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**LUND UNIVERSITY**  
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# **Mapping of cost drivers in continuous flow production**

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## ABSTRACT

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The master thesis work has been performed at Tetra Pak AB in Lund in collaboration with the department of Industrial production at Lund University. The objective with the master thesis work was to create a cost model for continuous flow process for Tetra Pak and to investigate the possibilities of implementing the generic cost model from Ståhl in a continuous flow production process.

The continuous flow process in question is a pre-commercial production system with both processing and packaging equipment included. Tetra Pak has an incitement to map and analyze cost drivers to find areas of improvement, the cost model created during this master thesis work is a tool to evaluate the production system and the cost that arises in it.

Frequent interviews and meeting with process and packaging engineers at Tetra Pak were held alongside a literature study to be able to map the flow of the process and identifying process activities. The mapping of the production was crucial for the next step in the master thesis work, to implement a cost model based on the generic cost model from Ståhl.

The cost model was created using the software Microsoft Excel, as it is the preferred software at Tetra Pak. The cost model reflects the pre-commercial production facility including all support equipment, main line equipment and consumables. The user input creates possibilities for production economic simulation and even real time cost analysis for the manufacturing process. As it sits, the cost model supports cost driving analysis in two separate levels, both for the main production line and for the whole facility.

The master thesis work will hopefully be used as a software for cost driving analysis for current and future production facilities at Tetra Pak.

**Keywords:** Cost model, Cost drivers, Continuous flow process, Dairy production, Generic cost model from Ståhl

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# 1 Introduction

## 1.1 Company description

Tetra Pak is world leading in process and packaging solutions for liquid foodstuff and is a part of the Tetra Laval Group founded in Sweden. With over 8 850 packaging machines and 74 450 processing units currently in active production Tetra Pak employs over 23 600 globally.

The facilities in Lund are directly connected to the foundation of the company back in 1951 by Dr. Ruben Rausing and still operates with development and manufacturing of processing units and packaging machines. Tetra Pak manufacture and distributes complete processing and packaging solutions and packaging material, and the products can be found in over 170 countries worldwide. (Tetra Pak AB, 2017)

## 1.2 Background

The division of Production and Materials Engineering at Lund University has developed methods to integrate production and processing parameters with cost analysis to illustrate the effects the performance of the manufacturing process has on production economics. The methods have shown the possibility to calculate cost of manufacturing for metal cutting of mechanical components, assembly, sheet metal forming and other similar processes.

Tetra Pak is currently analyzing the performance of a pre-commercial production system that integrates both processing and packaging solution. Being able to map the performance of the production system and its cost drivers, Tetra Pak will be able to find areas where improvement-work can be performed.

## 1.3 Problem description

In manufacturing processes, it is of interest to be able to map and analyze the manufacturing cost and to determine how well the process is operating, often with key performance indicators or KPIs. The possibility to analyze these performance indicators on the newly constructed process facility has been of great interest to Tetra Pak and their customers. The generic cost model formulated by Ståhl has shown to be useful in manufacturing process but has not yet been implemented on continuous flow production such as processing of beverages.

The main questions for this master thesis are;

- How can cost drivers be mapped and analyzed in the continuous flow process in question?
- How does one construct a cost model for continuous flow processes?
- In addition, how can the generic cost model from Ståhl be applied to continuous flow process?

## **1.4 Objective**

The objective is to make the evaluation if the generic cost model from Ståhl can be implemented on continuous flow process such as the pre-commercial production system at Tetra Pak. The aim with the master thesis work is to create a cost model that should be able to calculate total cost of manufacturing of milk products based on production data. The master thesis work should also evaluate if the generic Ståhl cost model can be used as a tool to identify cost drivers in a production system with continuous flow.

## **1.5 Delimitations**

All calculation and the structuring of models are based on the pre-commercial production system at Tetra Pak. If similar calculation or models will be performed on other production systems, the structure and work procedure may vary from this master thesis. The master thesis is limited to applying the generic cost model from Ståhl on the production system.

## **1.6 Confidentiality**

All data collected is confidential to Tetra Pak and any calculations or display of numbers in the master thesis is therefore not based on true data. The master thesis only represents the structure of the cost model and how it can be used, not how Tetra Pak will use it.

## **1.7 Target audience**

The target audience for this master thesis are production and development teams at Tetra Pak, both for packaging solutions and processing. The department of industrial production at Lunds University is also considered as the target audience for further research and development of the generic cost model from Ståhl.

## 1.8 Disposition

The master thesis is sectioned as followed:

- *Introduction*

This section introduces the reader to a short description of the company and the background of the master thesis. The problem description and objective is introduced as well as delimitations and intended target audience. Lastly, the master thesis disposition is presented.
- *Theory*

The basic theory of dairy production and continuous flow production is followed by theory for mapping and analysis of production systems. The generic cost model from Ståhl is presented in detail with supporting functions such as production performance matrix and areas where the cost model can be used for simulation or production development.
- *Method*

The theory behind the chosen methods are presented followed by the course of action for the master thesis work. How sources are critiqued and evaluated is presented and which obstacles and limitations that is involved with the master thesis work is lifted.
- *Results*

The results are presented in the structured way according to how the analysis was performed. The different methods on mapping the production are followed by the implementation of the generic cost model and how to use it.
- *Discussion*

In this section the differences between the Ståhl cost model and the cost model implemented is discussed. Also, the usage of methods for mapping and analysis are discussed and how they are used for this specific case.
- *Conclusion*

In short, the conclusions of the results are presented and if the master thesis meet the objectives set from the start of the project.
- *Future work*

Future work and further analysis that can be performed is presented. Some of the future work relies on sufficient amount of data for further analysis.



## 2 Theory

This master thesis relies on theories of analyzing and mapping different kind of production facilities in terms of process activities and drivers of cost. To be able to understand the process in question it is vital to have a greater understanding of the process flow and the steps involved in the production of beverages, specifically dairy production. To be able to create a dynamical model that can be further developed and tailored to different processes, computer aided tools will be necessary to finalize mapping of cost drivers in a cost model.

### 2.1 Dairy production

Dairy production is a quite complex process involving technical steps to ensure that the product is produced at the right quality as the product many times are intended for human consumption. This master thesis will not analyze the quality of the product in this stage but rejections from poorly executed processing will affect the cost of manufacturing. This master thesis will create a tool to analyze the cost drivers in the production as is and will support the user with the opportunity to later add rejections, downtime, etc. and translate it to costs. Before the cost drivers can be mapped and analyzed, the different steps in the production need to be explained to help us understand the production flow.

The basics of producing dairy products usually consists of the following steps.

- *Cooling*
- *Quality testing*
- *Separation*
- *Homogenization*
- *Heat treatment*
- *Packaging*
- *Distribution*

The first step after milking is to cool the milk. This is often performed at the farm within two hours from milking. The milk is cooled down to about 4 degrees Celsius to prohibit growth of microbes. Milk can be held at 4 degrees Celsius up to 72 hour before being processed, but is often processed within the first 24 hours.

Secondly, upon delivery to the dairy plant the milk is tested. The milk can vary in quality, fat percentage, pH, protein percentage and other and is therefore tested in this early stage of the process to ensure a high quality product. Antibiotic residue is always a concern and each load of milk delivered is tested to make sure no residue is present.

An average fat content of raw milk from a cow is about 4.4 % fat while standard milk one can buy from the stores have only 3 % fat. To be able to achieve the right fat content the milk needs to be separated until the right fat content can be achieved.

Once the right fat content is achieved, the milk needs to be homogenized. The un-homogenized product is pushed with high velocity and pressure through a narrow gap breaking the large fat globules into smaller globules. The homogenization of the milk leads to less cream-line formation and a more appetizing color of the product.

With the right fat content and a homogenized product it is time for heat treatment, of the milk often called pasteurization. This step is crucial for the shelf life of the product and a HTST (High Temperature, Short Time) pasteurized milk is held at a temperature of 72-75 degrees Celsius for 15-20 seconds which is a common pasteurization in the dairy industry.

After the heat treatment is finished, the product is ready for packaging. Packaging can be done in many different material, most used are paper or plastics, and in different shapes and sizes depending on the requirements from the final consumer. Packaging has a great impact on distribution, how well the packages can be handled, stored or shipped. (Tetra Pak AB, 2017)

## **2.2 Continuous flow production**

Continuous flow production is characterized by producing in units of tons, liter, meter, etc. instead of separate pieces. The production steps are often linked together making them dependent on each other. Usually, there is some kind of raw material going in from one end and at the other end, finished product is going out. Some of the most common continuous flow productions are gasoline-, paper-, metal-, fabrics-, beverages manufacturing.

Most of the production facilities with continuous flow production have a narrow range of products and the investment costs are usually high which means that production volume dimensioning when investing is of great importance, changes down the road can be costly. Because of the non-flexible production system, utilization of equipment and customer relationships in terms of orders is important for a cost effective production. (Olhager, 2000, ss. 138-141)

## **2.3 Value stream mapping**

Value stream mapping is a tool commonly used when implementing lean manufacturing in different production processes. Value stream mapping intends to map the flow of material and information in a production process through different action, both value-added and non-value added. When mapping the flow, it is possible to trace the actions needed to turn raw materials into finished products but also where future improvements can be implemented to optimize the flow of production in the facility.

According to Lasa et al (2008), value stream mapping consists of five selected phases:

1. *Selection of a product family;*
2. *Current state mapping;*
3. *Future state mapping;*
4. *Defining a working plan; and*
5. *Achieving the working plan.*

The first step is to select a product family is vital for the value stream mapping. Often in manufacturing companies there are a wide range of product families produced whilst only a few is worthwhile performing a value stream mapping project on. When the product family is selected, the current state map is prepared with the most outstanding features such as demand, physical systems and information systems. An example of a current state map is presented below in figure 1 for the product family TSM7.

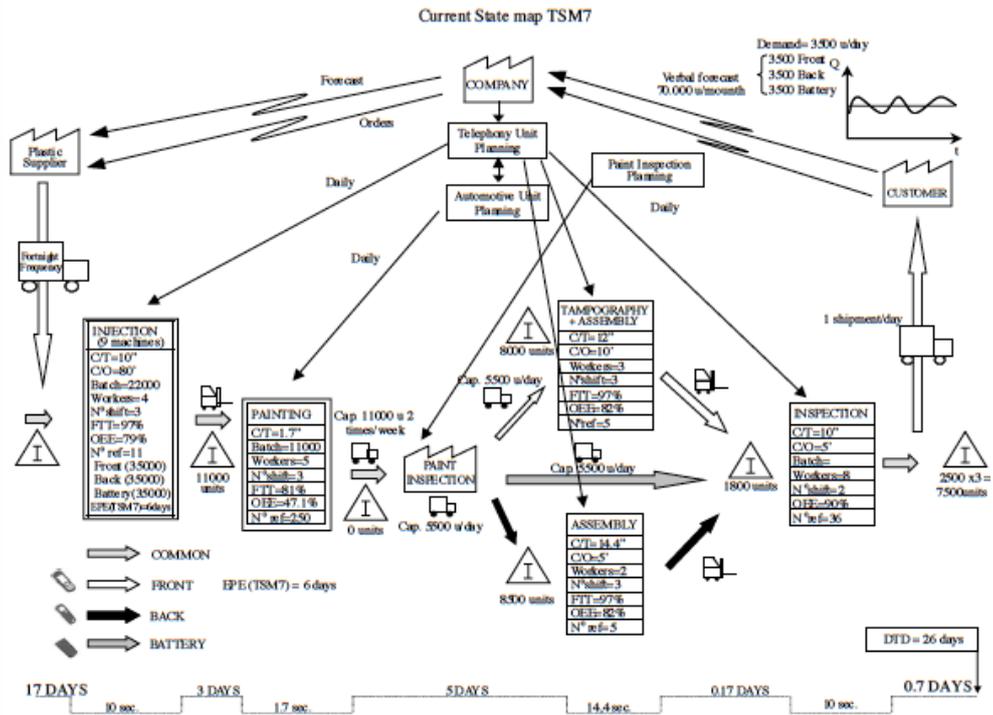
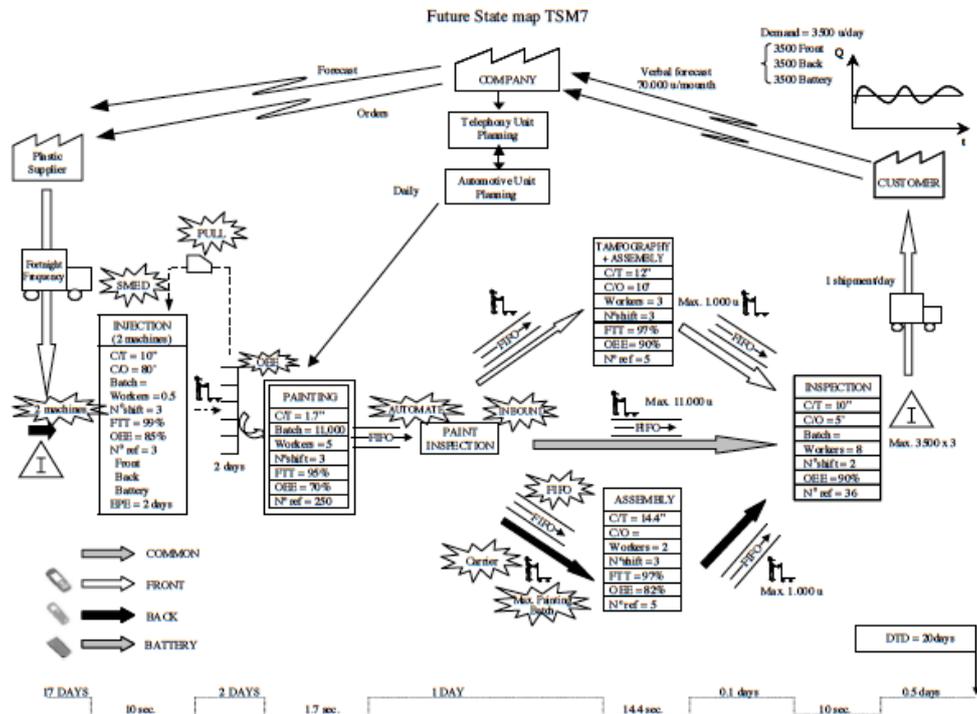


Figure 1: Current state map. (Lasa, de Castro Vila, & Laburu, 2008).

After applying suitable lean manufacturing actions to the process, the future state map is conducted. The aim with lean manufacturing actions can be to create a single pull system between two activities or to optimize continuous flow in the production by implementing automated operations that are low-value added. The future state map of the product family TSM7 is presented below in figure 2.



**Figure 2:** Future state map. (Lasa, de Castro Vila, & Laburu, 2008).

With the actions suggested from the future state map, a working plan can be defined to implement the improvements over a suitable timeframe. With the working plan defined, the target is to execute the working plan within the set timeframe. Follow up meetings and reviews should be carried out to analyze the implemented actions. (Lasa, de Castro Vila, & Laburu, 2008)

## **2.4 Activity-based costing**

Activity-based costing or more commonly known as ABC is a way to locate and distribute cost to certain products with both direct costs linked to the specific product but also with overhead depending on the variety of products and quantity produced.

### **2.4.1 Background**

Activity-based costing was introduced to meet the requirement to locate cost of products or services and help establish an understanding of which products are most and least profitable. With better understanding of cost drivers in production and allocating costs to specific product, it is possible to get a clear picture of what consumes resources and what generates revenue.

### **2.4.2 Usage**

The usage of activity-based costing is widely spread and is often used in production facilities. It has become clear through time that activity-based costing is useful not only in the factory but for other part of the administration as well, such as distribution, facilities, brands, etc. The result and implementation of activity-based costing is a better understanding of the production to help managers to locate areas that need attention and resources for improving, to give the greatest impact. When areas in need of attention has been located, either the consumption of resources should be reduced or the output should be increased to make the product or products more profitable.

### **2.4.3 Implementation**

A full implementation of activity-based costing can be quite substantial and time-consuming and it is recommended to try to implement the model on a pilot project which can be a small part of the production or a specific business unit. Often a team of five to six team members work together where the team members have different knowledge about the area where the model will be applied.

Velmurugan (2010) has presented a nine-step implementation of activity-based costing that vary in time depending on the scale of the project where activity-based costing is implemented on. The different steps of implementation are presented in short below.

#### ***Identify and asses ABC needs***

The first step of implementation is to assess the existing cost system and if the organization is viable for implementation. It should also be assessed how accurate the cost system is and what are the sources to inaccuracy. The different range of products, services and their supporting processes should be identified and assessed and what is the organizations key business issues and concerns.

#### ***Training requirements***

Basically most of the personnel involved in the project of implementing ABC should undergo training to get an understanding of concept of the model. Such training can be through workshops or seminars with the purpose to make others aware of the challenges and potential problems with the existing costing system. Training is an essential phase for the team members assigned to the pilot project.

