply that the machine is operating at its maximum capacity while producing. The results might therefore not be completely accurate in relation to reality. Moreover, according to the results, the company is using a higher total amount of energy than planned. However, the energy consumption without downtime is lower than planned, which implies that more energy could be saved without downtime. It is also possible to establish this from table 5.8 in the results when comparing the *total energy consumption* with the *energy consumption*. By including downtime in the planning time, it becomes easier for the company to optimize their time and therefore also track their waste. The energy consumption value is registered in *F. Unknown factors* in the complete PPM since the factors behind the increased production time are unknown.

The second subsection includes wasted materials in matters of the blend. In the complete PPM, it is distinguished that the blend is either wasted during the change of IBC or at the end of production - during the washing and cleaning of the line. As established earlier, during the change of IBC, an amount of blend is spilled either into drains on the ground or a bucket placed underneath the opening of the IBC. This amount is preserved and used for the re-bottling of other products, which favors the sustainable use of raw materials. The amount of blend being spilled differs from employees' working methods but is also based on the type of product. A more viscous blend does not have the same emptying rate as an easy-flowing blend, for instance. The production runs documented in the shift protocols did not include products of this type, which is why conclusions regarding viscosity and emptying rate cannot be drawn in this study. Furthermore, only 15 liters of the blend is discarded due to this factor out of all the shift protocols and it was only one protocol that included blend spillage during the IBC change. Judging by the observation of the production lines, this might not conclude the whole total amount of spilled blend during the eight production lines, and it is possible that employees assessed that the amount of spillage was too little to record. Yet again, this shows the importance of documenting production runs in order to record occurring wastes.

Furthermore, when the production line is to be cleaned after production if the leftover quantity is estimated as insufficient to save, it is thrown away. Another reason why the blend is wasted at the end of production could be due to the washing and design of the IBCs. It might be difficult to retrieve the last amount of blend in the IBC due to its design and this is therefore wasted during washing. In addition to this, it is even more difficult to empty out a viscous blend. Despite this, none of the products examined in the shift protocols are viscous and this is therefore not one of the reasons why the blend was thrown away for this particular study. An improvement for this could be to make a more precise amount of blend at the beginning in the blending station. However, it seems that it is difficult to establish another improvement for this, but is important to mention in this discussion about waste and its factors.

The third and last subsection deals with wasted packaging materials on the production line. A few bottles were discarded after the density check during production. The main reason behind this is due to the fact that; once the density of a blend in a bottle is checked and the blend is poured back into the IBC, it is impossible to ensure that the quantity of blend inside the bottle is correct if it were to be bottled again. Therefore, it is safer to throw away the bottle since having the correct amount of blend in the bottle is a value setter for the customer. It is also considered too complicated and time-consuming to wash these bottles to refill them again while maintaining sterile conditions. Additionally, only a few bottles are discarded each run due to this factor compared to the total amount of discarded bottles, and therefore, further improvements to this factor group (*A1. Density-check*) seem unnecessary. Moreover, *E3 deviation in packaging materials* is the biggest factor behind packaging materials being thrown away. Whether this is because of deviations occurring before or during production is unclear. Either packaging materials are broken during production, which might lead to other downtime factors such as technical issues, or they were already broken in the sealed packaging. By pinpointing exact causes, these numbers can be reduced, which in turn reduces waste and optimizes the line further.

Bottle caps are thrown away if they are dropped on the ground, which ensures the sterile conditions of the end product. It is more desirable to throw away a contaminated cap than to destroy the value of the entire product, but even so, it is considered waste. However, only an amount of 2 caps are recorded to be thrown because of this factor. Not enough caps are discarded per run for this to be a major problem, thus, it seems excessive to put more emphasis on this. When it comes to labels, these are the most thrown-away packaging materials. As seen in the complete PPM, this happens during *B2 Refill labels* and is most likely due to the design of the rollers. However, the only product material that is thrown during *E7 Washing time* are labels and this is most likely due to the difficulty of saving rolls with too few labels. A question that is raised is if the producers of the rolls can develop a better design for the rolls - a design that leaves room for the installation of rolls on the line and is more standardized in the number of labels. Thus, this appears to be a problem beyond Clemondo's control. On the other hand, it is conceivable that the line operators could save the first labels that are simply thrown away, but this also requires a time adjustment to be able to devote time towards this. This is an imaginable improvement since this practice is already being used by employees on some products.

