Cost Based Prioritization of Overhaul Process Improvements
- A case study at Faiveley Transport

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Abstract

This thesis was written in collaboration between Faiveley Nordic in Landskrona and the Division of Production and Materials Engineering at Lund University. It was set out to find improvements or cost reductions of the overhaul process at Faiveley. The overhaul process at Faiveley is a process were used and worn train brakes are taken apart and overhauled for further use. To achieve this goal, among other influences, Ståhls Cost model was used to create the so-called "Cost model system". The Cost model system is an excel-based system of interlinked tables were data gathered from multiple company entities are inserted to provide a cost analysis, which can be used for production development.

To make the analysis, a lot of data was needed from multiple departments at Faiveley. To get accurate and thorough data on the processes, a time study was performed, for which a software tool, the so-called Time-study system was developed. All data gathered was inserted to the cost model system that provided insights about the current situation at Faiveley. The analysis from all data gathered and the results from the Cost model system, brought many issues to light which were then evaluated to create improvement suggestions. Some of these suggestions were picked for further evaluation in the Cost model system. The Cost model system showed that great cost reductions are possible, but of course to reach this point, investment in new equipment must be made.

Although the Cost model system was at first only intended to be used for the analysis conducted in this thesis, it turned out to be a powerful tool that shows great potential to be used at any production company for many more purposes than just production development.

Keywords: Cost model, Cost model system, Process improvement, Production development.

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1. Introduction

1.1. Background

Faiveley Transport is a Global company that provides both new equipment and services like repairs, overhauls and upgrades to the railway industry. The site in Landskrona, Faiveley transport Nordic, that is of interest for this thesis, manufactures new- and overhauls old (among other products) brake actuators (BFCs).

The overhaul and maintenance line for the BFCs is today, both in regards of the flow and the individual processes, not sufficiently efficient which is partly due to problems with machine breakdowns down and many man hours to complete an overhaul, ending up making the overhauls expensive to execute. Furthermore, during the last couple of years, the turnover for newly manufactured equipment have decreased while at the same time the turnover for overhauls and repairs increased significantly. This trend is also expected to continue during the upcoming years.

For Faiveley to stay ahead of competition and continue to get orders for overhauls a reduction of cost per overhaul unit is essential. Faiveley are today aware of the issues in the overhaul process but not sure what should be done about it. It would be of great benefit to Faiveley to get a well-thought-out and clearly motivated suggestion of improvements.

The product cost at Faiveley is in general based on one thing, process time. To calculate it, the processes cycle times are gathered through time studies and a fixed rate is multiplied by the time and on top of that comes overhead. This way of tracking cost does not take in to account that different processes have different cost. If one for example use a 6-axis CNC-machine for an hour the cost would most likely be different from using a screwdriver for an hour, yet this would be the same cost at Faiveley. To track cost in a more appropriate way a cost model is introduced. By doing so the real cost acting on the right processes and products can be targeted to be improved.

1.2. Purpose

The purpose of the master thesis is to investigate the process all the way from receiving to delivery and identify process and overhaul line improvements for an improvement program aiming at a total cost reduction for the overhaul.

The thesis will give a deeper understanding in cost modeling, value stream mapping and analyzing overhauling lines performance. This will give broader knowledge of application of the cost model and how it can be used in an improvement process, in this case improving an overhaul process.

1.3. Challenges

The following challenges were emphasized in the beginning of this research:

- The overhaul process is performed on a wide array of products with different requirements, finding a suitable process for all products will be difficult.

- The products being overhauled are in often in different conditions, this makes the processes vary a lot both in which parts to be replaced and the time the overhaul takes.

- Aspects such as supply of spare parts, that are outside of the scope, may have a big influence on the results, to disregard these might be a challenge.

- As it is an interdisciplinary field, reaching insights to every aspect of the overhaul process in the noted timeframe will be a challenge.

1.4. Milestones

The Milestones were set in the beginning of the project and have served as a rough preliminary outline of the project. During the time of the project other milestones were added. For a deeper insight to the methodology, see chapter 3.

- Work practice period
- Data and information gathering
- Process value stream mapping analysis
- Evaluation of current process efficiency and cost
- Find alternative processes and technology
- Evaluate alternatives / Propose process improvements
- Design the process and conclude cost reduction achieved

1.5. Company description

1.5.1. Wabtec Corporation and Faiveley Transport

As of first of December 2016 is the Wabtec Corporation the majority ownership of Faiveley Transport. The combination of Faiveley and Wabtec makes it one of the largest public rail equipment companies in the word with nearly 20 000 employees, over 100 manufacturing facilities in 30 countries around the world. The combined revenue is estimated to $4.2B and it segmentation can be seen in Figure 1 [1], [2].
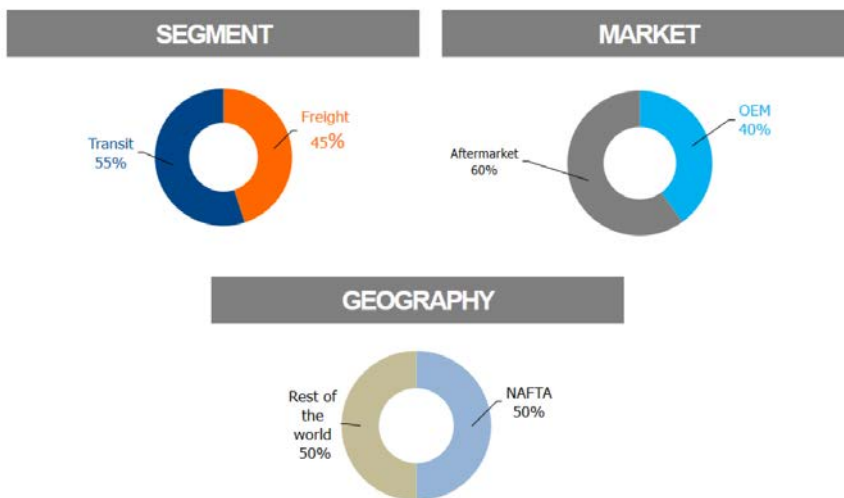
Figure 1: Wabtec Revenue segmentation [1].

Faiveley transport by itself is divided by 4 main divisions, which are "Brakes and safety", "Access and Mobility", "Energy and Comfort" and "Services".

The Access & Mobility Division supplies a range of passenger access systems like external and internal doors of trains and platform screen doors.

Brakes and Safety Division offers braking systems and safety solutions for all types of rolling stock, and cover the entire braking command chain in trains.

The Energy and Comfort Division is divided in two product groups related to a train's energy management chain, which are Heating, Ventilation and Air Condition, and Power & Information consisting of auxiliary inverters, pantographs, switches, CCTV and event recorders.

The Services division, supports customers with long-term maintenance of their original equipment, including optimization solutions and spare parts. Services is the largest division with 45% of the sales which is the result of a sales growth of +9% in 2015-16 [3].

1.5.2. Faiveley Transport Nordic

Faiveley Transport Nordic is located at two sites in Sweden, Stockholm and Landskrona. The site in Stockholm constitutes of a sales division and maintenance operations out in the field. In the year 2016 Faiveley Transport had about 185 employees most of which located in Landskrona. The Landskrona site, which is of interest for this thesis, is a site with a wide range of operations in different departments. The different departments are Market & Sales, Project Management, Engineering, Research & Development, Purchasing & Supply Chain, Manufacturing, Service & Overhaul, Quality Management, Finance & IT and Human Resources [1]. Though there are wide range of products in Faiveley portfolio the focus of Faiveley Transport Nordic are brakes of various types.

Faiveley Nordic have a revenue of 438 MSEK in 2015/16 which was an increase of 120 MSEK from 2012/13. During this period, the OE Brakes reduced from 95 MSEK to 79 MSEK in turnover which was compensated by the Overhaul and repair Services that experienced a growth of 62%, which made it stand for 82% of the turnover [4].

The Landskrona main product portfolio of OE Brakes, constitutes of a Push version and a Clamp version of the BFCB, DP, DRV and BFC and BFCF, the Products can be seen in Figure 2 and Figure 3 [1]. The Overhaul and repair services at Landskrona constitutes of three departments UH1, UH2 and UH3. UH1, which is the one focused on for this thesis, does overhauls and repairs on the self-made products and similar products from other manufacturers such as Calipers, PB, AC and a few more. UH2 department does pneumatical brake controllers and UH3 does, among other products, heavier equipment such as train couplers and MBT (magnetic track brake).