### ***Define the project scope***

It is essential for the team members and managers to define the project scope and evaluate what is required and what is possible. Limitations can be time and resources from which the extent of the project should be formed. Some definition of what should be included in the project is necessary to limit the project so that it can be executed. What business unit, products, services, cost elements, etc. that will be included should be defined.

### ***Identifying activities and drivers***

When identifying activities and drivers it is preferred to do this using a process map. With a process map, some of the identifying of activities and drivers is already completed. Information regarding number of people involved and time spent in each activity along with resources such as machines and consumables should be determined. By doing time studies alongside the process it is possible to sample time connected to each activity.

### ***Create a cost and operational flow diagram***

By creating a schematic diagram of the flow in the process it is possible to see where resources are used in the different activities in the process. The diagram should also help to understand how activities form steps in the processes and how these processes produce the services or products.

### ***Collect data***

Data of how different activities consume resources during operation should be collected, measured in units of time. It is interesting to know how an activity did perform and how much resources it consumed during a period of time.

### ***Build a software model, validate and reconcile***

A software model can be created in different software programs such as Microsoft Excel, MathWorks Matlab, PTC Mathcad or other. All the data collected and relationships should be put into the model with the purpose to calculate cost of drivers, activities, processes, products, services, etc. The model can also handle data for activities with non-value-added time or processes. The model should be validated so that it reflects the reality and reconciles to the general ledger.

### ***Interpret results and prepare management reports***

One of the most critical steps in the process is interpreting results and preparing management reports, it can be a "make it or break it" step. The outcome from the model must be properly analyzed so that all significant management issues are identified. Profitability of products and comparing these to each other is one objective that need to be addressed. The cost of the process in another objective that should also be included in these reports. Often the results will include unexpected benefits.

#### ***Integrate data collection and reporting***

Once the model is validated for the pilot project it can be used in future analysis. The integration of data collection can be manual, automated or a combination of both. A Manufacturing Execution System (MES) could feed the model with production data for a continuous analysis. An Executive Information System (EIS) must be established to feedback results to functional activity-based costing team. (Velmurugan, 2010)

#### **2.4.4 Risks and difficulties**

One of the risks with activity-based costing is that the focus is on non-expensive resources. Therefore it is important that the resources that can make the greatest impact on the product cost is located. For example, a high technology company should study the demands on engineers, product improvement and process development whilst a consumer goods producer should analyze marketing, distribution and service costs.

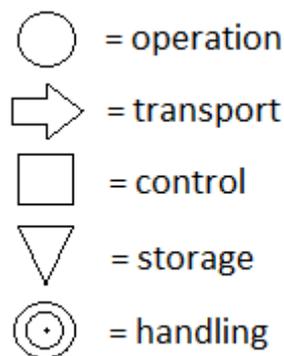
As the tracing from resources to activities to specific product cost can never be 100 % accurate, the results must be carefully analyzed keeping in mind that it is better to be correct with activity-based costing to within 5 % or 10 % than completely off the mark with outdated allocation techniques. (Velmurugan, 2010) (Cooper & Kaplan, 1999)

## 2.5 Process flow analysis and mapping

The idea with a process flow analysis is to analyze and map the different activities involved in the process in a detailed manner. Often these activities are presented in a graphical way to help the understanding of which activities that are involved and add value to the product. The general steps of process flow analysis is constructed through five steps that include an analysis of possible changes in the process.

1. Identifying and categorizing process activities
2. Document the process as a whole
3. Analyze the process and identify possible improvements
4. Recommend appropriate changes
5. Implement approved changes

Certain symbols for different activities are commonly used to categorize the activities during the process. These symbols can vary but the symbols presented below are an example of how they can look according to Olhager (2000), see figure 3.



*Figure 3: Activity symbols modified after Olhager (2000).*

**Operation**, implies to the activity of processing and adding value to the product by changing its physical or chemical properties, assembly or disassembly. Planning, calculating and other similar activities can be classified as operation.

**Transport**, transporting of objects. Does not affect the properties of the product only the location.

**Control**, a support activity performed to examine or verify a previous performed activity. Weight, measurements, quality can be controlled during these activities.

**Storing**, an activity performed during holding of product in warehouses or storage before shipment, sales or another activity.

**Handling**, often performed as a shorter transport, for instance between different operations.

The symbols for the different activities are mainly used in process scheduling or in process flow charts for further production analysis and optimization. (Olhager, 2000)

## 2.5.1 Process flow chart

With the process flow chart presented by Olhager (2000) it is possible to map and follow the different processes that the work-piece or product flow through, both value adding and non-value adding. The process flow chart helps to present an overview of the whole production and summarizes the different activities, lead-times and distances as shown in the example in figure 4 below. The value code, V/N/S/?, informs if the activity is value adding (V), non-value adding (N), supporting value adding activity (S) or has unknown value-effect (?).

Process flow chart		Object: Product A								
		Process: <input type="checkbox"/> Existing <input type="checkbox"/> Suggested								
Step	Description	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Time (hours)	Distance (m)	Valuecode (V/N/S/?)	
1	In storage				X		40		?	
2	To automated assembly		X					60	N	
3	At automated assembly				X		6		N	
4	Automated assembly	X					2		V	
5	To control		X					70	N	
6	At control				X		4		N	
7	Control			X			4		?	
8	To manual assembly		X					55	N	
9	At manual assembly				X		8		N	
10	Manual assembly	X					2		V	
11	To control		X					70	N	
12	At control				X		4		N	
13	Control			X			4		S	
14	To wave soldering		X					70	N	
15	At wave soldering				X		4		N	
16	Wave soldering	X					4		V	
17	To completion		X					10	N	
18	At completion				X		8		N	
19	Completion	X					4		V	
20	To control		X					70	N	
21	At control				X		4		N	
22	Control			X			4		?	
23	To test		X					80	N	
24	At test				X		20		N	
25	Test	X					8		S	
26	To storage		X					60	N	
	Sum	5	9	3	9	-	130	545	-	

*Figure 4: Current state process flow chart modified (Olhager, 2000).*

With all activities listed in a process flow chart it is possible to find redundant activities that can be eliminated and achieve a shorter lead-time and less non-value adding activities. Olhager (2000) presents a second, improved, process flow chart with suggested changes that eliminates some transport distances and shortens the lead-time for the product. This work procedure serves as an optimization tool in the early stages of process analysis. The updated process flow chart that Olhager (2000) presents is similar to the modified chart presented in figure 5. (Olhager, 2000)

Process flow chart		Object: Product A							
		Process: <input type="checkbox"/> Existing <input type="checkbox"/> Suggested							
Step	Description	○	⇨	□	▽	⊙	Time (hours)	Distance (m)	Valuecode (V/N/S/?)
1	In storage				X		40		?
2	To automated assembly		X					60	N
3	At automated assembly				X		6		N
4	Automated assembly	X					2		V
5	To manual assembly		X					55	N
6	At manual assembly				X		8		N
7	Manual assembly	X					2		V
8	To control		X					70	N
9	At control				X		4		N
10	Control			X			4		S
11	To wave soldering		X					70	N
12	At wave soldering				X		4		N
13	Wave soldering	X					4		V
14	To completion		X					10	N
15	At completion				X		8		N
16	Completion	X					4		V
17	To test		X					80	N
18	At test				X		20		N
19	Test	X					8		S
20	To storage		X					60	N
	Sum	5	7	1	7	-	114	405	-

*Figure 5: suggested process flow chart modified (Olhager, 2000).*

## 2.6 Ståhl cost model

### 2.6.1 Introduction

Ståhl (2012) has presented a cost model for calculation of the production cost for one unit in one planning point. The cost model presented consists of four terms in its generic form. The terms are the following:

- Material Cost  $K_b$
- Equipment cost during production  $K_{c1}$
- Equipment cost during downtime  $K_{c2}$
- Labor costs  $K_d$

The cost model itself is presented in equation 1. The model will hereafter be referred to as the Ståhl cost model or Ståhl cost equation.

$$k = \frac{k_B}{N_0} \left[ \frac{N_0}{(1-q_Q)(1-q_B)} \right]_b + \frac{k_{CP}}{60N_0} \left[ \frac{t_0 N_0}{(1-q_Q)(1-q_P)} \right]_{c1} + \frac{k_{CS}}{60N_0} \left[ \frac{t_0 N_0}{(1-q_Q)(1-q_P)} * \frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb} \right]_{c2} + \frac{k_D}{60N_0} \left[ \frac{t_0 N_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb} \right]_d \quad (1)$$

The cost model is based on the assumption that it is possible to isolate one value-adding step in the manufacturing process that has its own discrete cycle time and that one can identify so-called loss terms for that particular step.

One point of planning can consist of one or more value adding steps so called stations. In a flow type production line, the whole line or just one value-adding step in it be a planning point. (Ståhl, Industriella tillverkningsystem Del II - Länken mellan teknik och ekonomi, 2012, ss. 84-102)

## 2.6.2 Loss terms

Ståhl (2012) introduces the variables called loss terms to let the cost equation include cost due to rejections and downtime in that particular manufacturing step. The loss terms used in the generic cost equation are the following:

- $q_B$  Material waste rate

The material waste rate is calculated by equation 2 where  $m_{tot}$  is the total volume of material per part going in to the process and  $m_{det}$  is the material volume in the finished product. The loss term is formulated to describe how effective a process is in terms of material usage. The lost material can be due to removing of chips during metal cutting or material lost on clamping surfaces during sheet forming.

$$q_B = \frac{m_{tot} - m_{det}}{m_{tot}} \quad (2)$$

- $q_Q$  Scrap rate

The scrap rate is calculated by dividing the number of rejected details,  $N_Q$  with the number of details that is to be made in total to fulfill the order, including the rejected parts, here noted as  $N$ . The equation is presented in equation 3. Ståhl (2012) also introduces the Term  $N_0$  which is the order size, in other words the quantity of correct products that has to be manufactured to meet the order.

$$q_Q = \frac{N_Q}{N} = \frac{N - N_0}{N} \quad (3)$$

- $q_P$  Production-rate loss

Production rate loss is a result of problems in the process that demands for the process to be run at a slower phase to be able to produce without problems. Production rate loss occurs when the process cycle time,  $t_{0v}$ , has to be increased above the normal cycle time  $t_0$ . Production rate loss is calculated using equation 4.

$$q_P = \frac{t_{0v} - t_0}{t_{0v}} \quad (4)$$

- $q_S$  Downtime rate

The downtime rate is used to handle disturbances in the manufacturing process that leads to a real production time,  $t_p$ , being longer than the process normal value adding time  $t_0$ . The downtime rate is calculated by the means of equation 5, where  $t_s$  is the downtime of the process.

$$q_S = \frac{t_s}{t_p} = \frac{t_p - t_0}{t_p} \quad (5)$$

(Ståhl, Industriella tillverkningssystem Del II - Länken mellan teknik och ekonomi, 2012, ss. 67-74)

### 2.6.3 Other variables

Apart from the central "loss terms", the Ståhl cost equation consist of a number of input parameters. The nominal cycle time  $t_0$  and nominal batch size  $N_0$  are described earlier in the loss term section.  $T_{su}$  is the set-up time for the process, it is the time where the equipment resources are allocated to setting up the next job and therefore cannot be used for other value adding activities such as producing another job.  $U_{RP}$  is the degree of utilization and it is computed by equation 6 below, with the input parameters  $T_{plan}$  which is the total number of planned production hours for the year and  $T_{free}$  which is the free production capacity in the production system on a yearly basis.  $T_{pb}$  is the calculated production time per batch which is a sum of; production time per batch  $t_0 * N$ , downtime  $t_s * N$  and set up time  $T_{su}$ .

$$U_{RP} = \frac{T_{plan} - T_{free}}{T_{plan}} \quad (6)$$

Input parameters to the cost equation are also resource terms that are distributed to the product through the cost equation. Such resource terms include:

- $k_B$  Material cost per unit  
The material cost per unit is the cost of the incoming workpiece or raw material to the production step to be calculated.
- $k_{CP}$  Hourly machine rate during production  
The hourly machine rate during production consists of all costs, fixed and variable, which is associated with running the equipment.
- $k_{CS}$  Hourly machine rate during downtime  
The hourly machine rate during downtime consists of fixed cost associated to the machine.
- $k_D$  Hourly labor rate  
The hourly labor rate is the total cost of labor per hour in the production station. The rate depends on the number of operators assigned to the production step and their salary cost.

(Ståhl, Industriella tillverkningsystem Del II - Länken mellan teknik och ekonomi, 2012, ss. 90-95, 99-102)

## 2.6.4 Machine rate calculations

### 2.6.4.1 Introduction

Together with the cost equation Ståhl (2012) also presented a method for calculation the hourly machine rates. The machine rate calculation uses annuity to distribute the investment cost of the equipment during its lifetime. The annuity method is used instead of calculating the machines by its yearly depreciations on the basis of its present value, doing so will lead to very costly production in new machines and very low-cost production in older depreciated equipment. The phenomena of constantly variable machine rates during the equipment's lifetime can lead to that the products are constantly moved around between machines or facilities depending on the machines age. When calculating the machine rate, it is important to use the equipment's technical lifetime to calculate the yearly payment that has to be made on the machine, instead of using the machines economical lifetime from the company's financial accounting. Failing to do so will lead to a high cost at the start of production and a cost of zero when the machine is fully depreciated.

### 2.6.4.2 Equations

Ståhl (2012) presents the following equations (7-8) for calculation of machine rates. The rate during downtime,  $K_{CS}$ , is the rate during production excluding variable costs. And  $K_{CP}$  the machine rate during production includes all cost associated with running the equipment.

$$k_{CS} = \frac{a_f * K_0(1 + k_{ren} * N_{ren}) + Y * k_y}{T_{plan}} \quad (7)$$

$$k_{CP} = \frac{a_f * K_0(1 + k_{ren} * N_{ren}) + Y * k_y + T_{plan}(\frac{k_{UHH}}{h_{UH}} + k_{ph})}{T_{plan}} \quad (8)$$

The variables in the machine rate equations is presented below

- $a_f$   
Factor of annuity is calculated using equation 9 that uses interest rate  $p$  and a period  $n$  to calculate the yearly payment for the equipment.

$$a_f = \frac{p * (1 + p)^n}{(1 + p)^n - 1} \quad (9)$$

- $K_0$   
Is the investment cost of the equipment including installation cost.
- $k_{ren}$   
Is the ratio of the initial investment that has to be paid to restore the equipment after a certain time, this should not be mixed up with regular maintenance.

- $N_{ren}$   
Is the number of renovations the equipment has to undergo under its lifetime besides regular maintenance.
- $Y$   
Is the floor space that is allocated by the machine.
- $k_y$   
Is the cost per area of the floor space used by the machine.
- $T_{plan}$   
Is the number of planned production hours per year. This is a critical parameter to the machine rate calculations, one problem that can occur is that the market demand varies after the machine rates are calculated, this phenomenon will lead to an over- or underestimation of the machine rates. Varying demand will therefore complicate a correct estimation of machine rates.
- $k_{Uhh}$   
Is the hourly rate for maintenance on the equipment.
- $h_{UH}$   
Is the ratio between the maintenance interval and the maintenance time.
- $k_{ph}$   
Is the variable rate per hour associated with running the machine. This variable includes cost post that cannot be assigned to other variables, that arise when the machine is operating.

The machine time cost calculated here are just an example of an application, Ståhl (2012) encourage users to tailor the equations to their demands. In the equations for machine rate presented the resale value or cost associated with decommissioning of the machine not accounted for. It is suggested that the initial investment is reduced with the net present value of the resale value, positive or negative. (Ståhl, Industriella tillverkningsystem Del II - Länken mellan teknik och ekonomi, 2012, ss. 90-95)

## 2.7 Production Performance Matrix

The Production Performance Matrix, PPM is a tool that in a structural way sorts and stores information during a production analysis. The PPM is a structured tool to use when translating production data in to loss terms for use in the Ståhl cost equation. A generic PPM as described by Ståhl (2012) is presented in figure 6. (Ståhl, 2012, s. 191)

<b>Factor groups</b> A-G and H	<b>Result parameters</b>				<b>Sum Factors</b>
	Quality parameter Q	Downtime parameter S	Production loss parameter P	Environmental parameters MK	
A. Tools					
B. Workpiece					
C. Process					
D. Personnel and org.					
E. Maintenance and service					→
F. Special factors					
G. Peripheral equipment					
H. Unknown factors					
<b>Sum</b>		↓			
<b>Result parameters</b>	←				→

*Figure 6: Generic PPM modified from Ståhl. (Ståhl, 2012, s. 192)*

## 2.7.1 Factor groups

The PPM is built up on several factor groups. In the generic PPM as described by Ståhl (2016) the factor groups are tailored to accurately represent problems occurring in a metal cutting process. The factor groups are the following:

- **A Tools and tooling system**  
Geometry related factors, surface relate factors and material related factors all in the tool itself.
- **B Workpiece and workpiece materials**  
Geometry related factors, surface relate factors and material related factors all in the workpiece itself.
- **C Process and process data**  
Equipment related factors, process data and machine settings, process additives and procedural failures.
- **D Personnel and organization**  
Standard operating procedures, managerial functions, action plans and work structures.
- **E Maintenance and service**  
Tool and equipment failure related factors, planned and unplanned maintenance.
- **F Special factors**  
Factors unique to the process in question, such as burr formation in metal cutting or weld splatter in a welding operation.
- **G Peripheral equipment**  
Factors related to material handling equipment, gripping tools, conveyor belts and such.