6.4.4 Improvements and Future Studies

The production performance matrix of this study is limited to examining the company's specific production line and, thus, does not take any other stages of the manufacturing process into consideration. During observation of the company's working method to gain a broad perspective of the production site, it was noticed that plenty of raw materials is wasted during the blending station. Therefore, there is potential for the company to further optimize its whole production and look into other stations as well - such as the blending station. Overall, this study is the first analysis for this company that calls for future analyses. The study does not include all parts of the manufacturing process but has laid the foundation for waste analysis and enables future in-depth analysis. For future studies, however, it is desirable to include several production runs that cover many different products in order to create a more accurate picture of reality. As of right now, the company has to reconsider the cycle times for some of its products and get better at documenting and separating parameters regarding their production such as downtimes, set-up times, washing, changeover times, and other waste. In order to structure their analyses better, it would be beneficial to be more selective with which runs and products they examine and to analyze one product at a time. The reason why different products are analyzed in this study is that an overview of the production was desired. Lastly, the analysis could have included monitoring of lights and heating systems, etc. to establish a more realistic energy consumption and is therefore considered an improvement for this study and an additional possibility for a future study.

6.5 Updated EVSM of Case 1

The updated EVSM involves more descriptive characteristics of the manufacturing process, with downtimes being added to represent an actual scenario of production. This helps in establishing a more realistic overview of the process as well as viewing the value-creating and non-value-creating activities in production. By adding downtime to the EVSM, the waste in terms of time can be more easily distinguished, which leads to indications of factors in production that should be improved. With the added downtime, the updated EVSM shows how much time is actually value-adding within the processing time. This shows that outwardly seen value-adding time may contain downtime when analyzing further, and therefore creates a new perspective on value-adding and non-value-adding time. With the downtime added into the mapping, it is also possible to determine the uptime of production. The downtime resulted in a machine uptime of 87 %, which can be stated as being in between optimal and not optimal efficiency. The energy consumption, when taking downtime into account, was lower than for the initial EVSM for Case 1. This is because the downtime consumes about 85 % of the full capacity, which results in a smaller increase in energy consumption. This does not imply that downtime results in lower energy consumption in general, but rather that the energy consumption calculated in the initial Case 1 is unrealistic. Additionally, by minimizing occurring disturbances and downtimes, the overall energy consumption would be even lower. These points further strengthen the suggestion to document issues frequently to identify causes and improve thereafter. It should also be noted that, although the updated energy consumption is less than the initial case, it is still an increase of 5.2 kWh, which should be kept in mind when making decisions from an economic and environmental standpoint. Furthermore, the downtime affected the cycle time of Case 1, as it is shorter than for the initial EVSM. In turn, this further indicates that the defined takt time for the case is incorrect based on the current resources. It is therefore perforation to update the chosen planned production speed in order to make it possible to achieve the time. By doing so, production may flow as planned.

6.5.1 Improvements and Future Studies

Although the use of EVSM has been shown to contribute to useful and valuable information for this study, a developed approach could have led to a more deep-going analysis. Firstly, the use of EVSM in this study only evaluates the current state of the company and detects areas needed for improvement. The next step should be to determine an ideal state, which serves as a realistic goal for the overview of the process. Moreover, in the study, only one of the investigated cases could be chosen for an updated EVSM based on downtimes. Optimally, the other two cases would have been analyzed as well in order to gain further insights and make conclusions thereafter. Furthermore, the use of EVSM only takes into account the operations that take place at the manufacturing facility. Therefore, times for deliveries of goods from suppliers as well as time for shipping are not accounted for. This is certainly something that affects the overall manufacturing process and something that is recommended to involve in the process for future studies. The main analysis in this study involves the bottling and packaging station, i.e., the production line, which is why only this station includes an analysis of material waste and energy consumption. The other value-adding operation is the blending station. Material spillage and the increased energy consumption is also present in this station and is therefore recommended to do an analysis in future studies. By adding deliveries from suppliers, the blending station, and shipping to a developed EVSM, a more thorough analysis can be made that provides a more realistic overview of the manufacturing process as a whole.