The main focus in this thesis are the products BFC and BFCF overhauled and repaired in UH1. Both products are versions of the product-group with the generic group name BFC. In reality there are many variants of this product, but to simplify it has been chosen to only distinguish between BFC and BFCF. Since there are also some other products handled in the UH1 department, sharing resources, these cannot completely be disregarded.
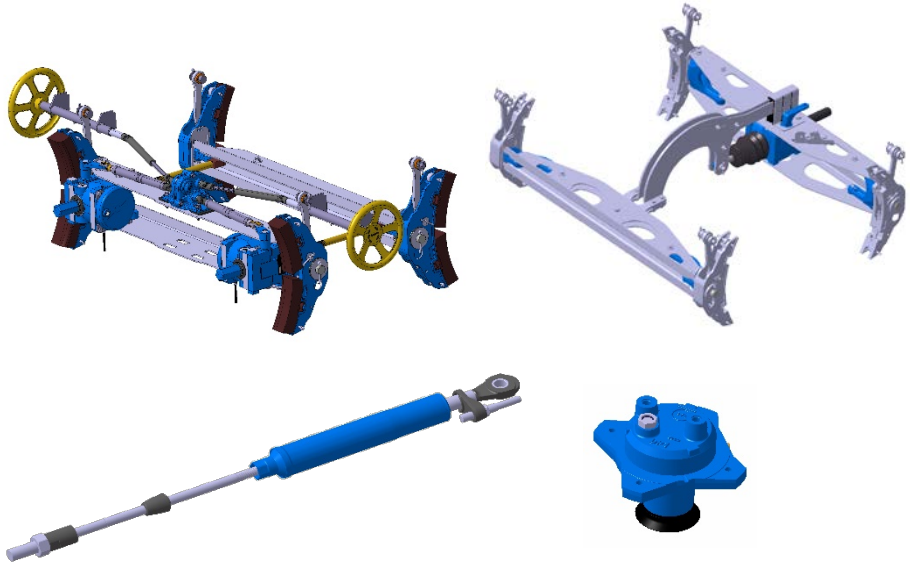
Figure 2: *Top Left: The Push version of the BFCB. Top Right: the clamp version of the BFCB. Bottom Left: DRV. Bottom Right: DP* ***[1]****.*
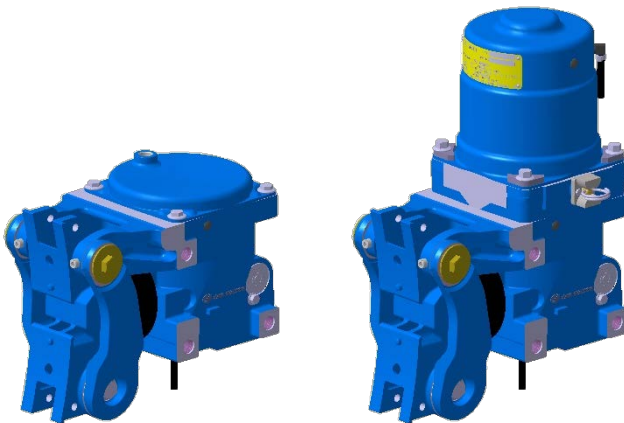
Figure 3: *Right: BFC. Left: BFCF* ***[1]****.*

2. Theory

2.1. Industrial manufacturing systems development

In 1937 the "just in time" concept was created, and a new philosophy was borne, today it is commonly known as "Lean Production". It was the succeeding development step to Mass production and its principles established by Ford Taylor and Ford, emphasized by standardization of products and processes. What the next production philosophy will be or if new discoveries will just be a complement to lean, is yet in the future to see [5].

A suggestion for a new philosophy, and to go beyond lean is the "NEXT STEP". The NEXT STEP philosophy suggests the creation of a clear link between technology and economics and the use of economic indicators as a basis for decisions. This is suggested to be done using a model for calculating changes in a parts cost, a cost model. This model enables in turn deterministic production development and production economic simulation which can be used to analyze and develop production in a systematic way [5], [6].

The development steps or philosophies and their positive characteristics can be seen in Figure 4.

*"Obtaining a **complete breakdown of the costs** of manufacturing a product or a part is essential for being able to give adequate priority to the measures needed and to solve the problems that are of greatest importance. In line with this, it is important to know, for example, whether it is the costs for rejects, downtimes, slowdowns, waste of materials, adjustment times, or costs connected with some other parameter or variable, that are most cost-consuming, and how in a more detailed way these various cost sources compare with one another." Ståhl* [5]

Developmental steps or philosophies	Positive characteristics
NEXT STEP ⟹	➢ Production analysis concerning costs per cell ➢ Developmental goals ➢ Economically based key performance indicators ➢ Economic basis for decisions ➢ Clear link between technology and economic considerations
Lean production ⟹	➢ Insight into problems through visualization and use of key performance indicators ➢ Involvement, participation and motivation ➢ Formalized tools and working approaches ➢ Administration and development within one and the same organization ➢ Effective use of resources
Mass production ⟹	➢ Scientifically sound methods ➢ Standardization ➢ Standardized working methods
Manual and work-intensive Manufacturing ⟹	➢ Adaption of wishes of the individual customer ➢ Flexibility

Figure 4: principles and methods from different developmental steps used within the production area [5].

2.1.1. Ståhls cost model

The cost model by Ståhl [6] for calculating of product cost k, see Equation 2.1.

$$k = \frac{k_B}{N_0}\left[\frac{N_0}{(1-q_Q)(1-q_B)}\right]_b + \frac{k_{CP}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_p)}\right]_{c2} +$$

$$\frac{k_{CS}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_p)} * \frac{q_s}{(1-q_s)} + T_{su}\right]_{c2} + \qquad \textit{Equation 2.1}$$

$$\frac{k_D}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_p)(1-q_s)} + T_{su}\right]_{c2}$$

Where N_0 is the nominal batch size, T_{su} is the is the set-up time for the process, k_B is the material cost per product, exclusives of material waste and rejections and k_D is the cost of staff per hour. The other variables are described below.

2.1.1.1. The machine rates

k_{CP} and k_{CS} is the Cost of equipment per hour when it is in operation and when it is not in operation respectively and are calculated by Equation 2.2 and Equation 2.3 respectively.

$$k_{CP} = \frac{a_f * K_0(1 + k_{ren} * N_{ren}) + Y * k_y + T_{plan} * \left(\frac{k_{UHh}}{h_{UH}} + k_{ph}\right)}{T_{plan}} \qquad \textit{Equation 2.2}$$

$$k_{CS} = \frac{a_f * K_0(1 + k_{ren} * N_{ren}) + Y * k_y}{T_{plan}} \qquad \textit{Equation 2.3}$$

Where the annuity factor a_f is a function of the discount rate p and is the technical life n of the equipment. a_f is calculated by Equation 2.4.

$$a_f = \frac{p * (1+p)^n}{(1+p)^n - 1} \qquad \textit{Equation 2.4}$$

K_0 is the acquisition cost of the equipment, k_{ren} is the cost to renovating it in present value, expressed as the ratio of the

acquisition cost of the equipment, and N_{ren} is the number of renovations needed during the technical life of the equipment. Y is the floor area used by the equipment and k_y the cost per area. k_{UHh} is the cost per hour for maintenance and h_{UH} is the number of running hours for every hour of maintenance. T_{plan} is a time plan or the planned production time for a given period.

2.1.1.2. Loss factors:

-   The material waste loss factor q_B is calculated by Equation 2.5.

$$q_B = \frac{m_{tot} - m_{det}}{m_{tot}} \qquad\qquad \textit{Equation 2.5}$$

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 quality loss factor or the rejection rate q_Q is calculated by Equation 2.6.

$$q_Q = \frac{N_Q}{N} = \frac{N - N_0}{N} \qquad\qquad \textit{Equation 2.6}$$

Where N is the number of parts that needs to be produced within a given batch in order to obtain the nominal number N_0 of correct parts. and N_Q is the number of parts that are faulty.

-   The rate loss factor or production-rate loss q_p is calculated by Equation 2.7.

$$q_p = \frac{t_{0v} - t_0}{t_{0v}} \qquad\qquad \textit{Equation 2.7}$$

Where t_0 is the normal cycle time and t_{0v} is the "real cycle time" which is an increased cycle time due to due to rate losses which correspond to the slower rate either so as to meet a particular quality requirement or to avoid an unplanned downtime.