To not corrupt the above listed factor groups a group H can be created that can collect factors that cannot be directly allocated to the above listed factor groups.

Each factor group consists of several factors or root causes that directly affect the production performance. (Ståhl, 2016, s. 19) (Ståhl, 2012, ss. 188-190)

## 2.7.2 The PPM and production analysis

According to Ståhl (2012) the PPM has 4 primary uses.

- Serve as a base for evaluation of an ongoing production process in an effort to identify which parts of the process that need to undergo development work to achieve a more stable and cost effective process.
- Serve as a knowledge base for development of new production systems, based on data collected in PPM from other similar production processes.
- The PPM may be use as an assessment tool, aiding in making decisions that can affect the result parameters and the individual factors. Decision such as choice of tools, process equipment, process data etcetera.
- To provide a basis for the documentation and assessment for the documentation of competence and experience gained when studying the production system.

(Ståhl, 2012, s. 192)

## 2.7.3 Building the PPM

When building the PPM and choosing parameters it is important to consider a few things. First, the quality parameters Q1, Q2 and Qn must reflect why the product was rejected for example incorrect dimensions, surface or function and not the underlying factor that caused the problem because that information is represented in the factors itself.

All the result parameters must be able to convert into loss parameters for use in the cost model and for calculation of key Performance indicators. Therefore, it is important to use the correct units on all values in the PPM. It is for the same reason important to distinguish between unplanned and planned downtime. To be able to create the loss parameter QP it is important to use a continuous scale for logging production rate loss, the author also suggest a simpler approach to logging rate loss where each parameter represent a discrete rate loss for example P1 =  $\frac{1}{4}$  normal production rate and P2 =  $\frac{1}{2}$  production rate.

The individual factor in the factor groups is hard to identify before the actual work with production analysis starts. Some factors are by experience or other obvious means possible to identify before the analysis but some of them will derive from issues after the production analysis has started. The content of the factor groups are there for non-stationary and may be updated as more problems are uncovered or an higher level of detail is desired in the analysis. (Ståhl, 2012, ss. 195-196)

## 2.7.4 Data collection

In industrial production work is carried out with more or less automation. Data collection and the use of PPM is much easier and more accurate in highly automated processes. Automatic reporting of time and quality problems in manual processes is technically hard to implement. In addition, manual reporting of data from manual workstations is time consuming and experience shows that it is hard for individuals to report problems that themselves are part. (Ståhl, 2012, ss. 193-196)

## **2.8 Deterministic production development**

Ståhl (2012) has presented a concept in deterministic product development. The purpose of general production development is to increase the performance of the production system in some way. It can be by, cost reduction, increased capacity or some other measure. In deterministic production development the purpose of the project is to achieve a set goal. The goals can be formulated using goal functions. The goal functions are tied to an economic model of the production system so that the set goals result in an economic gain.

The cost of the production development project can be compared to the economic gain that is achieved by meeting the set target. By allowing the gains or possible profit from multiple projects to be compared to each other to determine where resources should be spent. By calculating the economic effect of changing a parameter it is possible to calculate the budget for the production development project that results in a profit. (Ståhl, 2012, ss. 211-212)

## **2.9 Production economic simulation**

Production economic simulation is done by creating an economic model of the production system in a software for example Microsoft Excel. By defining input parameters to the program a result in terms of cost and production times are generated. The simulation tool can then be used to identify how the cost of produced goods varies by changing input parameters, as well as which input parameters that affect the product cost the most. Reliable data to the economic modelling of the process is important for the success and the possibility to do a production economic simulation. (Ståhl, 2012, ss. 228-231)



## **3 Method**

### **3.1 Theory**

There are different kind of methods that can be applied when performing a scientifically project or when looking into a problem such as in this master thesis. The methods used for gathering material, describing, comparing, putting up a hypothesis or predict something will effect and permeate the whole analysis of the problem. In this section, the theory behind the methods used during the master thesis will be described in short.

#### **3.1.1 Literature study**

A literature search, consisting of mostly printed material such as books, articles, reports, essays and thesis, is always followed by a literature study. The published material should have credibility and relevance to the study with equally credible references.

#### **3.1.2 Interviews**

An oral communication with an objective to gather information and opinions from respondents often with expertise within the area of interest. The interviewer should be prepared, well-structured and have questions that opens up for discussion and free thinking for the respondent.

#### **3.1.3 Description**

One of the simplest of method is the description. The goal is for example to describe how a specific system is working, an organization is structured or how a tax-system is functioning. The description should be purely empirical but the analysis can be initiated from value-based reasons such as improvement of the system.

#### **3.1.4 Quantifying**

By quantifying the data, it is often translated into numbers or terms equivalent to numbers called "hard-data". The objective is to use the quantified data statistically and in models to make it understandable to the receiver who can interpret the data themselves and do calculations and assumptions on their own.

#### **3.1.5 Modelling**

A model is a product of an underlying theory. The goal with a models is that it should reflect a certain image of the reality and the more complicated the model is, the possibility of it reflecting the whole reality increases. The level of complicity and sheer span of the model will be a consequence of its purpose. The objective with economical models can be to use them for simulations and to perform different event calculations.

(Ejvegård, 2007)

## **3.2 Course of action**

In this section, the overall procedure of the master thesis is described in a few steps that all link to the methods presented above. Each step is dependent on the other steps in the process to make sure of a complete and structurally solid course of action.

This course of action was chosen as the objective with the master thesis was to investigate the possibility to implement the generic cost model to continuous flow production and through the model analyze the cost drivers. Even if other cost models exists such as the cost model for metal cutting presented by Vafadar et al. (2016), the cost model by Ståhl was the primary choice for this master thesis. The cost model from Ståhl has been proven to work in previous production facilities for example when implemented at a manufacturing company in Landskrona, Sweden, calculating production costs in real time. (Vafadar, Tolouci-Rad, & Hayward, 2016)

### **3.2.1 Interviews and meetings**

To be able to get an understanding of the process and the different activities involved in producing milk-products several interview and meetings were held with process-engineers and projects managers at Tetra Pak. The objective with the interviews and meeting was to broaden the knowledge of the process, equipment and steps involved in the process and map these as carefully as possible. Consulting meetings were also held on a regular basis with experts in modelling the cost model at LTH.

### **3.2.2 Literature study**

An extensive literature study was performed and founded the basis for the master thesis. The literature study was based on published works from LTH and other research-institutions. Published books, articles and thesis from renowned researchers was also used as a basis for the master thesis.

### **3.2.3 Determining control volume**

Constructing a model for the whole process including construction of the facilities, maintenance of the facilities, rent of property, shipping of equipment, installation, production, etc., can be very complicated. Therefore, it is of importance to restrict the model and determine a specific control volume early in the project to focus on areas of interest. The control volume can be restricted to a specific machine or equipment, a section of the production line, a particular product or whatever part of the company that is of interest to analyze. The idea is that the control volume has open system boundaries through which mass and energy can flow and enter or leave the system or systems within the control volume. The only restriction is therefore to which parts of the organization and facility that are included, not the resources or mass used in the process.

### **3.2.4 Identifying activities**

Normally when applying the cost model from Ståhl, it is applied to a single planning point and usually involves one piece of equipment that has a "floor to floor" discrete cycle time. However, in this particular case the nature of the process and the equipment prohibits this type of application of the cost model. Therefore, it was concluded that the production process should be divided into separate activities representing one value-adding step. In the continuous flow process, one activity can allocate one or more pieces of equipment at the same time and multiple activities can take place simultaneously performing value-adding steps to the same product.

By using Olhagers (2000) approach of mapping activities with a process flow chart and combining this with a value stream map, the process was mapped for further analysis that worked as a base for construction of the generic cost model. (Olhager, 2000)

### **3.2.5 Schematic cost and resource diagrams**

By forming schematic cost and resource diagrams of the process to begin with makes it easier to structure the approach to collect data and knowing which data should be collected. By using the activities as a backbone structure for the diagrams, resources and costs can be linked to each activity and between activities. For example, a cooling operation allocates cost for investment and installation of equipment but also operational cost for resources used such as cooling media and power supply. The diagrams forms a first impression and overview of the process and how resources and costs flow through it.

### **3.2.6 Collection of data**

Collection of data was performed in a few different ways and from different sources, all listed below.

- Tetra Pak internal documents
- Interviews
- E-mail correspondence
- TCO-calculations, Total Cost of Ownership

Most of the data was collected from Tetra Pak internal documents with information about investment cost, installations costs, resources required to operate, etc. Along with several interviews and e-mail correspondence with site managers, the correct processing times in each step of the process was also determined. Existing TCO-models of the facility was also collected for analysis. The most crucial data needed for the implementation of the cost model was defining processing times and the correct order of activities and steps in the manufacturing process. It was also of importance to define which steps where performed simultaneously in order to calculate correct time-plans for the facility. This data was collected from process engineers at Tetra Pak through interview and continuous meetings.

### **3.2.7 Implementation of cost model**

For the implementation of the cost model the Microsoft Office tool Excel was used. Excel was chosen as the preferred calculation tool as it is the most common calculation tool at Tetra Pak. The idea with the cost model was to make it usable for a user with basic knowledge of Excel and possible to add and remove sections from the model. The structure of the interface was therefore a vital part when constructing the worksheets to make it intuitive and easy to use.

## **3.3 Criticism of the sources**

The sources used in the master thesis for theories and methods are gathered from literature studies of published book, articles, papers and publications found on the internet. The information gathered with this literature study will give the master thesis a wider perspective and relevance ensuring the analysis will have a strong theoretical foundation.

All sources used are analyzed and checked so that they have a renowned academic background or has been published as scientific articles, publications or papers. The sources used are controlled to have enough credibility by comparison to other independent sources and by using logical scientific assessments.

## 3.4 Obstacles and limitations

During the course of the project, some obstacles and limitations have occurred holding back progress and prohibited some deeper analysis of the production facility. These obstacles and limitations will be pointed out and discussed in the section.

- Unable to visit site
- Relying on corporate competence
- Lack of production data
- Assumptions

With this type of analysis site visits are a great advantage and simplifies the possibilities to analyze the flow in production, map resources used, detect areas with issues in operation, to comprehend the overall production planning and management and so on. Without being able to observe to machines operating, most of the analysis will be relying on gathered data from operators or management on site that of course brings some insecurity to the reliability of the information.

As said before, without visiting the site some of the data will rely on corporate competence instead of actual logged data or clocked cycle times. As Tetra Pak is a worldwide company with great knowledge about their own product, this necessarily does not apply on sourced products. Yet again the quality of the data relies on the corporate competence.

The production facility is currently in the first stages of operation with limited production data available. Without proper and qualitative production data, preferably automatically logged from the machines, the cost model will only work as a tool for simulation of production cases with more or less fictive data. With correct production data, a more elaborate analysis can be made with correct cycle times, downtimes, rejections, usage of resources, etc.

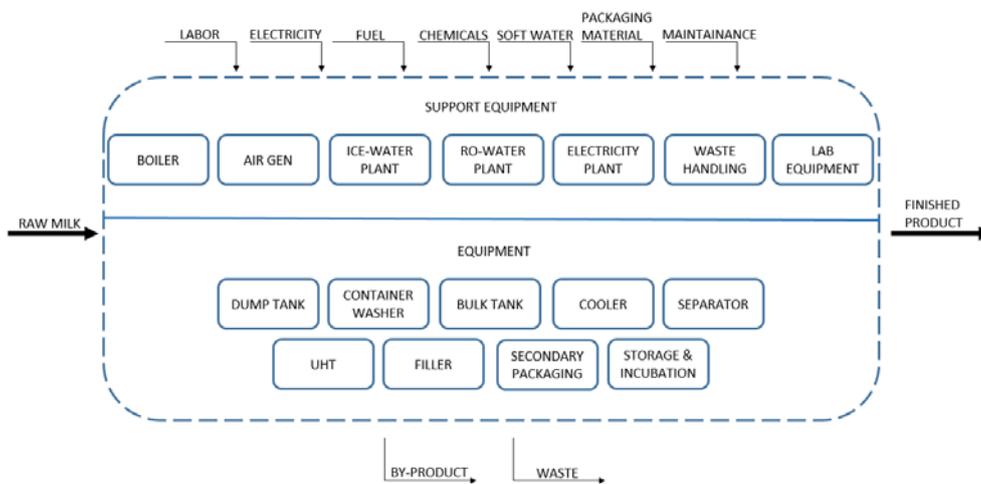
As there is basically no productions data available for this project most of the production data in the model will be based on assumptions and qualitative guessing from technical product information. The model will be structured in such a way that the user can change the input data when production data will become available.



# 4 Results

## 4.1 Control volume

The control volume includes the facilities equipment and support-equipment including lab-equipment. The building, land, transportation, logistics, management and other support functions are excluded from the control volume. Ingoing cost parameters that are used in the model are labor, electricity, fuel, chemicals, soft water, packaging materials and maintenance. Outgoing parameters are bi-products and waste. The control volume is illustrated in figure 7 below.



*Figure 7: Control volume of the facility.*

The raw material, in this case milk, is assumed to be accessible at the facility and the finished product, packaged milk, leaves the control volume after storage and incubation. This means that transportation is excluded from the control volume and the cost model except for internal handling.

## 4.2 Process flow chart

The automatically collection of production data from the facility was not in operation and therefore not available for analysis. Manually collected data from some of the first trial runs of the production was on the other hand available but varied in batch size and processing times. This could be as the facility was still in first break-in period at the time and test-runs where conducted to validate the performance of the production system. The data used in the process flow chart below in figure 8 is from one of these test-runs and the production times should therefore be taken lightly. On the other hand, the process flow will be the same for the test-runs as well as for the future production that will support the understanding of the activities, both value adding and non-values adding, in the process.

Process flow chart		Object: Milk					Process: <input checked="" type="checkbox"/> Existing <input type="checkbox"/> Suggested		
Step	Description	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Time (hours)	Distance (m)	Valuecode (V/N/S/?)
1	Unloading	x					0,5		N
2	To reception					x			N
3	At reception				x				N
4	Testing	x					1,75*		S
5	Weighing	x					1,75*		N
6	Dumping	x					1,75*		N
7	Chilling	x					2,5*		V
8	Separation	x					0,1*		V
9	Testing	x					0,4*		S
10	Standardization	x					0,2*		V
11	Testing	x					0,8*		S
12	Storing bulk tank				x		0,75		N
13	Heat treatment	x					0,75**		V
14	Filling	x					0,75**		V
15	Control			x					S
16	To secondary packaging					x			N
17	Secondary packaging	x					0,75**		V
18	To storage		x					?	N
19	At storage				x		168		N
20	To test					x	?		N
21	At test				x		?		N
22	Test	x					?		S
	Sum	13	1	1	4	3	172,5	0	-

*Figure 8: Process flow chart of the process.*

The process flow chart shows that multiple activities are performed at the same time. This is illustrated with \* and \*\* for different processing times for the activities. This suggests that when cost of equipment will be distributed to activities, the activities will allocated different costs depending on which other activities are performed at the same time. If cost of equipment should be distributed to activities they will be dependent on some sort of time plan that governance the distribution.

## 4.3 Value stream map

By using the first two phases of value stream mapping, the process is mapped systematically with all value adding activities and storages involved. The product family is easily selected in this case thus there is only one product currently produced at the facility, cartridges of milk. As the lead-times of each activity is not yet clearly mapped in this newly established production facility they are loosely defined in the value stream map presented below. Even with loosely defined lead-times, the value stream mapping gives a great overview of the process, which helps defining the general time-plan, and time utilization cases that serves as a base for distributing costs in the generic cost model. The value stream map also helps to understand the relation between production lead-time and values added time in the production. In the current state map, one unit produced is described as one kiloliter of milk.

The value stream map in Appendix A illustrates the flow of the product through the value adding activities. What this value stream map does not illustrate is the non-value adding activities needed to produce that take place simultaneously as the value-adding activities. For example, before the heat treatment and filling can be executed the equipment needs to be sterilized. The sterilization should be performed during the activities quality control and transfer, cooling and separation. These kind of setup-activities can be interpreted as setup-times and therefore handled as downtime as Ståhl suggests for his generic cost model. The risk with dealing with setup-times in continuous flow production is that activities can be performed at the same time in different parts of the production line. The setup-activities are there for defined as separate activities and not combined with main-activity that they serve. By separating the setup-activities from the main-activities it is also possible to distribute different consumptions of consumables to the activities which would have been complicated if the setup-activities are combined with main-activities.

A future state map was never established for this production facility and the value stream mapping process ends after phase two for this project. The reason is that the first two phases of value stream mapping are the only two of interest for the implementation of a generic cost model. The current state map serves, as mentioned before, as a basis to help structure the time plan and time utilization case needed to distribute costs to activities.