6.6 Increase of the Production Capacity

Based on the PPM, the company has a higher production speed than the planned one and shows a possibility to increase its production capacity. Since the production speed is generally faster, this suggests that the company has the ability to produce more parts per hour. Despite this, if the production capacity were to increase, the storage capacity would have to be increased. Additionally, the company would have to be more resource-efficient, which entails that lead times and idle processes need to decrease. Therefore, to be able to fit the increased production capacity within production hours, disturbances leading to unutilized production time would have to be minimized. Furthermore, an increase in production capacity is only necessary if there is a lack of capacity, which is the case if the company wishes to produce more than currently. However, judging by the pallet places in table 2.2, it can be established that this is not the case for the company, since they have more finished products than raw and packaging materials in storage.

Although, there are drawbacks to an increased production capacity and having more finished goods in storage. This is because it is more beneficial to have raw materials, blend, or packaging materials than finished products since it is more expensive to have finished products in storage as it adds to the tied-up capital. Despite this, it is always favorable to shorten lead times and other processes. In contrast, if the production capacity is increased, it would also affect the peripherals of the manufacturing line. For instance, the driving distance for the forklift would have to be doubled if the capacity was doubled. This leads to higher wear and tear but also a higher number of workers needed. Additionally, it might not be beneficial financially with tied-up capital. Although it is beneficial to minimize tied-up capital, it is not more important for Clemondo than achieving a customer-order-driven production with high delivery performance.

In summary, the company seems to have the ability to increase its production capacity when looking at its production speed, but an increase would perhaps not be of desire. This is because the company does not seem to be in lack capacity, nor would it be economically beneficial when valuing customer orders. Moreover, an increase would affect peripheral resources such as the wear of forklifts and the need for more employees. However, it is always beneficial to shorten lead times and idle processes in order to optimize the planning.

6.7 Calculations of Manufacturing Costs

To be able to further emphasize the impact of the different identified wastes, both an ideal case of the production is calculated as well as an actual case that includes material waste and downtimes. By doing this, it is possible to receive the impact of the wastes compared to the current ideal case. The difference that is seen in the results is that the company spends 13 000 SEK extra per batch due to occurring disturbances. By focusing on optimizing waste, a significant amount of money could therefore be saved per year. The costs will decrease with less downtime, especially for greater batch sizes. This is why it is important to analyze the production, as even small changes, such as short downtimes and wasted materials each production, affects the total cost.

Despite these results, it is important to mention that rough estimates have been made during the calculations. For instance, the decision that the machine's hourly costs for running and idling should be the same is a reasonable estimate to make, but it also affects the final cost. The energy cost can be taken into account in running machine time, which could have been calculated if the energy consumption was measured to a more accurate value that includes mentioned peripherals. Additionally, since the machines on the specific company line are old, the initial cost value is estimated. The company lumps together all costs for the maintenance of lines, which implies that the renovation cost is also roughly estimated. However, it is unquestionable that minimizing waste leads to lower part and batch costs. It is therefore even more important for the company to track their wastes but also to separate lumped costs to be able to achieve an optimized production with reduced manufacturing costs.

Furthermore, when it comes to labels, these are the most thrown-away packaging materials, which is interesting considering their price. This was one of the most expensive packaging materials and affects the final manufacturing cost per part. If all used labels were to be switched to plastic material instead of paper, this price would rise to an even higher number. This is therefore yet another reason why the number of labels that are thrown away should be minimized.

6.8 Developed KPIs and Suggested Improvements

The analysis has helped with gaining an understanding of what strengths the production has as well as discovering its flaws. Waste reduction is the main target of this study, and the results of the chosen methods help in targeting what areas should be improved. The company's current KPIs focus on delivery precision, capacity, and cost efficiency, and have shown to be suitable measurements based on the strategies and visions. What was highly desired from the company, is to implement KPIs that help with optimizing waste in production. With foundational information achieved through the analysis, waste-related KPIs are established. The KPIs can be divided into three primary categories of waste; time-related, cost-related, and material-related.