-   The down time loss factor q_S is calculated by Equation 2.8.

$$q_s = \frac{t_s}{t_p} = \frac{t_p - t_0}{t_p} \qquad\qquad \textit{Equation 2.8}$$

Where t_p is the real production time including downtime and t_s is the downtime.

2.2. Activity-based costing

Activity based costing, ABC is a method for assigning costs to products, services projects, tasks or acquisitions based on activities that go into them or resources consumed by these activities. By using the method, one can better understand the true costs of goods and services. It arose from critic against the methods of traditional costing methods that was too simplified, and which often allocate overhead costs only to one volume sensitive driver, typically direct labor. ABC uses cost driving a vast range of drivers like quantities, orders, machine-hours, tests, items per package or variants to distribute costs more precisely. ABC can be used for identifying truly profitable and truly unprofitable products, finding and eliminating unnecessary costs, pricing products to achieve acceptable margins and much more. When ABC is implemented and used to manage a company it is referred to as activity based management, ABM [7] [8].

A simple calculation example comparing traditional costing to the ABC method created by Solution Matrix Ltd [9]. In the example the Management must estimate the profitability of each product in order to decide which products to produce and how to price them. The results can be seen in Figure 5 and shows the different results gotten when applying traditional casting allocating overhead based on direct labor compared to ABC costing using a multiple cost driving factors. In this case, it is clear that if the traditional costing method were to be used, another decision would have been made by the management. To see full example, visit https://www.business-case-analysis.com/activity-based-costing.html.

		Product	
		Product A	Product B
Costing Method	Traditional Costing	45,2%	26,3%
	ABC Costing	26,1%	36,8%

Figure 5: *Comparison of profitability estimates from two different costing methods. Traditional costing shows product A more profitable than product B and ABC costing shows the reverse [9].*

When implementing ABC, it is important with support of senior management in the organization so that all people in the company get to be informed, involved and aligned. It is important to set the right expectations and explain thoroughly what and why it is to be done. It is suggested to start with a smaller pilot project that only looks at a small portion of the business. It is generally more effective to include more complexity than less since this can show more significant results and possibilities for further implantation [7].

Velmurugan [7], have suggested 9 steps for a successive implementation of ABC:

1. Identify and assess ABC needs - Determine viability of ABC method within an organization.

2. Training requirements - Basic training for all employees and workshop sessions for senior managers.

3. Define the project scope

4. Identify activities and drivers

5. Create a cost and operational flow diagram – How resources and activities are related to products and services.

6. Collect data

7. Build a software model, validate and reconcile.

8. Interpret results and prepare management reports.

9. Integrate data collection and reporting.

Tracking costs, from resources to activities to a specific product, is hard to do with surgical precision. It is better to be correct (using ABC) within 5-10% of the actual costs of a product, than to precisely wrong using outdated allocation techniques. Furthermore, there three rules suggested for implementation by Velmurugan [7]:

1. Focus on expensive resources since it is an area were ABC can make big difference in the product cost. In a company that make industrialized goods with high fabrication costs tracking manufacturing overhead to product is of importance.

2. Look deeper in to resources whose consumption varies significantly by product.

3. Focus on resources that are uncorrelated with traditional allocation measures like direct labor.

Critic and resistance for implementing and using ABC has historically arose. ABC is often considered to be complex, demanding a lot of work to implement and lacking standard formats when implemented. It forces big changes to traditions of using traditional costing methods. Since it will output more precise costs of different functions and aspects many departments can feel exposed since the real costs come to light within the company [8], [7].

Some of the critic against ABC have by one of the co-inventors of ABC, Robert S. Kaplan been taken in to consideration to create a new type of ABC, namely Time-Driven Activity-Based Costing or TDABC. TDABC doesn't use all the cost drivers used in ABC, but instead more or less only time as a driver and by that eliminate much of the complexity experienced by users of ABC [10], [11].

2.3. Value Stream Mapping

Value stream mapping is a tool to help one to get to an understanding of the processes in a value stream. It is done by using symbols to illustrate processes and flow of either products or information from supplier to customer. Among other applications it can be used to communicate, visualize, teach about the processes in a manufacturing system. By doing so issues in the system can be understood and improvements can be found [12].

The initial steps in the value stream mapping is shown in Figure 6. First a product family that should be mapped have to be determined. Not all products can be mapped at once. Then the current state should be mapped and after a future, improved state should be created. This can be an iterative process since often overlooked factors in the current state is found when doing the future state, and impartments which to be implemented are found when doing the future step. There should always be a future state map [12].

When doing the mapping one should always try to get a thorough understanding of the processes by walking through the shop floor and observing. When doing so a stopwatch can be a good help. One should be critical of using standard times. It can be hard to understand all flows and organizational boundaries often have to be broken to get the information needed, therefore a person in charge should be one with insights to different functions within the company. It should be noted that it is not intended to be something that should take much time, minor details and finetuning can be disregarded. The flow is drawn left to right in the order of processing steps, without concern for the actual physical layout in the factory [12].
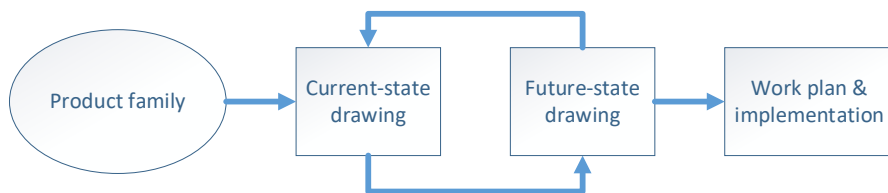
Figure 6: *Value Stream Mapping steps [12]*

2.4. Banks Simulation steps

A simulation model is the imitation of a real-world system over time, which involves the generation of artificial history to be able to observe the behavior of the model to draw conclusions about how the real-world system acts [13].

Banks et al. [13] has developed a methodology for conducting a simulation study as such. The steps in this methodology are displayed in Figure 7. Even if the methodology is followed at first it is not certain that simulation is the correct tool to use. In Step 2, "Setting of objectives and overall project plan" the question if simulation is the appropriate tool and should be conducted must be answered [13].

One of the reasons for conducting a simulation study is that is can give the synergetic effect of much valuable insight about processes which can create an understanding on many different levels of the company. Furthermore, A simulation model makes it possible to in a simple way try different scenarios and see the impacting results of those changes without interfering with the real system. In this way, new setups or routines can be tested and improvements can be found. On the other hand, in some cases, the model is simple enough to be solved by calculations or analytical solutions. If this is the case it is the preferable way to go, since creating a simulation mode demands both much data and work. Furthermore, since making a model demands a lot of data and work, the cost of making a simulation model might be greater than the benefit. If a system is too complex or cannot be defined, for instance if the system is much dependent on human behavior, simulation is not appropriate [13].
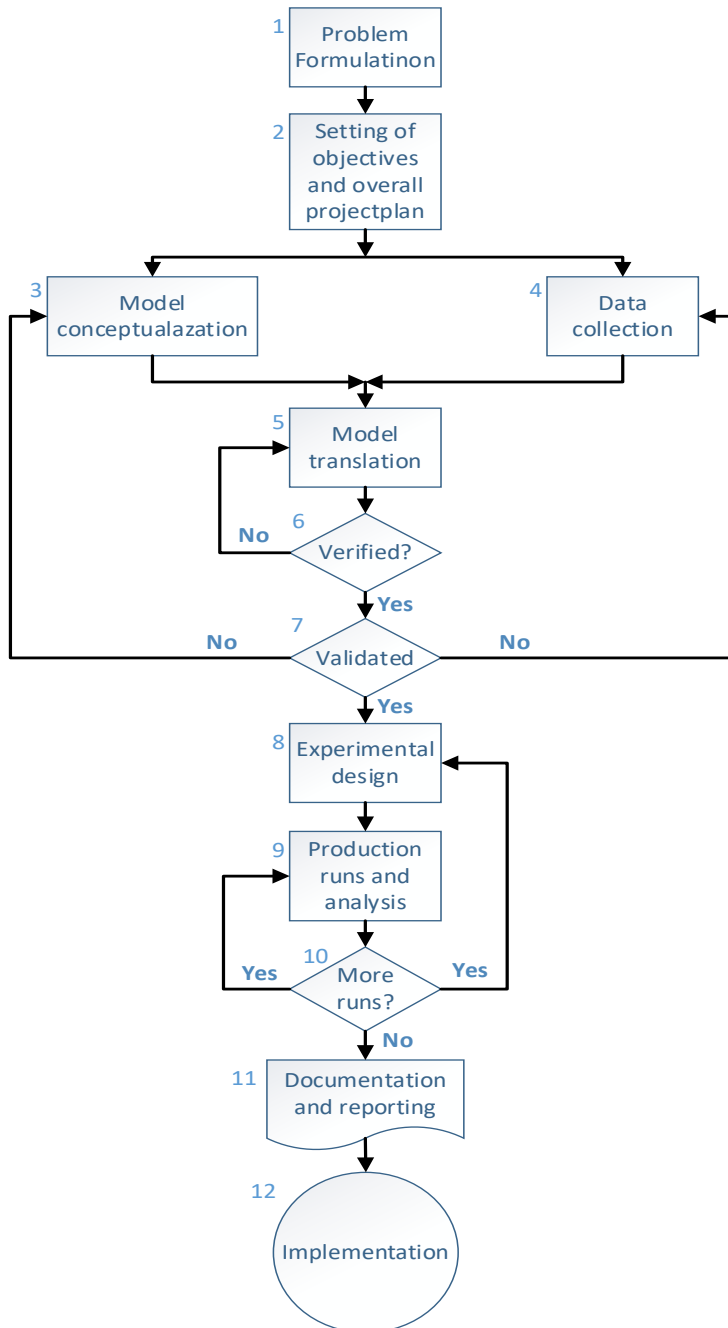
Figure 7: *Steps in a simulation study* ***[13]***