## **4.4 Schematic cost and resource diagrams**

To be able to support the generic cost model and help set the structure, a few different schematic diagrams were conducted regarding different areas of cost, usage of resources and usage of consumables. Depending on how elaborate the cost model shall reflect the reality, the different steps can be added or removed. For this case, four different diagrams were conducted explaining where cost, resources and consumables are located both in activities and support equipment.

### **4.4.1 Schematic diagram of equipment usage**

The diagram presented in Appendix B illustrates how the facilities equipment are used during the different steps of production. Some equipment is only used in one activity and therefore directly linked to that activity. Equipment that are used in multiple activities and at different times during the process, sometimes at the same time, are more complicated to distribute. These scenarios calls for a scheduler that distributes the cost for equipment dependent on active and non-active activities.

### **4.4.2 Schematic diagram of resource usage**

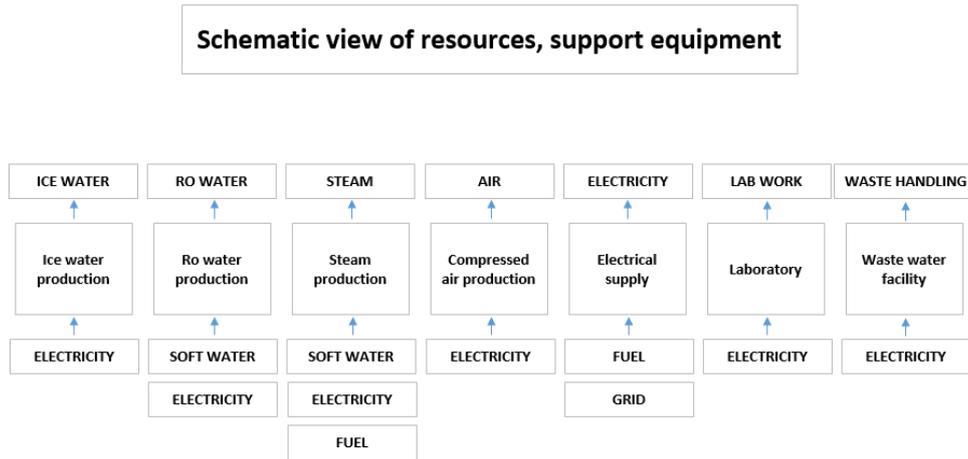
With the equipment distributed to activities it is of interest to locate how resources are used in the process. In Appendix C the schematic diagram shows how resources are being used in different activities. For example, electricity is one resource that is used in all activities of the process whilst usage of ice water is only located in the activity cooling and process. This diagram serves as the foundation of what later will be activity based costing of said resources. The base will directly depend on the total usage of resource in each activity.

### **4.4.3 Schematic diagram of consumable usage**

The usage of consumables differ from resources in the definition that they are directly bought and has no limit. For example, packaging material is one resource that should always be available and has a certain cost, for instance euro per meter material, instead of being dependent on batch size or on how much material is used in the process. In short, the consumables has a fixed cost per unit and is not related to activity based costing. In Appendix D the schematic diagram shows where consumables are being used in the production.

#### 4.4.4 Schematic diagram of resources, support equipment

The support equipment are in some cases the manufacturers of resources and some of those resources are used in other support equipment. Electricity is one of the resources that is used in most activities and in the manufacturing of other resources such as ice water. The schematic diagram in figure 9 below shows the three basic ingoing resources supplied from external parties, soft water, electrical grid supply and fuel. With these three resources and the support equipment, it is possible to manufacture the other resources used in the process.



*Figure 9: Schematic view of resources support equipment.*

## **4.5 Generic cost model**

### **4.5.1 Introduction**

The purpose with this master thesis is to investigate if it is possible to produce a generic cost model that can be used by Tetra Pak to map and analyze cost drivers in the current facility. Hopefully this cost model will be used on other facilities as well in the future. In this section the structure of the model will be explained, why it is built the way it is step by step and how and why different parts of the model interact with each other. With the understanding of how the model is built and how everything is linked together, the cost model can be altered to be implemented to other manufacturing processes.

### **4.5.2 Main considerations for creation of the cost model**

The main goal for the cost model is to be a tool for analyzing cost and cost drivers in a milk production system. The model should be able to map where costs arises in the production system and provide some basic production statistics on production capacity and production times.

#### *4.5.2.1 Modularization*

Since the target user of the cost model is not its inventors it is important that the cost model is both easy to use and easy to understand. The cost model is therefore built in a modular way for easy understanding and to allow the model to be tailored to user needs and applications on other production systems then the one studied when creating the model.

#### *4.5.2.2 Mapping of cost drivers*

The cost model is build to analyze cost drivers and cost to aid the user making business cases on production development and improvements to the production line. One of the tools considered for this application was the usage of production economic simulation. The cost model is therefore constructed in such way that it allows easy implementation of production economic simulation.

#### *4.5.2.3 Production performance matrix*

To successfully analyze and monetize problems or factors affecting the production line, the cost model is built to work in conjunction with a production performance matrix. Since the production system did not provide accurate production data during the time of the creation of the cost model no production performance matrix was created. The cost model is constructed to handle the output parameters from the production performance matrix, in terms of loss terms, as input parameters for cost modeling.

## 4.5.3 Structure of cost model

### 4.5.3.1 Nature of the production system

Cost modeling of a continuous or semi-continuous flow-production is different from modeling most conventional manufacturing processes such as machining where each work piece has a discrete cycle time in each discrete value-adding step. In flow production of a liquid substance there is no discrete work piece instead there is a quantity of liquid substance in the system that is being worked on with a continuous or non-continuous rate. Furthermore, the product can be in multiple value adding steps or equipment's at the same time.

### 4.5.3.2 Applying Ståhl generic cost model to the manufacturing system

To address the nature of the production system and successfully apply the Ståhl cost model. The process is divided into activities. An activity in the cost model is a value-adding step or a necessary support activity that is performed on the product or in the manufacturing system and can be considered a planning point. Ståhl considers a planning point as a manufacturing step that has a discrete cycle time. In the Cost model a planning point is value adding step that has a discrete rate or a discrete cycle-time per batch. Some of the activities use the same equipment at the same time, or blocks the next activity to be performed. Therefore, it is not possible to calculate an hourly machine rate in advance for each planning point or activity, since they are all dependent on each other. To solve the problems mentioned above the main production activities that share equipment has a separate time utilization case in the model where machine rates are calculated for each activity based on the simultaneous usage of the equipment by other processes. Only rates for equipment that is used by one or more activities in a production run is calculated through the time utilization case. The time utilization case only distributes fixed cost to activities ( a  $k_{CS}$  is calculated) since each activity has its own resource consumption which in many cases attributes to a much greater costs than the yearly fixed cost of equipment. A schematic overview of the implementation of the cost model to the production system is shown in appendix E.

### 4.5.3.3 Introduction to time utilization case

Since all the equipment that is handled under the time utilization case cannot be used standalone and is part of a flow production the easiest way of cost modeling the production system as one planning point and not consider each value adding step that takes place in the production line. However, the equipment that make up the production line is interchangeable and there is a desire to distinguish each value adding step that is performed in the production line for the possibility to make a production economic analysis in each value adding step, and or on each piece of equipment. To accurately describe which cost each value adding step adds to the product it is important to determine the cost of balance losses in the production line. For example if the cooling is very time consuming, it is blocking the usage of the UHT or packaging machine from being used and therefore adding to the possibility of the whole production system to produce more product that can lower the yearly fixed costs per package produced. The purpose of the time utilization case is to distribute the cost of waiting equipment to the activities starving or blocking the waiting equipment to be used.

## 4.5.4 Time utilization case

### 4.5.4.1 Structure of the time utilization case

The yearly fixed costs for the equipment, which consist of depreciation and capital costs, are divided by planned production time  $T_{PLAN}$ . This gives an hourly rate for the equipment that must be allocated to a product during planned production hours. The total production time per batch  $T_{PB\ system}$  is calculated by adding the production time per batch  $T_{PB}$  for each activity that is handled by the time utilization case and not occur simultaneously with another activity giving the actual time it takes for a batch of product to move through the system. The production time per batch for the system,  $T_{PB\ system}$  are then multiplied by the average or estimated number of produced batches per year giving the estimated yearly production time. By subtracting the yearly production time from the planned production time, the yearly average free capacity in the production system is calculated. The free capacity together with the planned production time is then used to calculate the degree of utilization for the equipment affected by the time utilization plan.

The hourly rates for each equipment is distributed to hourly machine rates for each activity. The distribution is handled automatically by the model. Figure 10 illustrates a schematic view on how cost is distributed by the model. During the activity cooling which takes place during the first four hours in the example, the activity cooling pays the cost not only for the cooling tank and the chiller which is utilized by the activity in question. The activity cooling is also paying the hourly downtime rate for the UHT and filler which is starved on material for the whole time the activity cooling is in progress. After two hours the SIP will start, and the activity SIP will pay for the UHT and filler. SIP will only start so that it is finished at the same time the cooling is finished. During the activity cooling the activity pays for the rate of the bulk tank and chiller it is using but also the downtime rate for the UHT and filler for the first two hours, since they are blocked by the cooling activity. When the activity process is working on the product, the activity pays for all the equipment, which is now blocked and waiting for the next batch, the same goes for the activity CIP.

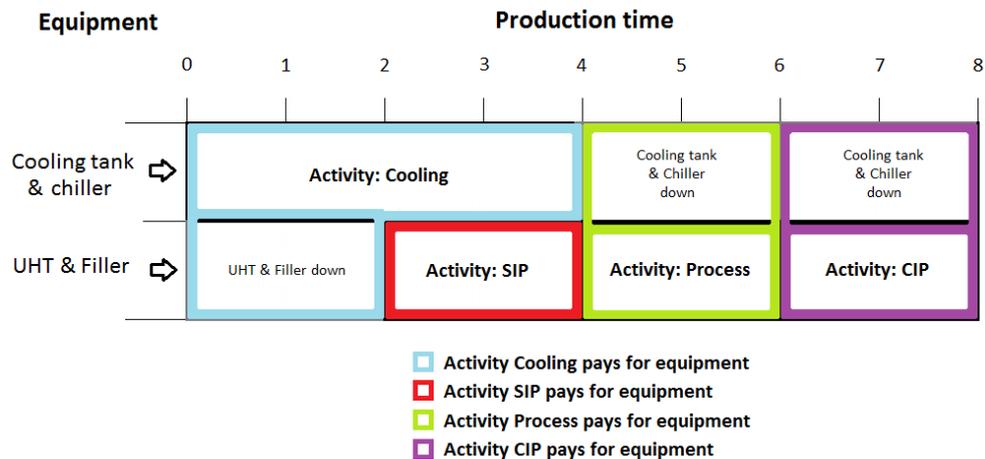


Figure 10: Schematic view of activities paying for the equipment during a production run.

#### 4.5.4.2 Implementation of time utilization case in the cost model

Physical implementation of the time utilization case is performed by building matrixes of billing time per batch from each equipment to the paying activity, such matrixes is shown in figure 11 where the top matrix shows the hours when an activity is using equipment. The middle matrix in the figure illustrates when an activity is paying for equipment that is waiting. The bottom matrix in the figure is the sum of the two upper ones and is used to check the functionality of the model in terms of that all the equipment are payed during the whole production run which is accomplice if the bottom row “Planned production time per batch” is equal for all columns. The bottom row in the lowest matrix also gives the total production time for the activities using the time utilization case.

Active time [hrs]				
Activity	Equipment			
	Tank	Cooler	Process	Filler
Cooling	1,00	1,00		
SIP			2,00	2,00
Process			0,80	0,80
CIP	1,00	1,00	1,00	1,00
Down time [hrs]				
Activity	Equipment			
	Tank	Cooler	Process	Filler
Cooling			0,00	0,00
SIP	1,00	1,00		
Process	0,80	0,80		
CIP				
Total time [hrs]				
Activity	Equipment			
	Tank	Cooler	Process	Filler
Cooling	1,00	1,00	0,00	0,00
SIP	1,00	1,00	2,00	2,00
Process	0,80	0,80	0,80	0,80
CIP	1,00	1,00	1,00	1,00
<b>Planned production time per batch</b>	<b>3,80</b>	<b>3,80</b>	<b>3,80</b>	<b>3,80</b>

Figure 11: Time utilization case.

The matrixes in the figure 11 in the model called “time utilization case” are then used to determine the hourly cost for the activities by multiplying them with the hourly machine rates calculated in each equipment page. This yields a second matrix of machine costs presented in figure 12, in the model called “cost plan”. The “cost plan” matrixes uses the data in the “time utilization case” matrix and multiplies each time entity with the respective hourly cost for each equipment, which is visible in the bottom row in the cost plan matrix below. The hourly machine rates for each activity are then obtain by summarizing the rows in the cost plan matrix to the get the total fixed part of the machine rates per batch in the column “SUM” in the cost plan matrixes. The total machine rates per batch are then divided by the total production time which is found in the bottom row in the “time utilization case” matrixes, this operation gives the hourly rate  $k_{CS}$  for each activity, the calculations are shown in figure 13.

Hourly cost calculation (distributed)							
Active time [hrs]							
Activity	Equipment				SUM [EUR/Batch]	Hourly rates [EUR/h] (kCS)	
	Bulk tank	Cooler	Process	Filler			
Cooling	0,86	0,86	0,00	0,00	1,73	0,00	
SIP	0,00	0,00	1,73	1,73	3,45	0,00	
Process	0,00	0,00	0,69	0,69	1,38	0,00	
CIP	0,86	0,86	0,86	0,86	3,45	0,00	
Down time [hrs]							
Activity	Equipment				SUM [EUR/Batch]	Hourly rates [EUR/h] (kCS)	
	Tank	Cooler	Process	Filler			
Cooling	0,00	0,00	0,00	0,00	0,00	0,00	
SIP	0,86	0,86	0,00	0,00	1,73	0,00	
Process	0,69	0,69	0,00	0,00	1,38	0,00	
CIP	0,00	0,00	0,00	0,00	0,00	0,00	
Hourly cost	0,86	0,86	0,86	0,86	[EUR/h]		

Figure 12: Cost plan.

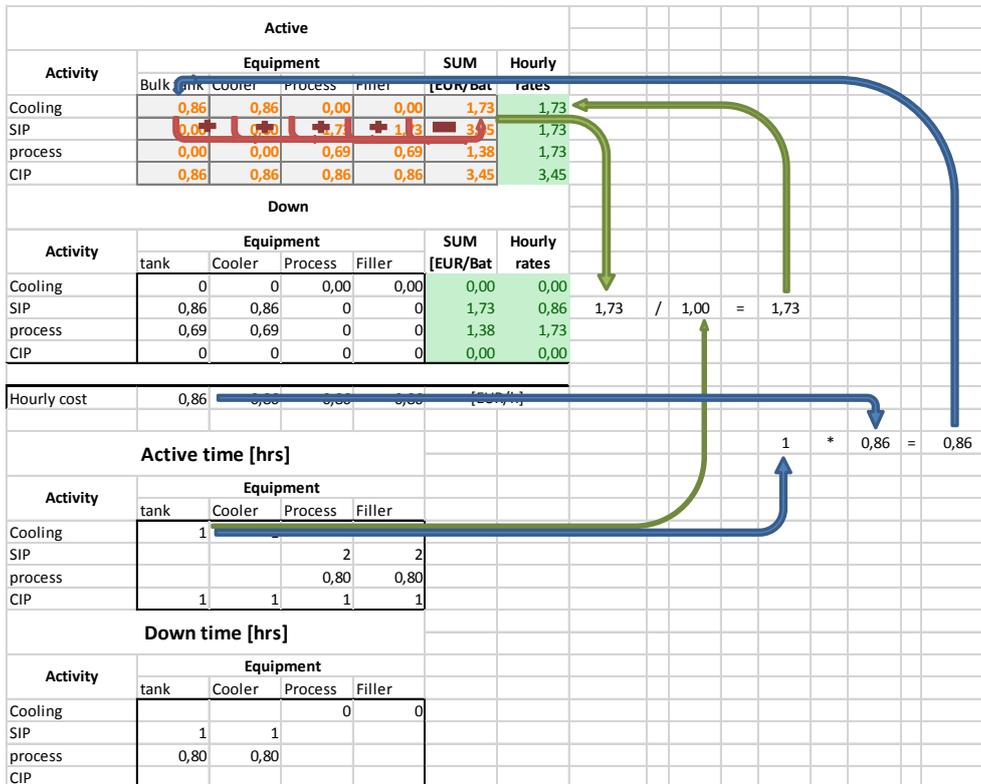
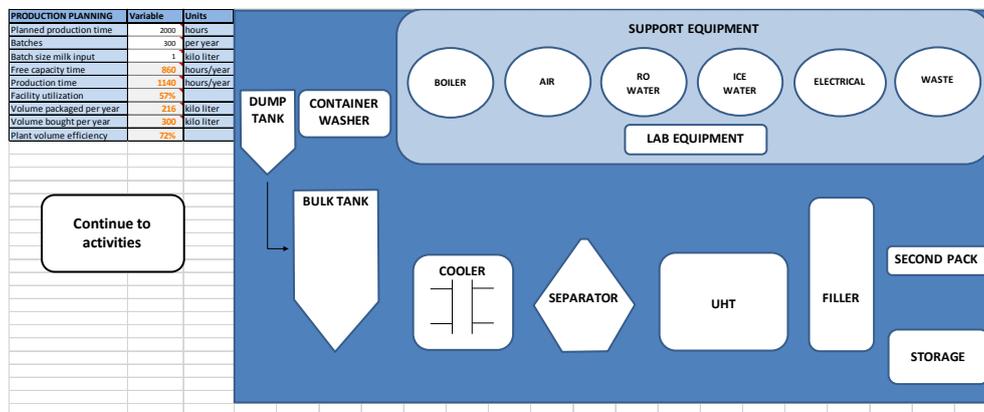


Figure 13: Example of calculation of hourly machine rates for equipment, using time utilization case and cost plan.