6.8.1 Time-related KPIs

Measure cycle time
Establishing correct cycle times is key in production planning. By continuously measuring the time based on production runs, an appropriate cycle time can be defined. Based on the analysis, it is apparent that the actual production speed of production runs does not reflect the planned speed. This results in production taking longer or shorter time than planned, which affects production planning. An appropriate cycle time takes into consideration actual production times without downtimes and thereby represents a realistic and achievable time used for each product. This can aid in identifying production process inefficiencies and waste-causing constraints.

Measure washing and changeover time
As of now, the company measures the set-up time and the washing time of equipment, but what also consumes time in production is the changeover. This changeover, as mentioned previously, involves technical adjustments and thereby does not involve the operators on the line, which is a probable reason why it is not measured. Although, changeover sometimes can take hours to perform, and resultantly has an impact on the total time used for producing each batch. Additionally, it is desirable to have a planned washing time since this practice is also performed during production hours. Measuring washing and changeover time therefore helps with adding it to production planning in order to optimize time consumption and planning of activities.

Measure lead time
Based on the EVSMs that were performed in this study, it is apparent that the lead times are relatively long in comparison to value-adding time. One measurement that could help in determining suitable waiting times for each product is tracking the lead time between each operation. One specific lead time that could be of perforation to optimize is the waiting time between blending finished until the blend is bottled and packaged. The lead time between the blending and the bottling station is, as presented, about seven days in order to have margin for the laboratory check and any possible adjustments to the blend. However, this time could possibly be optimized if the time is measured for how long the laboratory check and any other necessary tasks actually take in order to optimize the planning.

Measure downtime
As downtime affects the efficiency of production, it should be perforated to optimize. The analysis shows that downtimes occur frequently, but also that they often occur due to the same causes. By measuring when, where and for long downtimes are present in production, factors that cause stops can be identified and choices can be made of what to optimize. The PPM used in this analysis showed that one apparent reason for downtime is technical issues. This implies that there may be a preference to evaluate the machines that are used and if they should be upgraded or even replaced.

Labor efficiency Similar to measuring cycle time, it could be an optimal measurement to keep track of the time needed to finish a task or activity. This can aid in determining when production is taking longer than usual and in identifying the root cause of the delay. By measuring labor productivity, potential enhancements can be indirectly revealed in order to reduce waste resulting from overproduction or other causes.

6.8.2 Cost-related KPIs

Overall equipment efficiency (OEE)
OEE is a measure for the efficiency of production which, as presented in 3.2.4 Calculations of Manufacturing Costs, is calculated through the value-adding time, the total production time, and the shortage of occupancy. By performing the calculation the same way as presented in this study, follow-ups can be frequently implemented to evaluate if changes improve efficiency or not. Primarily, calculating OEE can be used to indicate what areas to focus on improving in order to streamline production. The current OEE is, as presented previously, 56 %. This is relatively low and calls for improvement.

Inventory turnover rate
The inventory turnover rate relates inventory levels to production velocity. A greater inventory turnover rate indicates that a company is producing goods at a quicker rate, thereby reducing its inventory levels. This reduces the possibility of stock expiration, damage, or obsolescence resulting in waste.

Cost of increased production times
Looking at the results from the EVSMs and the PPM, in a specific aspect, they contradicted each other. The data used for the EVSMs imply that in most cases, production ran for a longer time than planned. In contrast, the data used for the PPM instead indicate that production actually ran faster than planned. One probable reason for this is that the PPM takes into account downtimes, which will affect the resulting production speed. Although this implies that increased production time does not always occur, it would be interesting to establish how much the potential increased time would affect the manufacturing costs. A suggestion could be to calculate the cost of the increased production times, and how that relates to how much profit is wasted through the increased time.

6.8.3 Material-related KPIs

Tracking material spillage
As of now, the company's current data on produced amounts of products based on the used blend is relatively unstable. This is because often after the desired amount of products are produced, the blend is used for the same product in other formats. Resultantly, the initial blend that is documented does not represent how many products actually are produced. Moreover, the calculated amount of finished products is based on how many pallets of products are filled and not the actual amount, which further contributes to implausible numbers. Measuring the correct initial blend and the outcome in the form of finished products is an important measurement when attempting to reduce material spillage. By measuring how much blend is wasted along the process, certain bottlenecks can be detected, which will help in focusing on what areas need improvement.