3. Method

3.1. Introduction

When establishing what tool to be used for this analysis it was important that it would be able to grasp the full complexity of the case. At the same time, it should not be a method that was to be too demanding, complex and/or advanced, nor should the method be to flimsy. In the beginning Banks simulation steps, presented above, was followed but it was determined that a discrete event simulation, DES was not the preferable approach. The decision is justified by banks suggestions for when DES is appropriate and when it is not [13]. In this case there are criteria for both, but the conclusion is that a DES would simply be to time demanding in proportion to the output since the amount of data that would be needed is very high and the complexity of the system ought to be analyzed is to great. On the other hand, the method and principles were still, too wide extend considered to be applicable if using a cost model. The major difference of using a cost model in comparison to DES is that it is not based on randomness and does not show how the system acts in a specific point in time but rather shows the system in an aggregated way which gives a good, and in this case, a sufficient overview for managing and decision making in regards of the system of interest.

The idea is that economics is not just a system with which one trade goods and services, it is a system with which one can measure and compare everything. It is important to realize that Faiveley wants to reduce the cost of the products, but presently does only have rough estimates of the actual product cost. So, to reduce the cost and to be able to priorities which to reduce, in a structured manner, the costs must first be found. By using the cost model by Ståhl and the principles of ABC together, a system was set out to be created and implemented to determine costs to be able to find improvement opportunities in the processes. Though using these tools demand a lot of data they do not need as much as DES, to give a good analysis over a very complex system. Just doing the cost modeling can, as doing a DES study, give much valuable insight about the system of interest. It also, like a DES makes it possible to try different scenarios and see the impacting results of those changes without interfering with the real system. The conclusion is that it can give all the benefits of DES but demand less resources.

Value stream mapping was chosen to not be used to the full extent. This since it was deemed to have the limitations of not being able to visualize and aggregate all the complexity and data needed to evaluate the performance of this production system. Also, there is only so much that can fit on a piece of paper and it still being readable. For these reasons, the using of value stream mapping is majorly for demonstrational purposes and not actually the tool that evaluates nor lead to the improvements. The methods for conducting the mapping were still to some extent applied.

Implementation of results of this thesis can mean different things, it can imply the implementation of the model as such to be used to continuously improve the production, determine cost of products and other strategic decisions, or it can correspond to the implementation of the improvements suggested. One of which can have great affect over a long period and the other be a one time improvement. The steps of implementing ABC above have partially been used for conducting this thesis, but are mainly a guideline suggested for how to implement the cost model system as a more permanent tool. This thesis is, as suggested to be done by Velmurugan [7], the starting with a small pilot project, including much complexity and showing the potential of using this approach. In other words, this thesis is a pilot study with the intention of showing the potential of using cost modeling as a structured improvement tool.

3.2. Methodology

Below each step in the methodology is explained, the overview of which can be seen in Figure 8.

1. **The problem formulation** was in part done by Faiveley suggesting this master thesis project and different methods, like for example value stream mapping and/or simulation. These were further discussed and reformulated which the output of can be read more about in chapter 1.1.

2. **Setting of objectives and overall project plan.** The purpose, challenges and milestones were set to get the project going. This and more is described in chapter 1.2, 1.3, 1.4 and 3. It was also concluded at this point that discrete simulation was not the appropriate tool in this case. Different methods were looked in to and used to varying degrees. The theories and influences for the method described here are briefly described in chapter 2.

3. **Model conceptualization** is the design and early construction of the model to be built, from here and forward referred to as the "Cost Model System". It was based on the theories above together with insights gained from the work practice period and is conducted in parallel with the data collection for deeper insight. The model is further described in chapter 4.

4. **The Data collection** is the question of data needed as input for the model ought to be built. The data collection both provide the data needed in itself but also provided metadata about the formats of the data so that the model could be designed in a way that it would be easy to use and put data in. The data collection and refinement of the data is presented in chapter 5.

5. **Model translation** is the final model based on and with the data collected inserted. The model is further described in chapter 4.

6. **Verified?** Since the model is both static and mathematical verifying that it is functioning as intended is quite easily done by performing calculations by hand and comparing those with the output of the model.

7. **Validated?** To conclude if the model depicts the reality, the results were continuously checked against aspects emphasized by personal and observations on the floor. For instance, employees could emphasize that maintenance cost were high for a particular machine,

if the function of adding maintenance costs had not yet been implemented or the cost was relatively low at the moment, further data needed to be found and/or changes had to be made to the model.

8. **Current situation evaluation**. When the validation has been done the current situation can be described thoroughly and evaluated. The value stream map of the current situation is here presented to get an overlook of the processes. The description and evaluation can be seen in chapter 6.

9. **Experimental design.** At this point multiple ideas regarding possible improvements like investments or changes that can be done to improve the processes have been identified. These possible improvements have to be figured out how they can be argued to actually reduce cost, so it can be showed in the model. The experiments can be viewed in chapter 7.1.

10. **Model compatible?** This step has close relation with the previous step. It will become clear if the new concept that is wanted to be analyzed and tested in the model is possible to test. It might demand functions that does not already exist. For instance, if the improvements are that the disposal cost of a consumable is to be reduced and this function does not exist, one must go back to and ad this feature and gather the data. Another option is to try other options, most likely are the number of improvements that are thought of very high so letting one go to try another can be an option if there is a limitation on time.

11. **Experiment data collection.** To do experiments, more data is needed. This data has then had to be collected from different source like, experiments, scientists, catalogs or equipment manufacturers. The date used in the different experiments can be seen in chapter 7.1.

12. **Result analysis**. Finally, the results can be analyzed, and the most appropriate alternative can be chosen to go forward with. This is done in chapter 7.2.