## 4.5.5 Equipment

### 4.5.5.1 Introduction to Equipment.

All of the equipment located inside the control volume will affect the total cost of manufacturing and as a result the end price of the product. The equipment can in this case be sorted into equipment and support equipment. Support equipment is all the equipment needed to produce consumables such as cold water, steam, etc. Remaining equipment such as separators, heat treatment units, chillers, etc. are used in the manufacturing process and therefore only labeled equipment. Each individual piece of equipment has its one page in the cost model where the cost of capital and depreciation is calculated depending on the early usage by activities. The early usage and distribution of equipment costs are handled and linked to activities in three different ways depending on the type of equipment and how the equipment is used by the activities.



*Figure 14: Equipment overview.*

The general overview of all equipment used in the cost model is present as shown in figure 14 above. Through this first page, the user can maneuver to the different individual equipment and support equipment pages. In the top left corner, the user can choose input parameters that will apply for the whole cost model and see statistics on how much product is estimated to be produced given the users input to the production planning.



#### 4.5.5.2 *Equipment used by only one activity*

Some of the equipment are only used in one activity and are only used for making one product. Therefore, there is no need to take planned production hours for the whole production system and degree of utilization,  $U_{rp}$ , into consideration. Instead, the activity's production time per batch and the number of batches per year serves as a base of distributing costs. These activities are not included in the Time utilization case. Figure 15 earlier shows an example of an equipment sheet for an equipment only used by one activity.

#### 4.5.5.3 *Equipment used by the time utilization case*

Equipment that is handled through the Time utilization case uses the whole production systems planned production time,  $T_{plan}$ , as factor to distribute fixed yearly costs to hourly rates. With the usage of  $T_{plan}$  there is a need for implementing degree of utilization,  $U_{rp}$ , which is then used in the cost calculations in each activity for correctly setting machine rates taking free capacity into consideration.

#### 4.5.5.4 *Support equipment.*

Support equipment are used to produce consumables that are made and consumed within the production system and the control volume that is set for the analysis. Support equipment are modeled as a combination of both a production unit and a buffer and are generally not real time dependent in the model. This means that they are modelled to have a set production rate, but the consumption in any given moment from the activity using the produced consumable may be higher or lower.

Consider the example with the air compressor. When in operation it consumes X amount of resources and produces Y amount of compressed air per hour. The compressed air is stored in a tank attached to the compressor. The activities in the production system can consume 0,5 Y of air per time unit for a period of time Z. This yields a production time for the compressor that is  $0,5*Z$ , this can be seen as the tank depleting of air for half the time of Z and the compressor actually running and consuming resources for  $0,5*Z$ .

All the support activities using the support equipment are modeled the same way and the same method is used to calculate the yearly production time. The production time per year, for each support activity, is calculated by summing up the total yearly consumption from all activities using the resource being produced and dividing that volume by the nominal production rate of the producing support equipment.

<b>Air compressor</b>			
<b>Cost calculation</b>			
Equipment cost	10000	EUR	
Instalation cost	1000	EUR	
<b>Total cost of investment</b>	<b>11000,00</b>	EUR	
Investment lifetime	10	Years	
Resale value or decomissioning costs	100	EUR	
Interest rate	10%		
<b>Present value of resale value or decommissioning costs</b>	<b>38,55</b>	EUR	
<b>Present value of investment</b>	<b>10961,45</b>	EUR	
<b>Yearly rate for investment</b>	<b>1783,92</b>	EUR	
Calculated production time	<b>543,13</b>	hrs/year	
Fixed cost per hour	<b>3,28</b>	EUR	
<b>Usage of assets</b>			
<b>Activity</b>	<b>Usage per hour</b>	<b>Production time per year</b>	<b>Total consumption</b>
Reception and quality control	0,00	733,33	0,00
Cooling	0,00	1100,00	0,00
Separation	0,00	220,00	0,00
SIP 1	100,00	275,00	27500,00
SIP 2	100,00	165,00	16500,00
Process UHT	100,00	550,00	55000,00
Process Filler	925,00	550,00	508750,00
Secondary packaging	0,00	550,00	0,00
CIP	100,00	440,00	44000,00
Washing of containers	0,00	440,00	0,00
Washing of separator	0,00	880,00	0,00
Storage and incubation	0,00	36960,00	0,00
		Total yearly consumption	<b>651750,00</b> kg/year

**Figure 16:** Equipment sheet for support equipment.

All of the support equipment is listed individually as shown earlier in figure 14. As the support equipment produces consumables for the process the amount of produced consumables will serve as a base for distributing cost of investment as shown in the example above. With increasing production of consumables, the cost for each unit of consumable will decrease but the total cost will stay the same. The consumables are directly dependent on the production and how much of each consumable is used in every activity. An example of a support equipment page is shown in figure 16.

## 4.5.6 Activities

### 4.5.6.1 Introduction to activities

Each activity represents a value-adding step in the production process. An activity in the cost model can be an activity performed on the product itself such as packaging, or can be a non-value adding activity performed on the production system itself to be able to produce the main product such as a SIP or CIP. The term activities in the cost model is also used for support activities such as producing a consumable or resource that is consumed by the main production line. These activities can be considered semi value adding. For the purpose of the main production line, they may not be considered value adding, since producing compressed air to operate valves may not add value to the main product itself. If the support activities are considered to be own production sites or lines they may be considered value adding since they are refining a substance to something useful and potential sellable. The latter approach is the underlying fundamental base for integrating the support activities in the cost model, where the main production line is purchasing resources internally from the support activities at self-cost.

### 4.5.6.2 Integration of activities in the cost model

The main activities, value adding and non-value adding, is integrated in to the cost model based on the product flow or a precedence diagram of the production. The reasoning behind this is to allow for easy adaptation of the cost model at various production sites. Other production facilities of similar nature may not consist of all production activities listed in the model, or may contain buffers along the way that brakes the flow line. The main page of the activities in the cost model is shown in figure 17 below. The activities page consist of an overview of the activities in the production system both main- and support-activities, as well as the production statistics from the equipment page.

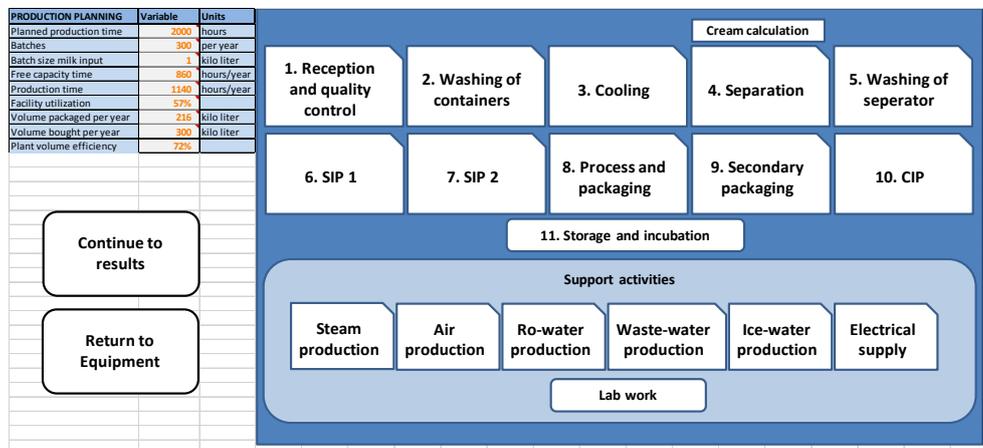


Figure 17: Activities overview page.

### 4.5.6.3 Basic layout of an activity page

The basic activity page that is used in all activities, more or less modified, consist of three main areas:

#### **Inbound data and Ståhl cost equation**

The main purpose in the activity page is to perform a calculation by the means of Ståhl cost equation, to evaluate calculate the cost added to the product in each production step. The result of the Ståhl cost equation is the outbound product cost from the activity in question. If the activity is a main activity this result will be the inbound material cost for the next activity in the production line. However, if the activity in question is a support activity the result will be the cost of which the resource is sold for internally to another activity.

To be able to execute the calculations in the Ståhl cost equation, inbound data is needed. This data is found in the sections “Inbound data to Ståhl cost equation” and “Resource consumption. The inbound data consist of a production rate, named “Nominal production rate in the model” which is used to calculate the cycle time  $T_0$ . The loss terms used in the model which is,  $q_S$  downtime,  $q_Q$  rejections and  $q_P$  production rate loss. The inbound data section is also used to calculate production time per batch as well as salary costs and machine rates per hour. The machine rate calculation utilizes  $k_{CS}$  from the equipment pages or time util case in conjunction with the section resource consumption, to calculate a  $k_{CP}$  machine rate. In figure 18 below an example of the cost calculation in an activity is shown.

<b>Cooling</b>		
<b>Inbound data</b>		
Nominal processing capacity	1	kl/h
qs	0%	downtime %
qq	0%	rejections %
qp	0%	production rate loss%
Batch size in	1,00	kl
Batch size out	1,00	kl
Utalization	57%	-
Production time per batch	1,00	h
Processing time per unit	1,00	h
<b>Product cost</b>		
Inbound material cost {kb}	1073,92	EUR/kl
<b>Machine rates</b>		
Fixed machine rate active equipment	1,73	EUR/h
Fixed machine rate waiting equipment	0,00	EUR/h
Other fixed hourly cost	0	EUR/h
<b>Hourly running costs during downtime {kcs}</b>	<b>1,73</b>	<b>EUR/h</b>
Hourly variable machine costs and consumables	17,27	EUR/h
Other variable hourly cost	0	EUR/h
<b>Hourly running costs during operation {kcp}</b>	<b>18,99</b>	<b>EUR/h</b>
<b>Salary costs</b>		
Labour cost per hour	10	EUR/h
Number of operators	0	operators
Other hourly salary costs	0	EUR/h
Labour overhead	0,00	EUR/h
<b>Total labour cost per hour {kd}</b>	<b>0,00</b>	<b>EUR/h</b>
<b>Product cost calculation (Stahl)</b>		
Cost per unit resource product {KB}	1073,92	EUR/kl
Cost per unit resource machine running {KC1}	18,99	EUR/kl
Cost per unit resource machine down {KC2}	1,30	EUR/kl
Cost per unit labour {KD}	0,00	EUR/kl
Cost of lab work per unit	0,00	EUR/kl
<b>Utbound product cost from activity</b>	<b>1094,22</b>	<b>EUR/kl</b>

Figure 18: Inbound data and Stahl cost equation in activities.

### Resource consumption

The resource consumption section is used to calculate variable cost when the process is in operation. The calculation of resource costs are done by setting a consumption rate when the process is in operation, in the activity page. This consumption rate and the production time per batch will be sent to the producing support activity to get a production volume. The support activity will then give a cost for the resources used. The resource cost together with the

nominal consumption will give the hourly cost for that resource. The sum of all resources used is the variable cost which is the difference between  $k_{CS}$  and  $k_{CP}$ . In some cases the resources used are not produced in the facility itself and are therefore not included in our control volume, an example of such resources is packaging material. Such resources will not have a calculated cost, which is dependent on the production volume, they will be bought from outside the control volume at a fixed cost per unit. In figure 19 a part of the resource section is shown.

<u>Ice-water</u>		
Nominal consumption	10000	l/h
Cost of Ice-water	16,22	EUR/h
<u>Electrical power</u>		
Power consumption	1	kw
Cost of Electrical power	1,05	EUR/h
<b>Packaging material</b>		
Cost of Packaging material	1	EUR/m
Nominal consumption	0	m/h
Cost of Packaging material	0,00	EUR/h
<u>Waste-water</u>		
From consumed water	0,00	l/h
From product	0,00	l/h
Cost of Waste-water	0,00	EUR/h
<b>Maintainance</b>		
Service work hourly cost	0	EUR/h
Spare parts hourly cost	0	EUR/h
Cost of Maintainance	0,00	EUR/h

*Figure 19: A section of the resource consumption table in an activity.*

### Result section in activities

The third and last section in the activity page is the production statistics. The production statistics section is not used in conjunction with the Ståhl cost model calculating the outbound product cost in the activity. The production statistics section is used to map cost drivers in the activity itself and forward statistics to the statistics section of the model. It will be covered later in the presentation of results section.

## 4.5.7 Presentation of results

### 4.5.7.1 Introduction

The purpose of the cost model is to accurately describe the production system in economic terms to aid in decision-making. The user may have different motives to use the model as a tool. The aim when creating the result section of the cost model is to provide as much information as possible to the user without sacrificing the user friendliness of the model. The results section of the cost model consists of four levels of analysis or perspectives. Which is considered the output of the cost model, the four sections are the following:

- **Self-cost**  
This data set provides a holistic overview of the production system to see the self-cost of producing milk and which components that make up the cost.
- **Cost driving activities**  
Is an analysis of how each production step or process make up the production cost or self-cost depending on the settings in the model.
- **Cost drivers main production line**  
Is an analysis of which cost drivers that makes up the self-cost of the product, in this section called “main production line” the control volume is set around the main production line and all resources going in to it is considered a cost driver. For example Ice-water is considered a cost driver in this level of analysis since it is an input to the main production line and not produced by it.
- **Cost drivers whole facility**  
This level of analysis is much similar to “cost drivers main production line” but with the difference that the control volume for the analysis is set to the whole production facility. The production of consumables, such as ice-water, are broken up to the resources needed to produce it such as, equipment, labor, and electricity.

All of the data used in the result section of the cost model derives from the activity pages each activity page consists of a result section as mentioned earlier. The result section in the activities consists of Ståhl cost model calculated for each resource in the unit, cost per product volume, EUR/kl. This data is then the input for the result section in the cost model.

#### 4.5.7.2 Results section in activities

##### Introduction

The result section in each activity serves two main purposes. First to analyze and visualize which resources that make up the production cost in that particular production activity and secondly to serve as a database for the result section in the cost model.

##### Cost drivers in activity, all consumables

This section of the results in activities corresponds to the section “Cost drivers main production line” in the cost models result section. Here all the resources consumed by the activity is quantified in terms of their contribution to the increase in product self-cost through the activity. An example of how the cost drivers are listed and displayed are shown in figure 20 below.

Cost drivers in activity, all consumables	EUR/kl	Value to plot [EUR/kl]	Only used for calculation
	Wasted product	0,00	#N/A
Labor	10,00	10,00	10,00
Equipment	5,76	5,76	5,76
Steam	0,00	#N/A	0,00
Air	0,00	#N/A	0,00
Ro-water	0,00	#N/A	0,00
Hot-water	0,00	#N/A	0,00
Soft-water	0,00	#N/A	0,00
Ice-water	0,00	#N/A	0,00
Electrical power	1,05	#N/A	0,00
Packaging material	0,00	#N/A	0,00
Waste-water	0,00	#N/A	0,00
Maintainance	0,00	#N/A	0,00
Chemicals 1 (type)	0,00	#N/A	0,00
Chemicals 2 (type)	0,00	#N/A	0,00
Laboratory work	24,40	24,40	24,40
Other	-	1,05	40,15
SUM	41,20		
Utbound product cost from activity	1041,20		
Checksum	0,0000		

*Figure 20: Example of cost drivers in activity, all consumables.*

The listed cost drivers are the same for all the activities in the production line. The support activities contains a shorter list with resources needed for their operation. The calculation of each cost drivers value in terms of product cost is done by the means of Ståhls cost equation. The wasted product cost driver is calculated by subtracting inbound material cost from the  $K_b$  term in the cost equation. Shown in equation 10 below.

$$\text{Cost driver wasted product} = k_b - k_B \left[ \frac{1}{(1-q_Q)(1-q_B)} \right]_b \quad (10)$$

The labor cost driver is the whole  $K_d$  term from the cost equation shown in equation 11 below.

$$\text{Cost driver labor} = \frac{k_D}{N_0} \left[ \frac{t_0 N_0}{(1-q_Q)(1-q_P)(1-q_S)} + \frac{1-U_{RP}}{U_{RP}} T_{pb} \right]_d \quad (11)$$

The laboratory work cost driver variable is calculated without using Ståhls cost equation. Laboratory work is traded in hours and are not affected by any loss terms, therefore it is calculated as multiplying the hourly rate for lab time with the lab hours needed per batch divided by batch size out from the activity, shown in equation 12 below.