EVSM and PPM of the blending station
The EVSMs and PPMs in this study were heavily based on the bottling and packaging station, as it represents the chosen production line. However, this does not represent the whole manufacturing process, as blending is a significant part of the process. It could be beneficial to execute both a more descriptive EVSM involving the blending station and a PPM of the blending station in order to detect any issues or downtimes, but most importantly to investigate material spillage throughout blending. As stated previously in this study, a significant amount of blend has the risk of sticking to hoses or pipes, which leads to wasted material. Therefore, by executing both EVSM and PPM in this specific area of the process, causes of spillage can be established and thereby chosen for areas to improve.

Energy consumption per unit or batch produced
Currently, the energy consumption of the production line is not being measured. This could be a valuable measurement since, solely based on the results of the study, the actual production time sometimes is longer than planned, and sometimes is not. The increased production time directly increases the energy consumption, and by tracking how much increased energy consumption is used, conclusions can be drawn about if the defined cycle time should be adjusted or not. Energy consumption could, as a proposition, be measured per unit produced or per batch produced. This is in order to identify the areas where energy usage possible can be reduced or optimized.

Waste reduction targets
After identifying the factors that lead to waste, it is necessary to determine which specific areas should be optimized. By establishing specific waste reduction goals, it is easier for the company to remain on track and assess its progress in minimizing waste continuously. For example, the PPM that was performed in this study identified the factors that were the biggest contributors to downtime and wasted material. These factors should then be evaluated to choose what concrete areas need optimization.

6.8.4 Overall Improvements for Waste Reduction

Besides the suggested KPIs, the analysis has contributed to revealing what areas to focus on for further optimization. These are based on the results from the chosen methods for the study and serve as suggestions for what improvements can be implemented in the current state of the manufacturing process. The primary potential improvement is related to the lead time before raw materials are moved to the blending station. What possibly could improve the waiting time before raw materials are blended is to plan production earlier than the current implementation. Currently, production planning is done approximately a month ahead, but a suggestion would be to plan even further ahead. This could help for making sure that raw materials are delivered closer to the date so that blending can be operated sooner than now. The second possible improvement is related to inventory. The current planning of storing raw materials and packaging materials works well for the current capacity, but if the company wants to expand its capacity, more inventory space is needed to fit more raw and packaging materials. This calls for more efficient production planning, which can be solved if planning is done further in advance. Another improvement could be to implement more JiT production in the planning. This is because it is apparent that some batches may be stored for several months before being shipped to the customer. By implementing more JiT production, more storage space can be used for other products or resources that may decrease the tied-up capital in finished products. One way to streamline the manufacturing process is to make use of Kanban systems. This implies that when a processing station requires additional components, a kanban is sent to the next preceding station, causing a chain reaction that extends farther and further back along the processing chain. This pull system could help in achieving JiT practices in order to efficiently use resources. For example, if an IBC of the blend is running out at the bottling station, then a Kanban could be sent to the forklift drivers to retrieve another IBC right in time for the changeover to occur. Another suggestion is to consider focusing on producing smaller formats of products. This is because the company has expressed that currently, the bigger formats are not being sold as much as the smaller ones, which results in re-bottling and thereby more work. Lastly, to perform production as planned, i.e., achieving the planned production time, speed, etc, operators should be trained to do as standardized work as possible. This is to avoid big fluctuations in the set-up time, production time, and washing time. By training operators to do the tasks in similar ways, more standard times can be achieved, which eases production planning. Overall, the primary suggestion is to make sure to document the manufacturing process more frequently and to focus on follow-ups. Spreading awareness of what issues and bottlenecks appear in the process is crucial for optimizing production, and in order to avoid such happenings in future production, all employees should be on board with what needs to be measured and how to improve the process.