13. **Documentation and reporting.** The last step that is needed to be done is the documentation and reporting, which if notes have been made throughout the project should not be an issue.
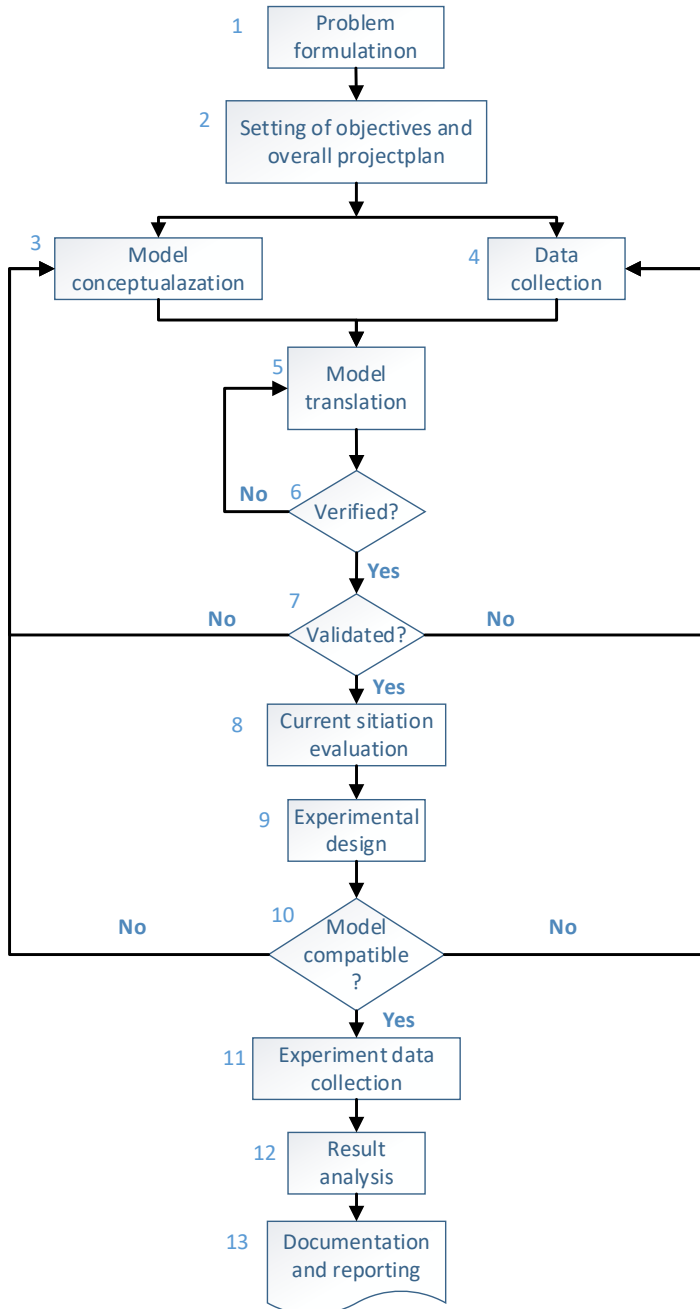
Figure 8: *Methodology steps*

4. Cost Model System

4.1. Introduction

The construction of the Cost Model System, CMS was an attempt of building a generic cost model that would be applicable in-, if not all-, most production processes to map costs, irrespectively of how or what was processed. The CMS provides a structured format where costs, sales quantity and production data can be put in tables and out comes a wide spectrum of figures, from revenue and profit margin both in total and for each product down to specific cost of a process or product. It was chosen to be implemented in Microsoft Excel since it is a commonly known and used software at both Faiveley, other industries and academia. It is in large based on the cost model by Ståhl [6] presented above, but since the structure in the CMS differ from Ståhls cost model does the denotations differ in some cases from the ones Ståhl are using.

4.2. Overview

To get a better overview of the cost model system, a map of the connections and dependencies between the different worksheets are shown in Figure 9. The boxes symbolize worksheets, were the stacked ones symbolizes multiple worksheets. The color of the boxes corresponds to the tab color for the retributive worksheets in the excel file. This map is in a way simplified, since to handle tables and data in an efficient way, the excel tool "Power Query", PQ was used. With this tool, it becomes easier to handle multiple tables in a consistent way. Tables can be appended, merged, aggregated and the data can be manipulated in a preferred way, both systematically and repeatedly. In the setup in the cost model system the PQ takes tables from the different worksheets and creates new tables which are loaded to other worksheets. For example, the Cost table and the TimePlan table consists of data from multiple tables that are loaded to the PQ, transformed, merged and then loaded to the CostRate and TimePlan worksheets. These tables are then used as sources for other tables in worksheets such as the Processes and Support Processes. The cost model map, modified to include dependencies to the PQ is shown below in Figure 10. The dependencies inside the PQ can be seen in Appendix A.

Costs in the CMS are connected to a product in three different ways, directly to a product, through process time of a product or last, overhead. Costs

connected directly to a product piece are such as the "kit" which is part directly added to the product and some consumables such ass paint or Loctite. Other costs such as depreciation of machines, cost of facility, cost of workers and some of the consumables cannot directly be dedicated to a product but instead be distributed based on time. The time can be such as how much a machine is used or how much worker time is needed for a specific product. Some costs are very hard to distribute based on previously mentioned methods, e.g. white-collar worker salary, and because of that they are distributed as overhead based on the previously mentioned costs. More details about this will be described below.