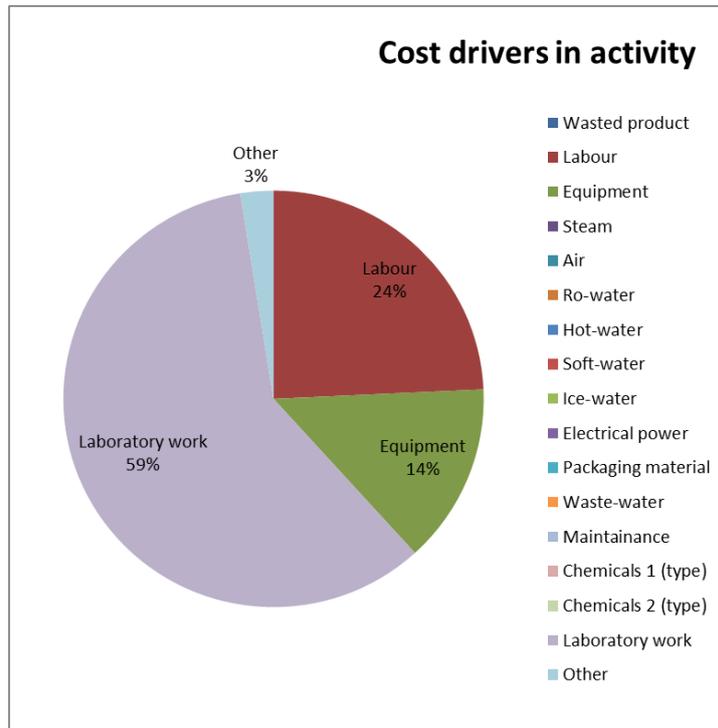
$$\text{Cost driver lab. work} = \frac{\frac{\text{Lab time}}{\text{batch}} * \text{hourly rate for lab}}{\text{Batch size out}} \quad (12)$$

The rest of the cost drivers are calculated using Ståhl cost equation. The  $K_{c1}$  and  $K_{c2}$  terms are added together, and the  $k_{CS}$  machine rate are inserted as both  $k_{CS}$  and  $k_{CP}$  to calculate the fixed equipment cost driver, as exemplified in equation 13. For The rest of the resources which is only consumed during operation only the  $K_{c1}$  term is used and the hourly rate for each resource is inserted as shown in equation 14.

$$\begin{aligned} &\text{Equipment cost driver} \\ &= \frac{k_{CS}}{N_0} \left[ \frac{t_0 N_0}{(1-q_Q)(1-q_P)} \right]_{c1} \\ &+ \frac{k_{CS}}{N_0} \left[ \frac{t_0 N_0 q_S}{(1-q_Q)(1-q_P)(1-q_S)} + \frac{1-U_{RP}}{U_{RP}} T_{pb} \right]_{c2} \quad (13) \end{aligned}$$

$$\begin{aligned}
 & \text{Cost driver} \begin{bmatrix} \text{Steam} \\ \text{Air} \\ \text{Ro - water} \\ \text{Hot - water} \\ \text{Soft - water} \\ \text{Ice - water} \\ \text{Electrical power} \\ \text{Packaging material} \\ \text{Waste - water} \\ \text{Maintenance} \\ \text{Chemicals 1} \\ \text{Chemicals 2} \end{bmatrix} \\
 & = \text{hourly cost} \begin{bmatrix} \text{Steam} \\ \text{Air} \\ \text{Ro - water} \\ \text{Hot - water} \\ \text{Soft - water} \\ \text{Ice - water} \\ \text{Electrical power} \\ \text{Packaging material} \\ \text{Waste - water} \\ \text{Maintenance} \\ \text{Chemicals 1} \\ \text{Chemicals 2} \end{bmatrix} \left[ \frac{t_0}{(1 - q_Q)(1 - q_P)} \right]_{c1} \quad (14)
 \end{aligned}$$

The calculated values of each cost driver are stored in the column EUR/kl in figure 20. The values are then graphically represented in the model by a pie chart shown in figure 21.



**Figure 21:** Pie chart of resources.

The purpose of this chart is to easily visualize the main cost driver for each activity. The greyed-out columns in figure 20 are used to increase the visibility in the pie chart. All pie charts in the cost model also has corresponding settings box called “display limit” shown in figure 22 below.

Display limit	
Cost driver	3%
Other	0%

**Figure 22:** Display limit for pie chart.

This “display limit” work in conjunction with the grey columns to exclude labels and entities in the pie chart smaller than the “display limit settings”. The display limit settings first row called “cost drivers” sets the minimum percentage that a cost driver must be greater than, to be shown as an own entity in the pie chart.

This is operation is done in the column “Value to plot” in figure 20, where an IF() function is implemented, if the cost driver is larger than the limit, it is displayed, otherwise it returns the NA() function to exclude it from the pie chart. All excluded pie cost drivers are summed up under the cost driver entity “other” to increase the visibility in the chart without loss of information. The last row named “only used for calculation” is used to determine the size of the “other” entity. It uses a similar IF() function as the value to plot column, but return zeros instead of the NA() function if a cost driver is smaller than the display limit. Those values are then summed up and the other entity is calculated as this sum subtracted from total sum of cost drivers in the first column “value to plot”.

The second row in the “cost driver display limit” settings box called “other” is used to set the NA() function on the “other” entity if it is smaller than the set limit. This is done to allow the possibility to exclude the other term from the pie chart if it is very small. A checksum is implemented in the result section which compares the sum of the cost drivers to the outbound product cost subtracted with the inbound product cost in the calculation section to verify the cost driver section, see figure 23.

Checksum	0,0000
----------	--------

*Figure 23: Checksum for calculations.*

### Cost drivers in activity resources bought

This section of the results in activities corresponds to the section “Cost drivers whole facility” in the cost models result section. Here all the cost drivers that consists of resources made in-house are broken up into all the cost drivers that it is made up of. To exemplify, Ice water which is made in-house are broken up into the cost drivers that goes in to make it such as labor, electrical power and equipment. This transformation is represented in the model by a matrix shown in figure 24 below. Where each resource made in-house by the support activities, which is represented by a column, are broken up into its cost driver fractions represented by a row. The row sum of each cost driver are then added to the cost drivers from the activity itself to form a cost driver table shown in figure 25.

Cost drivers in activity, resources bought	EUR/kl						SUM
	Steam	Air	Ro-water	Ice-water	Waste-water	Laboratory work	
Wasted product	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Labor	0,00	0,00	0,00	0,00	0,00	20,00	20,00
Equipment	0,00	0,00	0,00	0,00	0,00	2,30	2,30
Soft-water	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electrical power	0,00	0,00	0,00	0,00	0,00	2,09	2,09
Maintainance	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fuel	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Other variable hourly cost	0,00	0,00	0,00	0,00	0,00	0,00	0,00
SUM	0,00	0,00	0,00	0,00	0,00	24,40	
Checksum	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	

*Figure 24: Transformation matrix from all consumables to resources bought.*

	EUR/kl	Value to plot [EUR/kl]	Only used for calculation
Wasted product and consumables	0,00	#N/A	0,00
Labour	30,00	30,00	30,00
Equipment	8,06	8,06	8,06
Soft-water	0,00	#N/A	0,00
Electrical power	3,14	3,14	3,14
Maintainance	0,00	#N/A	0,00
Fuel	0,00	#N/A	0,00
Other variable hourly cost	0,00	#N/A	0,00
Hot-water	0,00	#N/A	0,00
Packaging material	0,00	#N/A	0,00
Chemicals 1 (type)	0,00	#N/A	0,00
Chemicals 2 (type)	0,00	#N/A	0,00
Other	-	#N/A	41,20
SUM	41,20		
Utbound product cost from activity	1041,20		

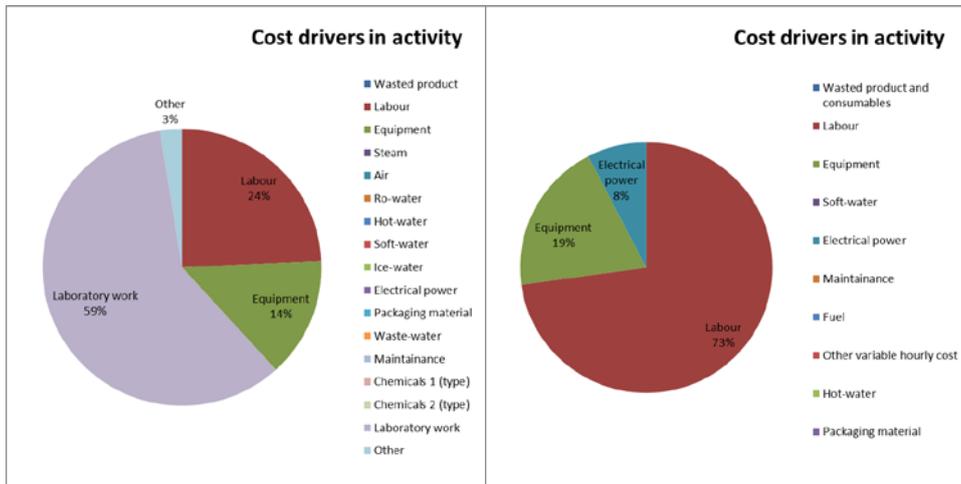
**Figure 25:** Cost drivers in activity, resources bought.

Note that the cost driver table in figure 25 is much similar to the one for “cost drivers in activity, all consumables” shown in figure 20 but does not include resources made in the facility which has been broken up to its components and added by the help of the matrix in figure 24.

The cost driver components in figure 24 are also calculated by the means of Ståhl cost equation. It uses the cost driver table for the support activities which is constructed in the same way as the “cost driver in activity, all consumables” section in a main activity to analyze which cost drivers one unit of the resource consist of. The support activities only have cost drivers that consists of resources that are brought in to the facility, and not made internally, therefor they only have one level of cost driver calculation. The calculation is done column wise in the matrix shown in figure 24, by the means on the equation 15 shown below.

$$\begin{aligned}
& \text{Cost driver in main activity } \left\{ \frac{EUR}{kl(\text{milk})} \right\} \left[ \begin{array}{c} \text{Wasted product} \\ \text{Labor} \\ \text{Equipment} \\ \text{Soft - water} \\ \text{Electrical power} \\ \text{Maintenance} \\ \text{Fuel} \\ \text{Other variable hourly cost} \end{array} \right] \\
& = \text{hourly consumption of resource in main activity } \left\{ \frac{kg, l (\text{resource})}{\text{hour}} \right\} \\
& * \text{Cost driver in support activity } \left\{ \frac{EUR}{kg, l (\text{resource})} \right\} \left[ \begin{array}{c} \text{Wasted product} \\ \text{Labor} \\ \text{Equipment} \\ \text{Soft - water} \\ \text{Electrical power} \\ \text{Maintenance} \\ \text{Fuel} \\ \text{Other variable hourly cost} \end{array} \right] \\
& * \left[ \frac{t_0}{(1 - q_Q)(1 - q_P)} \right]_{c_1} \quad (15)
\end{aligned}$$

Equation 15 is derived from equation 14, with the exception of hourly cost for resources are broken up into cost drivers from the producing activity. The “cost drivers resources bought” have the same graphical representation by a pie chart and display limit settings as the chart and data matrix from the result section “cost drivers in activity, all consumables”. An example of how a chart for the “cost drivers in activity resources bought” looks can be seen in figure 26 below. For comparison figure 21 is shown again in figure 26 to allow a side by side comparison. In this example the only cost driver made in-house displayed in the left chart is “Laboratory work”. In the right chart, representing “cost drivers in activities, resources bought” the laboratory work has been broken up to its cost driver components such as: Labor, equipment and electrical power and is therefore not displayed in this chart.



**Figure 26:** Side by side comparison of cost drivers. Left: cost drivers in activity, all consumables (main production line). Right: cost drivers in activity, resources bought (whole facility).



All entities in the cost summary contains clickable hyperlinks to references in the model where more information can be retrieved or values that affect the parameter are changed. A corresponding pie chart is displayed next to the table which shows the different cost fractions. Note that if cream generates a profit it will not be shown in the chart since it has a negative value, this is handled by an IF() function in the gray column named plot. The table also includes a checksum which compares the calculated self-cost with the outbound product cost from the last production activity.

By clicking on the “cost category” “production cost” the user will be forwarded further down the page where different summaries of the production costs are shown, see figure 28 below.

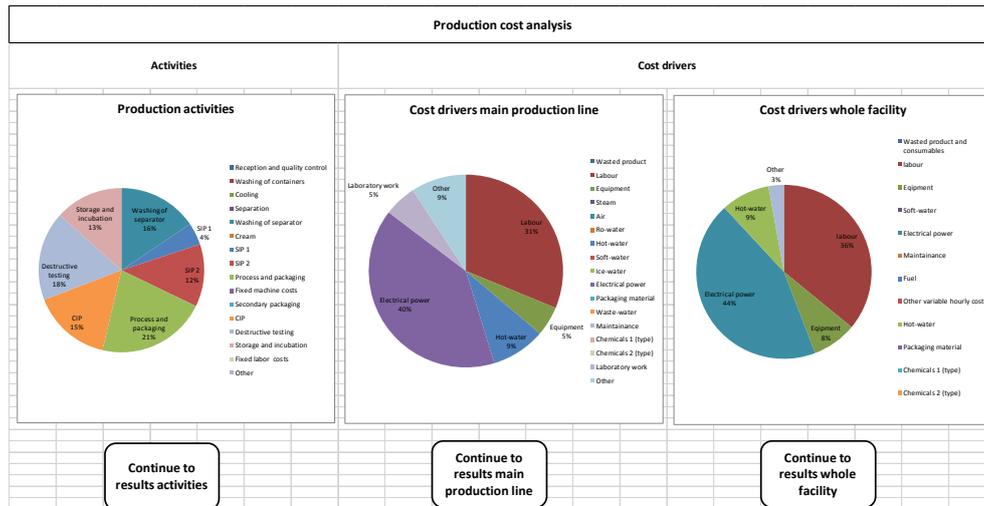


Figure 28: Results production cost analysis.

All three sections with corresponding charts contains an overview chart and clickable buttons to forward the reader to that section. The three sections are:

- Production activities**  
 Shows cost information on the different production activities and how much cost is allocated to each activity for production of one kiloliter milk.
- Cost drivers main production line**  
 Shows the distribution of different cost drivers consumed by the main production line to produce one kiloliter milk.
- Cost drivers whole facility**  
 Shows the distribution of different cost drivers consumed by the whole facility to produce one kiloliter milk.

#### 4.5.7.4 Production activities

The result section “production activities” are aimed at showing in which step of the production process cost arises. It contains a table of data and a pie chart to visualize the data. The data table is shown in figure 29 below.