6.8.5 Primary Recommendations for Clemondo

Although it is valuable to determine several ways of reducing waste in production, it is favorable to focus on a few measures to implement. Out of the suggested KPIs, four measurements are concluded as being the most relevant for Clemondo and what would benefit their production the most based on the current state of their manufacturing process. These include:

1. Measure all times in production including downtime (*time-related*)
2. Calculate OEE (*cost-related*)
3. Track material spillage (*material-related*)
4. Measure energy consumption per unit or batch (*material-related*)

The first KPI includes measuring and keeping track of all time-consuming activities in production. Among these times are set-up time, production time, occurring downtimes, washing time as well as changeover time. The reasons for why these times should be measured, as well as the reasons for the remaining KPIs are explained in *6.7.2 Cost-related KPIs* and *6.7.3 Material-related KPIs.*

7 Conclusions

This study aimed to guide Clemondo in reducing production waste by analyzing the waste present at the line and generating suggestions for optimization. Through information-gathering methods of citation chaining, observations, and discussions, as well as data-gathering methods of Environmental Value Stream Mapping, Production Performance Matrix, and Calculations of Manufacturing Costs, KPIs were generated for the company to implement in their production system.

EVSM results showed that the planned times for production were rarely achieved, and this implies that the takt time based on available production time is not reached and customer demand is not met. By re-defining the cycle time, the use of time will be optimized, and unplanned energy consumption reduced. Moreover, material spillage was present for two of the cases in production as the number of finished products was lower than the planned batch size. The third case did not involve material spillage but indicated that more blend is added to products than what was initially used. This scenario is assumed to be related to the minimum filling of products, or incorrect documentation of the initial blend used. Lastly, the lead time for the manufacturing process of the investigated cases consumed a relatively long time proportionate to the value-adding time. This has an impact on the tied-up capital that is related to unfinished products.

According to the PPM, refilling of labels, changing of IBC, and technical issues, were responsible for the most downtime during production. Frequent documentation of production runs and separating times that are included in the total production time will successfully identify causes for this downtime, as it is more favorable to separate planned downtime and unplanned downtime during production. Furthermore, it is beneficial to start documenting washing and changeover time since this will favor planning and make way for streamlining the process. The production run speeds also showed to be, in most cases, faster than the planned production speed. This calls for more precise documentation of production runs and the evaluation of optimal actual cycle time to optimize production planning. Environmental and recycling parameter results indicated that there was a significant amount of discarded blend and packaging materials in production. The primary discarded packaging materials were labels, which was most likely due to the design of the label rolls. This should be improved since it has a high impact on the resulting manufacturing costs. To get more accurate results of wasted blend and packaging material, more precise and accurate documentation is needed since some wastes were determined through observation but were not documented in the protocols.

Based on its production pace, the company can increase its production capacity, but the current level is adequate and makes way for tied-up capital. However, it may be beneficial to reduce lead times and idle processes. Calculations of manufacturing costs showed that the company spends approximately 13 000 SEK more per batch with present waste levels in comparison to an ideal case with no waste. This highlights the importance of improving documentation and reducing waste in the manufacturing process.

Finally, four KPIs are most applicable for Clemondo in their current state: (1) measuring all times in production including occurring downtimes, (2) frequently calculating OEE, (3) tracking material spillage, and (4) measuring energy consumption.

Future work includes conducting an ideal state of the EVSM, implementing PPMs on their production lines, as well as analyzing other stations in the production facility, preferably the blending station.

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Appendix A

Filled-out Shift Protocols

The filled-out shift protocols of each of the eight production runs are presented in the appendix. Each shift protocol had a front- and backside and all of these are included below.

Date and time: 20-03-2023

Batch number: 1

Before production

	Time [in min]
Changeover time (if necessary)	100

After production

	Liter/pieces discarded
Discarded blend	
Discarded bottles	
Discarded caps	
Discarded labels	
Discarded cardboard boxes	

Comment:

Figure A.1: Frontside of the shift protocol for shift # 1.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)	5			
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels				
B3: Refill tape	5			
B4: Change IBC	5			
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line				
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	10			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.2: Backside of the shift protocol for shift # 1.

Date and time: 21-02-2023

Batch number: 2

Before production

	Time [in min]
Changeover time (if necessary)	120

After production

	Liter/pieces discarded
Discarded blend	18
Discarded bottles	22
Discarded caps	
Discarded labels	23
Discarded cardboard boxes	8

Comment:

Figure A.3: Frontside of the shift protocol for shift # 2.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels	10			
B3: Refill tape				
B4: Change IBC	14			
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line				
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	4			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.4: Backside of the shift protocol for shift # 2.