In the processes worksheet, there are a table were each row is a process step for a particular process. In each step, one can type in the process, the time necessary for that step, which product and how many that the step is for, if a worker is needed, if the dedicated equipment is used or blocked and/or if a travers or wagon is used. From all of this we know how much time is needed for workers and equipment for each product in each process and process step. This data together with the product mix (the yearly quantities of each product) will provide a yearly time plan for each process. That time plan can be used to divide the yearly costs such as depreciation of equipment, cost of facility, consumption of some consumables, cost of repairs, maintenance and meetings and so on to get hourly rates. These rates are summarized in the in the Cost table in the CostRate worksheet. Using the Cost table as a source, the rates are connected to the retributive processes, time and criteria. Multipliying the rate and with the time of a process steps gives the cost of each process and process step in the processes worksheet.
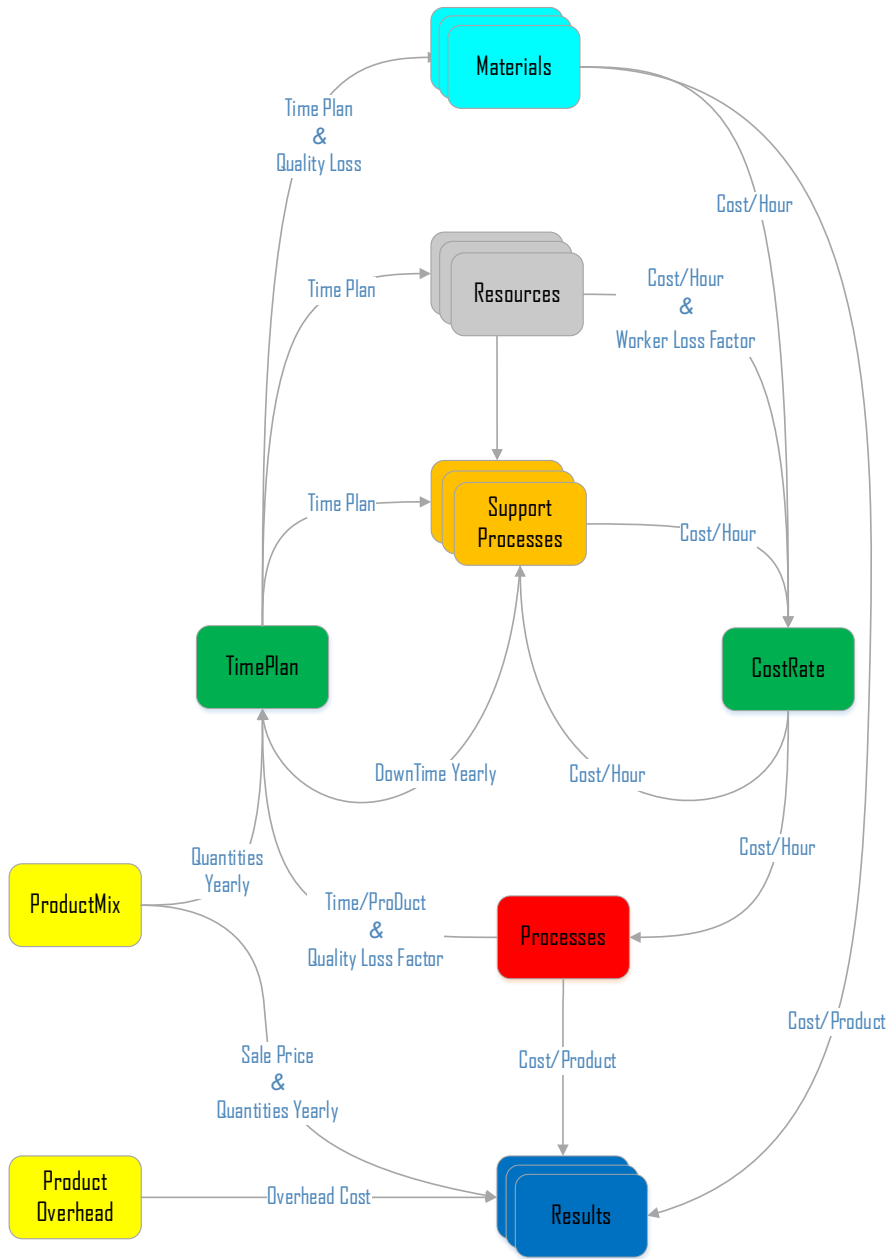
Figure 9: *Cost Model System Map*
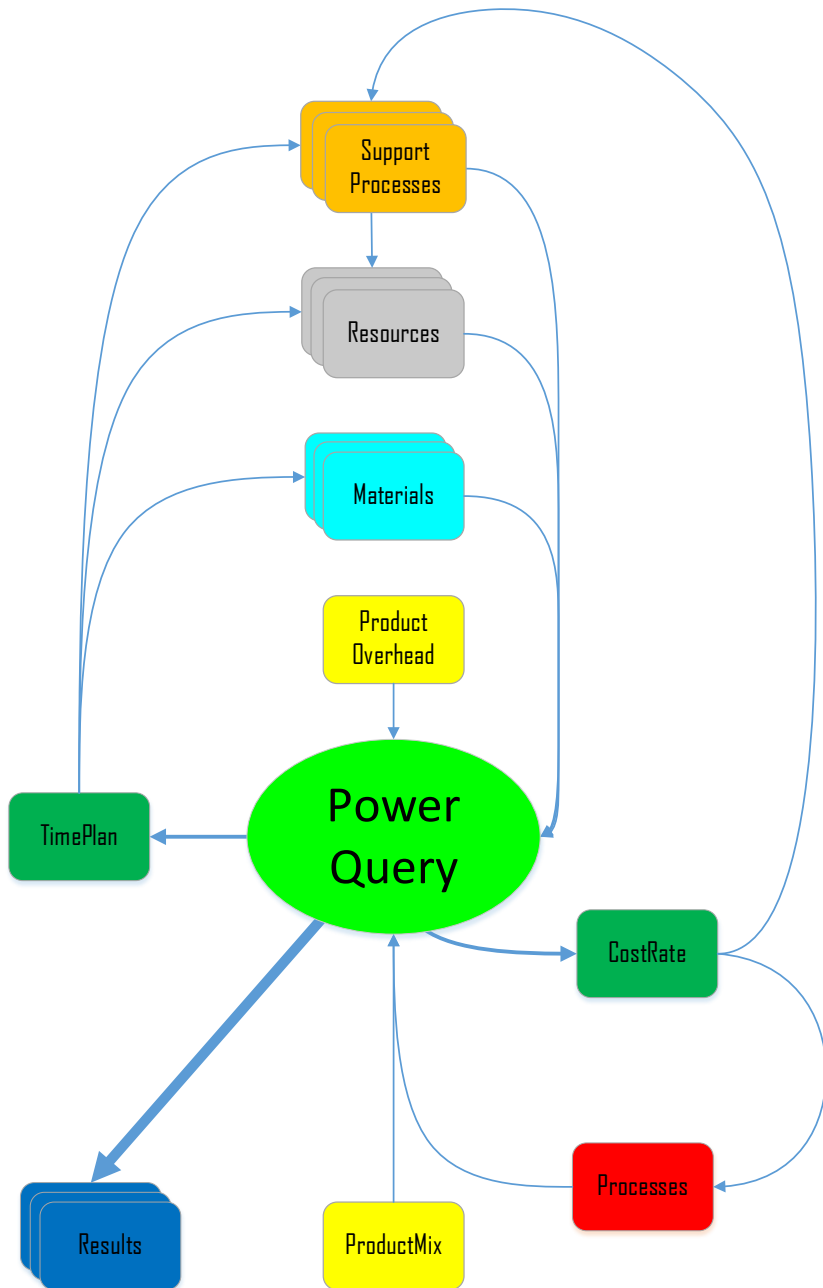
Figure 10: *Cost Model map with Power Query*

4.2.1. Technical aspects and other considerations

All costs are as explained above connected in one way or another to a product. This is how it must be done since all the costs of a company always must be paid for by the customers.

An aim when creating the cost model was to make it as generical as possible, consequently some functions implemented were never used in the case of Faiveley processes. The generic features of quality losses and the raw material worksheet are examples of this.

The CMS does not work in real time, meaning that results are not automatically updated when changes are made in the different tables and worksheets. To refresh the CMS one simply presses "Ctrl+Shift+R". This will run a VBA script that refreshes the power query in an efficient manner. It is possible to do this without the script but then it has to be done by clicking the "Refresh All" bottom under the data tab in excel, letting it refresh and then repeating this two more times. The script is preferable since it reduces the time for refreshing considerably.

It is important to note that the results of the CMS are not more accurate than its input. Since the time plans are calculated based on quantities and the durations of the different steps, not including the data for a product in a process shared among many products, will led to an overestimated cost of the products included. A quick fix, that is not recommended, is to reduce the cost of equipment to a fraction that is equal to the time a product of interests use it. But, this implies that estimates must be done for products that are not included in the CMS and then one might as well put them directly in CMS. In short, it can be said that it is better to add information then to estimate the fraction of a cost that is used.

4.3. The Worksheets

An excel file is referred to as a workbook inside of it are one or many worksheets that can be accessed from tabs at the bottom of the window. In every worksheet there are cells which can be grouped in to ranges or tables for easy access and referencing when doing calculations, formulas or queries with power query tool. Formatting a range as a table allows it to have a dynamic column length, so that when a new row is added it can be handled automatically by formulas and queries without any modifications in either. This functionality has been used to make the CMS more generic and continuously adaptable to changes of products or processes.

ATTENTION! The data shown in the tables below is only shown for the purpose of demonstrating the Cost model system and does not show all or in in most cases even the correct data as of the analysis of Faiveley.

Note that when a cell displays a time format of [hh:mm:ss] it corresponds to an amount of time as a fraction of a day which then has to be multiplied by 24 to get the time in hours.

4.3.1. Processes

The Processes worksheet is where the processes are defined in respect to their duration, what resources that are used, if it is automatic or manual process and/or if there are any quality or rework losses. This is the core of the system and is also were some of the most important results are gathered from.

The worksheet contains two tables, the "CostRate Control Panel" and the "Processes" table. An overview of this worksheet is provided in Appendix B, where the CostRate Control Panel is highlighted in green and the Processes table in yellow. The Processes table is divided in to three parts, the input columns the time columns and cost columns. Each row in the Processes table is a step in a process where the data, to needed describe that step, is inserted to the input columns. The CostRate Control Panel have inputs of "TRUE" and "FALSE" which are settings that apply to every row in the processes table and defines which costs that should be connected to a process step depending on what resources that are used.

4.3.1.1. Input Columns

The input columns, Figure 11, is where the processes are defined. The data of the different columns are described in the bullet-points below.

- **Process,** p is the process this step is a sub process to.

- **Step**, is a short description of this step, for reference.

- **Step Order** i is the order position of this step, in relations to all steps for the same product.

- **Product**, is the name of the product this step is for.

- **Time Nominal** T_0 is the nominal cycle time for this step, for the quantity handled N_s during the step.

  In case a nominal cycle time is not defined and/or it is a manual process it can be suggested to choose the shortest measured time for that step from a time study.

- **Time Average** T_A is the average cycle time for this step, for the quantity N_s handled during that step.

  It is important to note that when assessing the average time there are no influence of the loss terms q_{pr}, q_{pw} or q_Q which means that the time is measured <u>without</u> time of rework, <u>with</u> experienced personal and <u>without</u> quality losses.

- **Nbr of Products** N_s is the average number of products that are handled during this step.

- **Main Used** is "TRUE" if the dedicated equipment to this process is used during the step.

- **Main Blocked** is "TRUE" if the dedicated equipment is blocked for other products during this step.

  ATTENTION! Main Used and Main Blocked should not both be "True" in the same step, if Main Used is "True" the equipment is implicitly blocked.

- **Worker** is "TRUE" if a Worker is needed during this step, meaning that this step is not done automatically by a machine.

- **Wagon** is "TRUE" if a Wagon is used during this step.

- **Travers** is "TRUE" if a Traverse is used during this step.