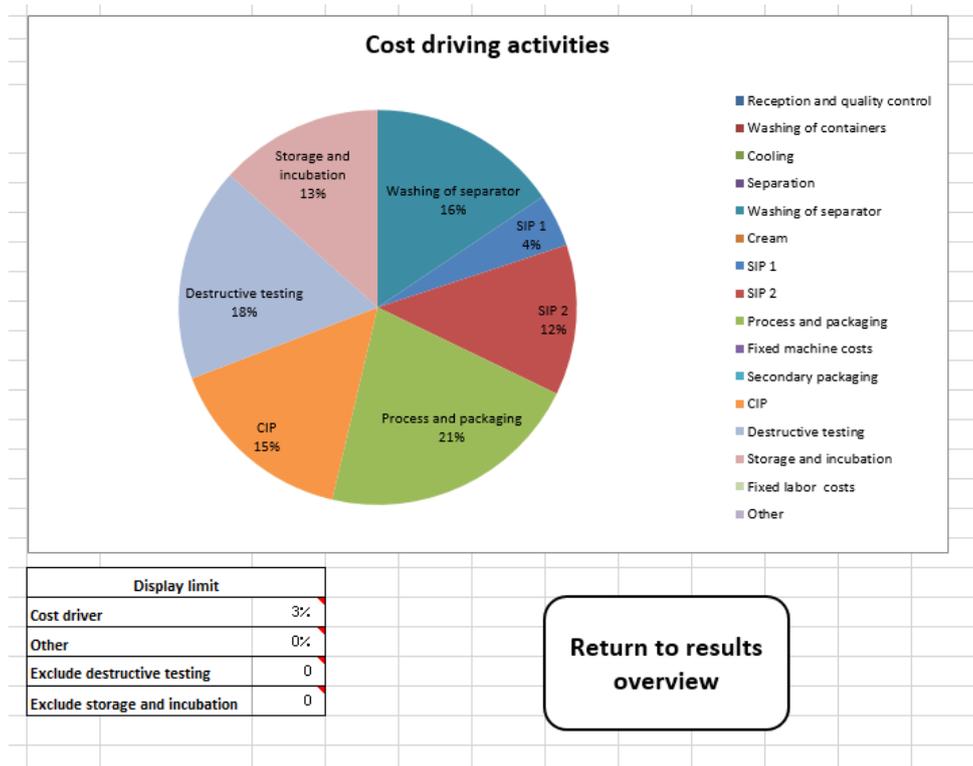
COST PER ACTIVITY					
Activities	Inbound cost	Outbound cost	Value adding EUR/kl	Value to plot [EUR/kl]	Only used for calculation
<a href="#">Reception and quality control</a>	1000,0	1041,2	41,2	#N/A	#N/A
<a href="#">Washing of containers</a>	1041,2	1073,9	32,7	#N/A	#N/A
<a href="#">Cooling</a>	1073,9	1094,2	20,3	#N/A	#N/A
<a href="#">Separation</a>	1094,2	1126,4	32,2	#N/A	#N/A
<a href="#">Washing of separator</a>	1126,4	1328,6	202,1	202,1	202,1
<a href="#">Cream</a>	1328,6	1328,6	0,0	#N/A	#N/A
<a href="#">SIP 1</a>	1328,6	1385,1	56,5	56,5	56,5
<a href="#">SIP 2</a>	1385,1	1545,4	160,3	160,3	160,3
<a href="#">Process and packaging</a>	1545,4	1824,7	279,4	279,4	279,4
<a href="#">Fixed machine costs</a>	1824,7	1824,7	0,0	#N/A	#N/A
<a href="#">Secondary packaging</a>	1824,7	1853,0	28,2	#N/A	#N/A
<a href="#">CIP</a>	1853,0	2054,0	201,1	201,1	201,1
<a href="#">Destructive testing</a>	2054,0	2282,3	228,2	228,2	228,2
<a href="#">Storage and incubation</a>	2282,3	2455,6	173,3	173,3	173,3
<b>Fixed labor costs</b>			0,0	#N/A	#N/A
<b>Other</b>			-	#N/A	#N/A
<b>SUM of production costs</b>			1455,6		
<b>Milk input cost</b>			1000,0		
<b>Output cost</b>			2455,6		
			Checksum		0,0000

**Figure 29:** Summary of cost per activity.

Here each production activity is listed, as well as some additional outputs from the model that is part of the resources that goes in to producing milk. The In- and outbound cost term from each production activity is linked to each activity in the model to calculate the value adding done in each activity. Apart from the production activities in the model there are some other entries in the table that is also part of the cost of producing milk.

Fixed machine cost is not a production activity and is used to circumvent the time utilization case in case of failure, this is a redundancy feature built in to the model which helps the user to make customization such as adding equipment or activities without fully integrating them in the time utilization case. Apart from that, the profit or loss from the removed cream is also listed, which is the same entry that can be found in the self-cost calculation in the “results overview” page.

Since destructive testing can be a such large part of the total cost it is shown as an own entity in the table even though it in the model is physically integrated in the production activity “storage and incubation”. The row fixed labor cost is used in a similar way as fixed equipment cost, if allocating workers to a specific production activity is hard a fixed labor cost per year can be inserted in the model. Both fixed labor costs and equipment costs are handled through the settings page which will be described later. A checksum is implemented in the “Cost per activity” table to verify it against the out-bound product cost from the last production activity. The information in the table is visualized in a pie chart shown in figure 30.



**Figure 30:** Pie chart showing cost per activity.

The pie chart displays information the same way as the result section in the production activities, utilizing the information in they greyed out columns in the table, with “display limit” settings to filter out small entities. Apart from that, there is a possibility to exclude “storage and incubation” and/or destructive testing from the chart to get the true production cost analysis.

#### 4.5.7.5 Result cost drivers main production line

The result page for “Cost drivers main production line” contains a large matrix tracking all cost drivers in the production activities a view of the matrix is shown in figure 31 below. The data in this matrix are directly linked to the result section in each activity from the table “cost drivers in activity, all consumables”. All the respective cost drivers are then summed up row-wise to calculate the total influence from that cost driver to the product cost. This values found under the column “SUM EUR/kl” are then plotted in a pie chart to visualize the cost drivers. The resulting pie chart is shown in figure 32. The chart utilizes the same “display limit” settings as the rest of the pie charts in the model.

	Reception	Washing of containers	Cooling	SUM EUR/kl	Value to plot [EUR/kl]	Only used for calculation	Paretoplot		
Wasted product	0,00	0,00	0,00	0,00	#N/A	0,00	#N/A	Display limit	
Labour	10,00	10,00	0,00	380,77	380,77	380,77	380,77	Cost driver	3%
Equipment	5,76	5,76	3,03	60,50	60,50	60,50	60,50	Other	0%
Laboratory work	24,40	0,00	0,00	65,73	65,73	65,73	65,73		
Other				-	112,06	1106,05			
SUM				1218,11					
Output cost				1218,11					
Checksum				0,0000					

Figure 31: Part of the matrix for cost drivers in main production line.

### Results cost drivers, main production line

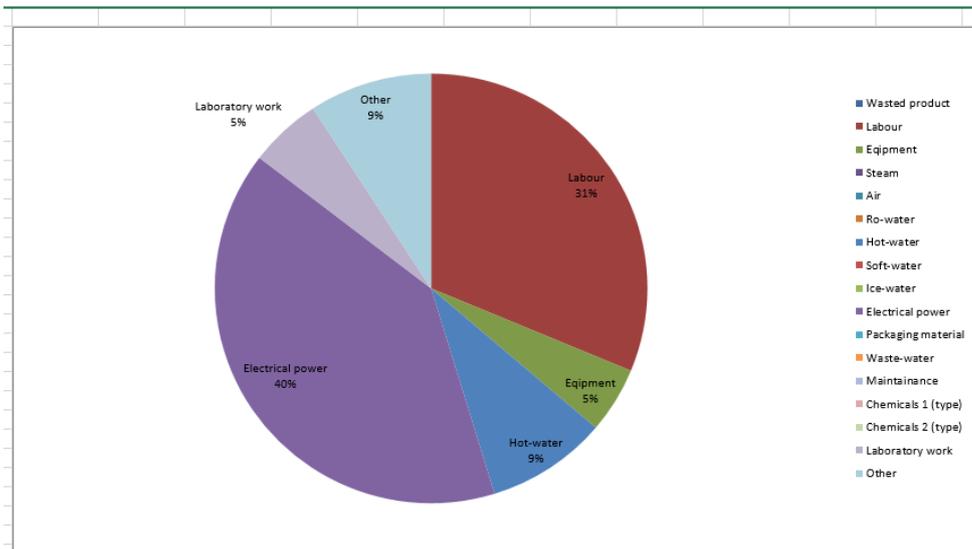


Figure 32: Pie chart of cost driver main production line.

Each column in the matrix shown in figure 31 has a clickable link to go the activity in question. Clicking the cost driver titles in each row will forward the reader to a more detailed view of that particular cost driver showing which activity that consumes most cost. In figure 33 below is an example of the page for cost driver electrical power which appears to be the largest in figure 32 with the exemplified data. Again all the activities are listed for easy tracking of cost drivers.

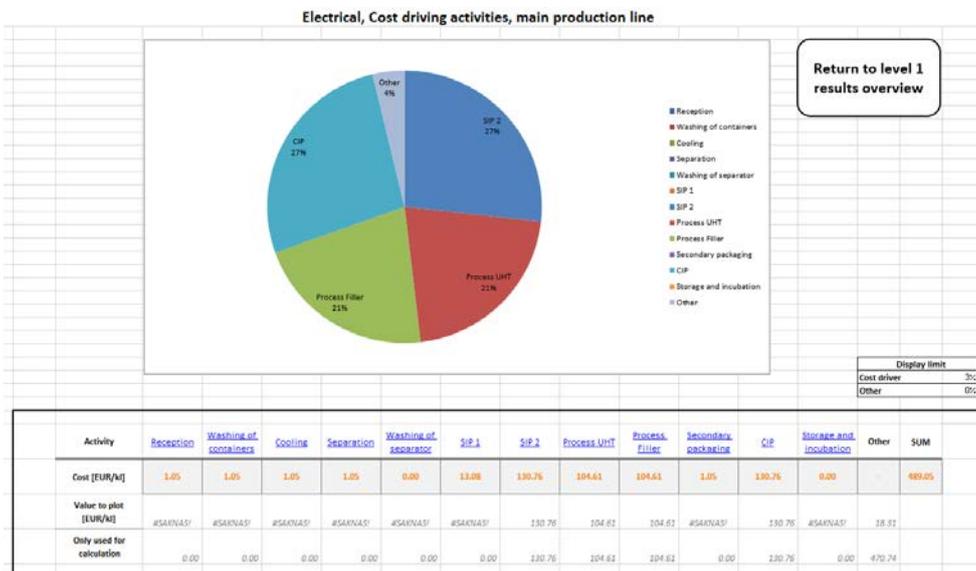


Figure 33: Example for tracking of cost drivers to activities.

#### 4.5.7.6 Result cost drivers whole facility

The result section for cost drivers whole facility is implemented and represented in the model in the exact same way as “Result cost drivers whole facility” the difference being the cost drivers represented, here only resources not made in the facility is represented. The data also here derives from the result section in each production activities page but are gathered from the table “cost drivers in activities resources bought” which is presented earlier in the paper in figure 25.

### 4.5.8 Additional functions in the model.

#### 4.5.8.1 Settings page

In the settings page, accessible from both the equipment overview and production activities overview page there are additional setting for fine tuning the result of the model. In figure 34 the settings page is displayed.

**Settings**

Distribute asset costs to activities	1	Input 0 or 1	<div style="border: 2px solid black; border-radius: 15px; padding: 10px; display: inline-block;"> <p><b>Return to Equipment</b></p> </div>
Distribute salary costs to activities	1	Input 0 or 1	
Salary cost total user adjustment	0	EUR/year	
Salary cost calculated direct through activities	111151	EUR/year	

*Figure 34: View of settings sheet.*

The settings page contains two major function areas. The ability to turn on or of fixed machine costs. And turn on and of fixed salary cost with the possibility to do an user input of real salary costs.

#### 4.5.8.2 Fixed machine costs

The setting “distribute asset costs to activities” turns on and off the time utilization case. The functions is implemented for the user to be able get a quick result when changing parameters in the cost model without updating the “time utilization case” and “time plan”. Changes of production rates, batch sizes etcetera are handled automatically by the “time utilization case”. However, adding a new activity and equipment, not linked to an existing equipment, will require modification of the time utilization case and the time plan. Turning the “Distribute asset costs to activities” off, will set hourly rates for equipment handled by the time utilization case to zero, and calculate a fixed equipment cost per liter. This fixed equipment cost are calculated as the sum of yearly equipment cost for all affected equipment divided by the yearly volume of produced packages per year. This “fixed equipment cost” will be added to the product outbound cost in the activity “process and packaging” as well as shown as a separate entity in the result sections “production activities”.

### 4.5.8.3 Labor costs

When trying to analyse the production facility and get data it was apparent that allocate personnel to each activity may be difficult, especially supervisory functions. Therefore two major functions to alter the cost for labor is included in the settings page. First, there is the possibility to remove all labor costs in the model and consider it a fixed cost, doing so will not distribute labor cost to any activity in the cost model, instead labor costs will appear in the result section as a fixed sum per produced volume. Secondly, in each activity there are specified input parameters to Ståhl cost equation, regarding labor cost. The input parameters are; the number of workers and salary level per hour. All those labor cost parameters from all activities are summed up on a yearly basis and be displays in the settings page under “Salary cost calculated direct through activities”. If the total actual labor cost is known, and appear to be different from the calculated value, the known value can be entered in the input box “salary cost total user adjustment”. Doing so will add a percentage to all hourly labor cost in all activity pages in the model to update the labor cost to the specified known cost. The feature is disabled by putting in the value zero in the input cell.

Even though user input and settings concerned labor costs are done in the settings page, calculations are performed in a separate sheet in the model, this sheet called “labor cost” calculates overhead rates and fixed labor cost. The “labor cost” page are represented by two figures and can be seen in figure 35 and 36.

Activity	Reception	Laboratory work	
<b>Labor cost calculated through activity</b>			
Nominal processing capacity	1,00	-	
Nominal cleaning time	-	-	
Labor time per batch	-	-	
qs	0,00	-	
qq	0,00	-	
qp	0,00	-	
Batch size out	1,00	-	
Utilization	1,00	-	
Production time per batch	1,00	-	
Processing time per unit	1,00	-	
Processing time per unit (nominal)	-	-	
Labor cost per hour	10,00	10,00	
Number of operators	1,00	1,00	
Other hourly salary costs	0,00	0,00	
Labor cost without overhead	10,00	10,00	
Total labor cost per hour {kd}	10,00	10,00	
Cost per unit labor {KD}	10,00	-	
Cost per unit labor {KD}	-	10,00	
<b>Labor cost calculated through labor model</b>			
	10,00	-	
	10,00	-	
	-	10,00	
Production yearly	-	1500	<b>SUM</b>
Labor costs yearly	3000	15000	111151
Adjusted labor costs yearly	0	0	0
<b>Labor overhead</b>			
	0,00	0,00	
Adjusted cost per unit labor {KD} calculated in labor model [EUR/unit] (kl, kg)	10,00	-	
Adjusted cost per unit labor {KD} calculated in labor model [EUR/batch]	10,00	-	
Adjusted cost per unit labor {KD} calculated in labor model [EUR/h]	-	10,00	<b>SUM</b>
Test calculation	3000	15000	111150,5263

Figure 35: Labor cost calculations.

Overhead calculation		
labor cost calculated through direct activities	111151	EUR/Year
User input of salary costs	0	EUR/Year
<i>Difference</i>	111151	EUR/Year
<i>Overhead</i>	-100%	
Debugging		
Checksum 1	0,0000	
Checksum 2		

**Figure 36:** Labor cost overhead calculation.

The top part of the page is linked to parameters, in each activity, that affect the  $k_D$  labor cost term in Ståhls cost equation for each activity. The middle part of the model performs the calculation of the  $k_D$  term, this is done to determine the total labor cost in the model even when the model is in fixed cost mode and the  $k_D$  term cannot be retrieved from each activity page, since it is set to zero in the activities. The yearly labor cost for each activity are calculated column wise and the results are summed up to get the total yearly labor cost for the facility. The total yearly labor cost are then divided by the total volume of produced milk out from the facility to obtain the fixed labor cost per kiloliter. The total yearly labor cost is also used in conjunction with the user input of salary cost to calculate an overhead rate. This overhead rate is calculated in the bottom section of the page and linked back to each activity.

#### 4.5.8.4 Cream calculation

One activity in the main production line is the separation of cream done in the activity “separation” in the model. In this operation product with a higher fat content, cream, is removed from the raw milk to decrease the fat content in the finished product. The removal of cream considered a separate activity after the activity “washing of separator” in the model. The reason for this is that the cream is valuable byproduct and has a potential to be sold and create an income. Therefore it is of interest to know the self-cost of producing cream and also how the value of cream affects the cost to producing milk. The cream calculation sheet is shown in figure 37 below.

<b>Cream calculation</b>		
<b>Inbound data</b>		
Desired fat content in packaged	5%	Vol %
Fat content in raw milk	10%	Vol %
Fat content in cream	30%	Vol %
Value of cream	1328,56	EUR/kl
Batch size in	1,00	kl
Removed cream	0,20	kl
Batch size out	0,80	kl
Milk input value	1328,56	EUR/kl
Net profit on cream	0,00	EUR/kl cream
Output value of milk	1328,56	EUR/kl milk

*Figure 37: Cream calculation sheet.*

The input values to the cream calculation is the fat content in the raw milk, removed cream and the desired fat content in the package. A control volume is set up and the volume of removed cream is calculated. The value of cream is also an input to the cream calculation sheet, however the default setting in the model is to value the cream at input milk value. Doing so will not affect the self-cost of milk and tells the user at which price cream can be sold to cover the self-cost to obtaining it. If cream is considered a rejection the value of cream should be set to zero and the output value of the milk will rise to cover for the value of lost cream. The output value of milk is calculated by the means of equation 16 below.

*Output value of milk =*

$$\frac{(Milk\ input\ value * Batch\ size\ in\ (milk) - Removed\ cream(volume) * Value\ of\ cream)}{Batch\ size\ out\ (milk)} \quad (16)$$

The volume of removed cream is calculated by the means of equation 17 presented below.

*Removed cream (volume) =*

$$Batch\ size\ in(milk) * \frac{Fat\ content\ raw\ milk\ (\%) - Desired\ fat\ content\ in\ package\ (\%)}{Fat\ content\ in\ cream\ (\%) - Desired\ fat\ content\ in\ package\ (\%)} \quad (17)$$

The control volume links the batch size out to the removed cream and batch size in through equation 18.

$$Batch\ size\ out\ (kl) = Batch\ size\ in\ (kl) - Removed\ cream\ (kl) \quad (18)$$

## 5 Discussion

Most of the mapping and analysis of the production was performed only to gather information about the process and its steps and therefore the value stream mapping and process flow analysis was only partially executed. The first steps of mapping with value stream mapping and process flow analysis helps to implement Ståhl cost model whilst the later optimization steps are not considered viable for the creation of the cost model. All of the information gathered from the values stream mapping help to illustrate the flow of the process and flow of information. The value stream map does on the other hand not take to an account the non-value added activities that are equally important for the cost model such as cleaning and sterilization.