Date and time: 27-02-2023

Batch number: 3

Before production

	Time [in min]
Changeover time (if necessary)	

After production

	Liter/pieces discarded
Discarded blend	
Discarded bottles	4
Discarded caps	
Discarded labels	35
Discarded cardboard boxes	

Comment:

Figure A.5: Frontside of the shift protocol for shift # 3.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels	26			
B3: Refill tape	3			
B4: Change IBC	50	15		
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line	25			
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues				
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials	15			
E4: Contaminated packing materials				
E5: Emptying of garbage can	20			

Figure A.6: Backside of the shift protocol for shift # 3.

Date and time: 28-02-2023

Batch number: 4

Before production

	Time [in min]
Changeover time (if necessary)	95

After production

	Liter/pieces discarded
Discarded blend	12
Discarded bottles	8
Discarded caps	2
Discarded labels	23
Discarded cardboard boxes	

Comment:

Figure A.7: Frontside of the shift protocol for shift # 4.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels				
B3: Refill tape				
B4: Change IBC	20			
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line				
C4: Take substance to the lab for check (during production)	10			
D. Wear and maintenance				
D1: Technical issues				
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.8: Backside of the shift protocol for shift # 4.

Date and time: 01-03-2023

Batch number: 5

Before production

	Time [in min]
Changeover time (if necessary)	

After production

	Liter/pieces discarded
Discarded blend	15
Discarded bottles	
Discarded caps	
Discarded labels	112
Discarded cardboard boxes	5

Comment:

Figure A.9: Frontside of the shift protocol for shift # 5.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels	20			
B3: Refill tape	5			
B4: Change IBC	10			
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line	5			
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	47			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.10: Backside of the shift protocol for shift # 5.

Date and time: 02-03-2023

Batch number: 6

Before production

	Time [in min]
Changeover time (if necessary)	

After production

	Liter/pieces discarded
Discarded blend	
Discarded bottles	5
Discarded caps	2
Discarded labels	90
Discarded cardboard boxes	9

Comment:

Figure A.11: Frontside of the shift protocol for shift # 6.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)			2	
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels	35			
B3: Refill tape				
B4: Change IBC				
C. Personnel and organization				
C1: Planned meeting	20			
C2: Unplanned meeting				
C3: Away from the production line	40			
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	65			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.12: Backside of the shift protocol for shift # 6.

Date and time: 06-03-2023

Batch number: 7

Before production

	Time [in min]
Changeover time (if necessary)	90

After production

	Liter/pieces discarded
Discarded blend	
Discarded bottles	3
Discarded caps	2
Discarded labels	30
Discarded cardboard boxes	5

Comment:

Figure A.13: Frontside of the shift protocol for shift # 7.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels				
B3: Refill tape				
B4: Change IBC				
C. Personnel and organization				
C1: Planned meeting	5			
C2: Unplanned meeting				
C3: Away from the production line				
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	6			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.14: Backside of the shift protocol for shift # 7.

Date and time: 06-03-2023

Batch number: 8

Before production

	Time [in min]
Changeover time (if necessary)	

After production

	Liter/pieces discarded
Discarded blend	8
Discarded bottles	1
Discarded caps	1
Discarded labels	10
Discarded cardboard boxes	

Comment:

Figure A.15: Frontside of the shift protocol for shift # 8.

Reason for downtime during production	Downtime [in min]	Discarded substance (more than 5 liters)	Discarded packaging material	Other notes
A. Work material				
A1: Density-check (each hour)				
B. Production process				
B1: Refill bottles and/or bottle caps				
B2: Refill labels	8			
B3: Refill tape	4			
B4: Change IBC	40			
C. Personnel and organization				
C1: Planned meeting				
C2: Unplanned meeting				
C3: Away from the production line	10			
C4: Take substance to the lab for check (during production)				
D. Wear and maintenance				
D1: Technical issues	25			
E. Peripheral				
E1: Wait for the blend				
E2: Deviation in the blend				
E3: Deviation in packaging materials				
E4: Contaminated packing materials				
E5: Emptying of garbage can				

Figure A.16: Backside of the shift protocol for shift # 8.