- **Rework Loss Factor** q_{pr} is the fraction of time, for all repetitions of this step, that this step is remade.

- **Quality Loss Factor Added** q_{QAi} is the quality loss or the rejection rate in this step i disregarding influence of succeeding steps. It is calculated according to Equation 2.6.

- **Quality Loss Factor** q_{Qi} is the quality loss factor in this step i considering succeeding steps and is calculated by Equation 4.1. Contradictory to the name of the section of columns (Input Columns) that this one belongs to, it is not an input column.

$$q_{Qi} = 1 - \left(1 - q_{QAi}\right) * \left(1 - q_{Qi+1}\right) \qquad \textit{Equation 4.1}$$

| | | | | Measured Time | | | Resources | | | | | | | |
| | | | | | | | Dedicated | | Shared | | | | | |
Process	Step	Step Order	Product	Time Nominal	Time Average	Nbr of Product	Main Used	Main Blocked	Worker	Wagon	Travers	Rework Loss Factor	Quality Loss Factor Added	Quality Loss Factor
Material	BFC_Dism	1	BFCF	0:00:20	0:00:29	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	BFCF_Ass	2	BFCF	0:00:19	0:00:22	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	EmptyWa	0	BFCF	0:00:20	0:00:24	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	EmptyWa	0	BFCF	0:00:19	0:00:21	1.5	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	GrindingA	0	BFCF	0:00:43	0:01:04	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	InsideWa	0	BFCF	0:00:20	0:01:02	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	Painting_	0	BFCF	0:00:19	0:00:44	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	Palletwag	0	BFCF	0:00:14	0:00:48	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	Parts_BFC	0	BFCF	0:00:32	0:01:04	4	TRUE	FALSE	TRUE	FALSE	FALSE			0
Material	Parts_BFC	0	BFCF	0:00:23	0:01:01	8	TRUE	FALSE	TRUE	FALSE	FALSE			0
Material	PreAssen	0	BFCF	0:00:44	0:01:13	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	PreAssen	0	BFCF	0:00:18	0:00:18	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	PreWash_	0	BFCF	0:00:45	0:02:27	4	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	Testing_T	0	BFCF	0:00:23	0:00:23	8	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	Washcart	0	BFCF	0:00:58	0:01:25	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	BFC_Dism	0	BFC	0:00:20	0:00:29	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	BFC_PreA	0	BFC	0:00:19	0:00:22	1	TRUE	FALSE	TRUE	TRUE	FALSE			0
Material	EmptyWa	0	BFC	0:00:43	0:01:04	1	TRUE	FALSE	TRUE	TRUE	FALSE			0

***Figure 11:** Processes Worksheet, Input Columns*

4.3.1.2. Time Columns

The time columns, see Figure 12, are only calculations and does not need any input. The columns calculate the nominal time, the losses in time and the time per product.

- **Nominal Time per product,** t_0 is the from the input columns divided by the "Nbr of Product". Nominal Time per product denoted t_0.

-   **General Loss,** $t_{q_{pg}}$ is the loss due to general variations in the production which makes the production pace slower and is calculated by Equation 4.3. Were the loss q_{pg} is calculated by Equation 4.2.

$$q_{pg} = \frac{T_A - T_0}{T_A} \qquad \textit{Equation 4.2}$$

$$t_{q_{pg}} = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})(1 - q_{Qi})}$$
$$- \frac{t_0}{(1 - q_{pw})(1 - q_{pr})(1 - q_{Qi})} \qquad \textit{Equation 4.3}$$

-   **Worker Loss,** $t_{q_{pw}}$ is a loss because of the learning curve of the workers which adds time to every step that needs a worker. On average, a process that have a lot of manual labor involved will take longer time with unexperienced personal. When the input column for worker is set to "TRUE". The loss factor, denoted q_{pw} is collected from the Worker table in the CostRate worksheet and the Worker Loss is calculated by Equation 4.4.

$$t_{q_{pw}} = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})(1 - q_{Qi})}$$
$$- \frac{t_0}{(1 - q_{pg})(1 - q_{pr})(1 - q_{Qi})} \qquad \textit{Equation 4.4}$$

-   **Rework Loss,** $t_{q_{pr}}$ is loss due to the fact that the work sometimes must be remade. The factor, denoted q_{pr} is taken from the Rework rate loss in the input columns. If the column is zero or blank there is no added loss. The Rework Loss is calculated by Equation 4.5.

$$t_{q_{pr}} = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})(1 - q_{Qi})}$$
$$- \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{Qi})} \qquad \textit{Equation 4.5}$$

-   **Quality Loss,** t_{q_Q} is loss due to parts having to be discarded. t_{q_Q} is calculated by Equation 4.6.

$$t_{q_Q} = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})(1 - q_{Qi})}$$
$$- \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})}$$

Equation 4.6

- **Total Loss,** t_l is the total loss because of the loss factors and is calculated by Equation 4.7.

$$t_l = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})\left(1 - q_{Qi}\right)} - t_0$$

Equation 4.7

Attention! The general loss, the worker rate loss, the rework loss and the quality loss cannot be summed by simple addition to get the total loss if more than one equals a non-zero value, a proof is provided in Appendix C. *They are displayed to show their individual contribution to the loss assuming a "fixed state" of the other factors.*

- **Time per Product,** t is the cycle time, including losses, for one product, calculated by Equation 4.8.

$$t = \frac{t_0}{(1 - q_{pg})(1 - q_{pw})(1 - q_{pr})\left(1 - q_{Qi}\right)}$$

Equation 4.8

Nominal Time per product	Time Loss					
	Factor				Total	
	General Loss	Worker Loss	Rework Loss	Quality Loss	Total Loss	Time per Product
0:00:20	0:00:09	0:00:01	0:00:00	0:00:00	0:00:09	0:00:29
0:00:19	0:00:03	0:00:01	0:00:00	0:00:00	0:00:04	0:00:23
0:00:20	0:00:04	0:00:01	0:00:00	0:00:00	0:00:05	0:00:25

Figure 12: Processes Worksheet, Time Columns

4.3.1.3. Cost Columns and CostRate Control Panel

The CostRate Control Panel, see Figure 13 is where one can choose which hourly rates that should be put on a time for the retributive column in the Processes table. All the rows under "Cost Title" are the optional rates for the corresponding resource. Some of the hourly rates are zero if looking at Figure 36, which is the source of the rates. If looking under the dedicated section one can see that all rows in the "Main Used" column are set to "TRUE", this means that all hourly rates will be put on all the times in the corresponding column. On the other hand, if one looks at the "Main Blocked" column only the Depreciation and the Facility rows are set to true, meaning that only those rates that will be put on the time. The columns in the CostRate Control Panel are handled as column vectors, were "TRUE" corresponds to 1 and "FALSE" to 0. The vectors are for columns "Main Used", "Main Blocked", "Worker", "Travers", "Wagon" denoted as $\overrightarrow{CRCP_{MU}}$, $\overrightarrow{CRCP_{MB}}$, $\overrightarrow{CRCP_{Wa}}$, $\overrightarrow{CRCP_{Wa}}$ and $\overrightarrow{CRCP_{Tr}}$ respectively.

For example, would $\overrightarrow{CRCP_{MB}}$ in the setup in Figure 13 correspond to:

$$\overrightarrow{CRCP_{MB}} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

In the CostRate table each row with rates for a process p correspond to a row vector with values of rates. The vectors are denoted $\overrightarrow{CR_p}$. For example, is the vector for the Process "MaterialHandling":

$$\overrightarrow{CR_{MaterialHandling}} = \begin{bmatrix} 0 & 0 & 0 & 176 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Attention! The main reason for the CostRate Control Panel is to visualize which costs that are caused by a process step depending on which and how resources are used. Also, it is used for calculational purposes. It should not be changed without consideration of the mathematical consequences since it does not have any control over the time plans.