The process flow map illustrates more of the non-value added activities than the value stream map as well as supporting activities for value added activities. The process flow map gives and understanding of which activities that are performed simultaneously and this supports the construction of the time utilization case. The process flow map is not analyzed further and a second flow chart is not presented in this master thesis thus it is not the agenda to optimize the process.

Lastly, the schematic cost and resource diagram rounds up the mapping of the process with insight on supporting equipment, resources and consumables used in activities and equipment used in the process. Without these diagrams the implementation of Ståhl cost model would be unfeasible.

The cost model presented in this master thesis is based on Ståhl cost model but differ in some ways. In the original cost model from Ståhl the calculation are based on one planning point for a specific machine, machines or process with a certain lead-time. In the model presented in this master thesis the cost model from Ståhl is adjusted and implemented on each activity based on processing rates and in some cases, lead-times. The product can also be located in a number of activities at the same time, which differs from the cost model from Ståhl, and the time utilization case is therefore needed to be able to distribute machine cost depending on active activities.

The advantages with the cost model presented in this master thesis is that all activities are independent and can be analyzed separately. It is therefore possible to analyze cost drivers in separate activities or for the whole process depending on the purpose of the analysis. The downsides is that the cost model will be quite extensive and requires a great understanding of the process and the calculations. If the object where to only analyze cost drivers in terms of consumables, resources and equipment for the whole process, the cost model could possibly be made less elaborate and less extensive. Although, this master thesis, the objective was to map cost drivers in each activity and create a base for production economic simulation, therefore the cost models complexity was inevitable.

Even though the cost model is built for production economic simulation, this was never performed because of insufficient data, both production related and investment cost related. When the data is available and collected, the model should work for this analysis as well.

The model is built to be compatible with a production performance matrix, PPM that will serve as a tool to locate and analysis cost drivers in terms of downtime, rejections and production loss. The PPM has not been constructed in this master thesis on the basis that it requires more analysis on site, elaborate production data and knowledge of the specific process.



## 6 Conclusion

The generic cost model formulated by Ståhl is proven to be applicable on a continuous flow process with some minor adjustments. Instead of using one planning point for the whole process and all machines, the cost model formulated by Ståhl is applied on each activity for the continuous flow process. Depending on the application of the cost model for a continuous flow process, the model can be more or less elaborate. If the purpose is to analyze cost drivers in each activity of the process, the model needs to be quite extensive. On the other hand, if the model should calculate the manufacturing costs for the whole process, the model does not need to as elaborate.

The level of complexity of the cost model results in very time consuming modelling which could have been avoided if a commercial cost analysis tool was used. This on the other hand would not investigate if the Ståhl cost model could be applied on continuous flow process, which was the objective from the beginning.

The cost model presented in this master thesis illustrates the different cost drivers for each activity in different levels making the analysis adjustable for the user to choose appropriate level of analysis for each case. The cost model also supports the possibility for production economic simulation and with the production performance matrix, sensitivity analysis of the process can also be performed.

In conclusion, the generic Ståhl cost model is very well applicable on these types of continuous flow processes. The complexity of the model is dependent on the level of analysis of costs and cost drivers. The cost model can serve as a tool for Tetra Pak to map and analyze cost drivers for the process in question and other as well.



## **7 Future work**

As the cost model presented is currently constructed without production data, some things are potential future work to be able to use the model to its fullest. A few key areas are presented in this section to highlight supporting function of the cost model and areas where the cost model can be used for further analysis.

### **7.1 PPM**

The production performance matrix is a vital function for the cost model and it needs to be constructed from either an automated or manually logged production data system. The parameters and factors in the PPM should be chosen dependent on the data collected. With the PPM in place, the model can be used for real-time production analysis or production economic simulation. With a greater amount of production data, the model can also be used for deterministic production development.

### **7.2 Deterministic production development**

The master thesis work was focused on building a cost model that reflects reality and can be used to simulate the production facility. In the future, when more data has been collected and submitted to the model it can be used to find areas of improvement using deterministic production development. Basically, the cost model can be used as a tool to achieve a set goal by changing different parameters in the cost model and improving productivity, make cost reductions or other improvements of variable in the model.

All changes should work towards the set goal in some way. For instance, improving downtime loss will result in more free capacity, which could be of interest if the goal is to produce more products per amount of time. The question is, where in the production line should the focus of improvements lie on and can these improvements help meet the set goal.

### **7.3 Production economic simulation**

With the cost model in place with all its cost and production parameters, it can be used for production economic simulation. Basically, the cost model can produce cost of manufacturing and total production time for the process depending on different parameters. Typically a software tool, for example Excel, can be used to simulate the cost model with different parameters for, downtime loss, scrap rate or production rate loss. The output will most definitely be a curve for cost per unit produced or batch produced dependent on the variable of the input parameter. The result can be used for analyzing potential cost reductions or be used for sensitivity analysis if the different loss terms should increase.



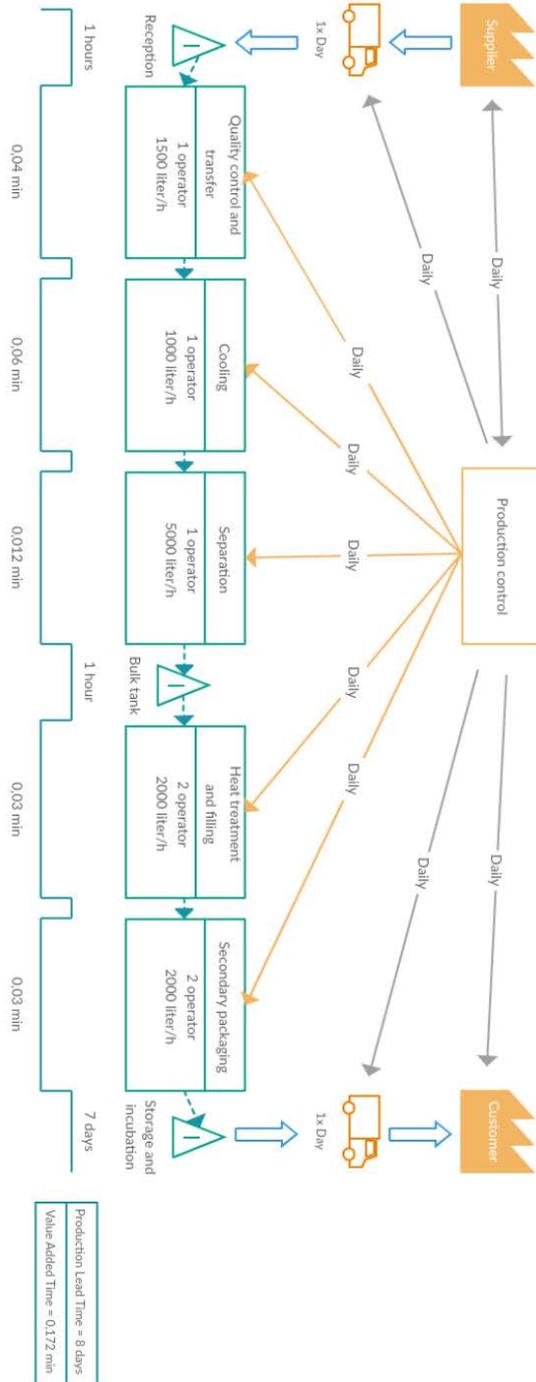
## REFERENCES

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- Cooper, R., & Kaplan, R. S. (1999). *Design of cost management systems*. Upper Saddle River: Prentice Hall.
- Ejvegård, R. (2007). *Vetenskaplig metod*. Lund: Studentlitteratur.
- Lasa, I., de Castro Vila, R., & Laburu, C. (2008). An evaluation of the value stream mapping tool. *Business Process Management Journal*, Vol. 14 Issue: 1, 39-52.
- Olhager. (2000). Produktionsekonomi. i J. Olhager, *Produktionsekonomi*. Lund: Studentlitteratur.
- Ståhl, J.-E. (2012). *Industriella tillverkningsystem Del II - Länken mellan teknik och ekonomi*. Lund: Industriell produktion, Lunds universitet.
- Ståhl, J.-E. (2016). *Development of Manufacturing Systems - The link between technology and economics* (Korrekturutgåva 2016: Version 4 uppl.). Lund.
- Tetra Pak AB. (den 31 May 2017). *About Tetra Pak: Facts & Figures*. Hämtat från Tetra pak official website: <http://www.tetrapak.com/us/about/facts-figures>
- Tetra Pak AB. (den 31 May 2017). *Dairy Processing Handbook*. Hämtat från Dairy Processing Handbook: <http://dairyprocessinghandbook.com/>
- Vafadar, A., Tolouci-Rad, M., & Hayward, K. (2016). New cost model for feasibility analysis of utilising special purpose machine tools. *International Journal of Production Research*, Vol 54, No 24, 7330-7344.
- Velmurugan, M. S. (2010). The Success and Failure of Activity-Based Costing Systems. *Journal of performance management*, 23(2), 3-.

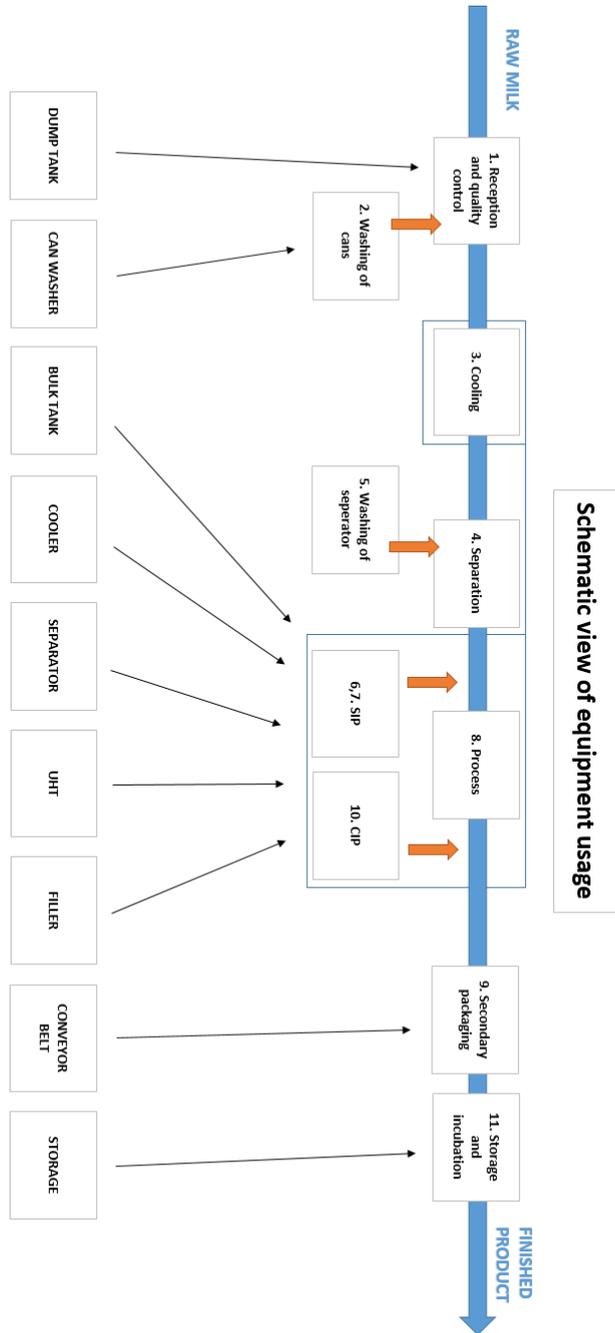
# Appendix A

## Value stream map



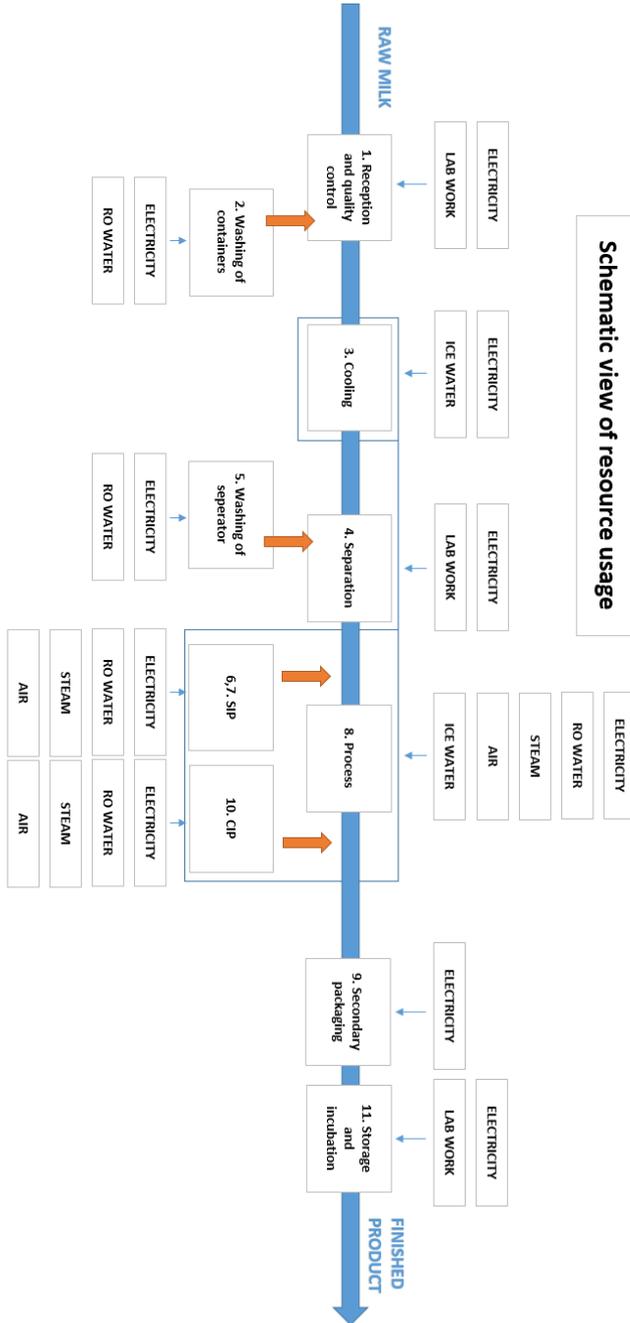
# Appendix B

## Schematic view of equipment usage



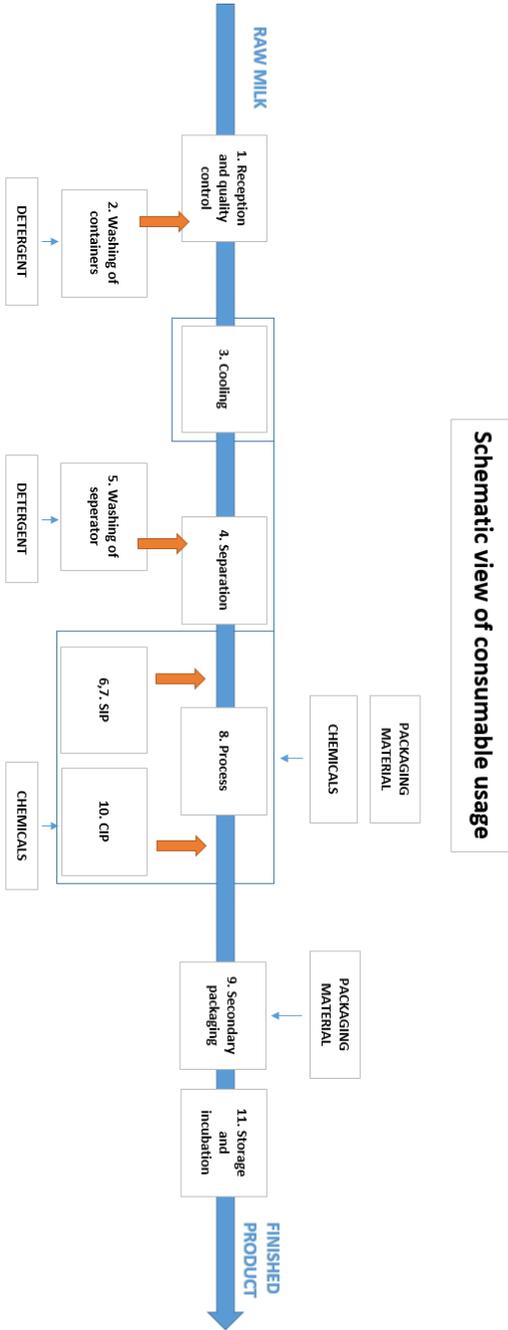
# Appendix C

## Schematic view of resource usage



# Appendix D

## Schematic view of consumables usage



# Appendix E

Schematic view of equipment costs.