The Cost columns are where the times are multiplied with the hourly rates from the cost table in the CostRate worksheet to get the cost of the steps. Depending on in the values are "TRUE" or "FALSE" in the resources under

the input columns, different costs are applied to the step. The Cost columns are presented below:

- **Cost Main Used, c_{MU}** is the cost of using the dedicated resource during the time t if the "Main Used" column of the Input Columns is set to "TRUE". The precedents are shown in Figure 14 and shows that in this case the cost is 1.57kr. c_{MU} is calculated by Equation 4.9. The reason for multiplying with 24 is only to adjust the time format from fraction of days to hours.

$$c_{MU} = t * 24 * \overrightarrow{CRCP_{MU}} * \overrightarrow{CR_p} \qquad \text{Equation 4.9}$$

- **Cost Main Blocked, c_{MB}** is the cost of blocking the dedicated resources during the time t. It has the same precedents offset one cell to the right and is dependent on the same logic as c_{MU}. c_{MB} is calculated by Equation 4.10.

$$c_{MB} = t * 24 * \overrightarrow{CRCP_{MB}} * \overrightarrow{CR_p} \qquad \text{Equation 4.10}$$

- **Cost Worker, c_{Worker}** is the cost of using a Worker during the time t and is calculated by Equation 4.11. It is only calculated if the "Worker" column of the Input Columns is set to "TRUE" and the precedents are shown in Figure 15.

$$c_{Worker} = t * 24 * \overrightarrow{CRCP_{Wo}} * \overrightarrow{CR_{Worker}} \qquad \text{Equation 4.11}$$

- **Cost Wagon, c_{Wagon}** is the cost of using a Wagon during the time t and is calculated by Equation 4.12. It is only calculated if the "Wagon" column of the Input Columns is set to "TRUE" and the precedents are the same as c_{Worker} but offset one cell to the right.

$$c_{Wagon} = t * 24 * \overrightarrow{CRCP_{Wa}} * \overrightarrow{CR_{Wagon}} \qquad \text{Equation 4.12}$$

- **Cost Travers, $c_{Travers}$,** is the cost of using a Travers during the time t and is calculated by Equation 4.13. It is only calculated if the "Travers" column of the Input Columns is set to "TRUE" and the precedents are the same as c_{Worker} but offset two cells to the right.

$$c_{Travers} = t * 24 * \overrightarrow{CRCP_{Tr}} * \overrightarrow{CR_{Travers}} \qquad \text{Equation 4.13}$$

- **Cost Total,** c_{Total} is the total cost for the step in a process and is calculated by Equation 4.14.

$$c_{Total} = c_{MU} + c_{MB} + c_{Worker} + c_{Wagon} + c_{Travers} \qquad \textit{Equation 4.14}$$

- **Cost General Loss,** c_{lg} is the cost that the Genera Loss contribute to the total cost and is calculated by Equation 4.15.

$$c_{lg} = \frac{c_{Total}}{t} * t_{q_{pg}} \qquad \textit{Equation 4.15}$$

- **Cost Worker Loss,** c_{lw} is the cost that the Worker Loss contribute to the total cost and is calculated by Equation 4.16.

$$c_{lw} = \frac{c_{Total}}{t} * t_{q_{pw}} \qquad \textit{Equation 4.16}$$

- **Cost Rework Loss,** c_{lr} is the cost that the Rework Loss contribute to the total cost and is calculated by Equation 4.17.

$$c_{lr} = \frac{c_{Total}}{t} * t_{q_{pw}} \qquad \textit{Equation 4.17}$$

- **Cost Quality Loss,** c_{lQ} is the cost that the Quality Loss contribute to the total cost and is calculated by Equation 4.18.

$$c_{lQ} = \frac{c_{Total}}{t} * t_{q_Q} \qquad \textit{Equation 4.18}$$

- **Cost Loss** c_l is the cost that the losses contribute to the total cost and is calculated by Equation 4.19.

$$c_l = \frac{c_{Total}}{t} * t_L \qquad \textit{Equation 4.19}$$

CostRate Control Panel

Cost Title	Dedicated		Shared		
	Main Used	Main Blocked	Worker	Wagon	Travers
Power	TRUE	FALSE	TRUE	TRUE	TRUE
Depreciation	TRUE	TRUE	TRUE	TRUE	TRUE
Salary	TRUE	FALSE	TRUE	TRUE	TRUE
Facility	TRUE	TRUE	TRUE	TRUE	TRUE
Consumables	TRUE	FALSE	TRUE	TRUE	TRUE
Maintenance	TRUE	FALSE	TRUE	TRUE	TRUE
Meeting	TRUE	FALSE	TRUE	TRUE	TRUE
Repairs	TRUE	FALSE	TRUE	TRUE	TRUE

Empty2	Cost Main Used	Cost Main Blocked	Cost Worker	Cost Wagon	Cost Travers	Cost Total	Cost General Loss	Cost Worker Loss	Cost Rework Loss	Cost Quality Loss	Cost Loss
	1.57 kr	- kr	2.91 kr	0.05 kr	- kr	4.52 kr	1.37 kr	0.12 kr	0.00 kr	0.00 kr	1.45 kr
	1.20 kr	- kr	2.23 kr	0.04 kr	- kr	3.47 kr	0.47 kr	0.09 kr	0.00 kr	0.00 kr	0.55 kr
	1.31 kr	- kr	2.43 kr	0.04 kr	- kr	3.78 kr	0.63 kr	0.10 kr	0.00 kr	0.00 kr	0.71 kr

(Cost Loss — Factor: Cost General Loss, Cost Worker Loss, Cost Rework Loss, Cost Quality Loss; Total: Cost Loss)

Figure 13: Under: Cost Columns. Upper: CostRate Control Panel

CostRate Control Panel

Cost Title	Dedicated		Shared		
	Main Used	Main Blocked	Worker	Wagon	Travers
Power	TRUE	FALSE	TRUE	TRUE	TRUE
Depreciation	TRUE	TRUE	TRUE	TRUE	TRUE
Salary	TRUE	FALSE	TRUE	TRUE	TRUE
Facility	TRUE	TRUE	TRUE	TRUE	TRUE
Consumables	TRUE	FALSE	TRUE	TRUE	TRUE
Maintenance	TRUE	FALSE	TRUE	TRUE	TRUE
Meeting	TRUE	FALSE	TRUE	TRUE	TRUE
Repairs	TRUE	FALSE	TRUE	TRUE	TRUE

Resources

Process	Dedicated		Time per Product	Empty2	Cost Main Used	Cost Main Blocked	Cost Worker	Cost Wagon	Cost Travers
	Main Used	Main Blocked							
MaterialHandling	TRUE	FALSE	0.00.29		1.57 kr	- kr	2.91 kr	0.05 kr	- kr

Figure 14: Cost Main Used Precedents

Figure 15: Cost Worker Precedents

4.3.2. ProductMix

The ProductMix Worksheet contains only one table with the same name and describes the **quantity yearly** Q of the products being produced and the individual sale price of the products, see Figure 16.

Product	Quantity Yearly	Sale Price
AC	10	10,000.00 kr
BFC	550	7,000.00 kr
BFCF	700	11,000.00 kr
Caliper	20	9,000.00 kr
DP	30	3,000.00 kr

Figure 16: ProductMix Worksheet

4.3.3. TimePlan

The TimePlan worksheet consists of three tables, "Calendar of Production", "TimePlan" and "Quantities", see Figure 17. The three worksheets will be explained in the following subheadings.

	Calander of Production	
Days/year	235	
Weeks/year	47	

TimePlan [Hours]						
Process	**Main Used**	**Main Blocked**	**Maintenace**	**Meeting**	**Repairs**	**Sum**
BFCF_ASSEMBLY	414.08	6.75				420.83
BFC_DISMANTLING	706.41	150.48				856.90
BFC_FINALASSEMBLY	771.19	60.50				831.69
BFC_PREASSEMBLY	794.51	4.39				798.90
INSIDEWASH	619.59		218.59		0.18	838.35
BFC_TESTING	188.29	266.50	27.59		0.95	483.34
GRINDINGANDINSPECTION	156.56					156.56
PAINTING	192.55	752.35	1.37		0.46	946.73
MATERIALHANDLING	317.14					317.14
PREWASH	174.93	69.55	131.71		0.13	376.32
RECEIVING_SHIPPING	86.88				0.15	87.03
SANDBLASTING	728.08	18.62	70.88		0.20	817.78
SANDWASH	82.04	169.06	3.53		0.24	254.88
WORKER	5335.63		274.44	94.00		5704.06
WAGON	6812.94					6812.94
TRAVERS	338.11					338.11
Total	**17718.9**	**1498.2**	**728.1**	**94.0**		

Quantities		
Product	**Quantity Yearly**	**Quality Loss**
AC	10	0
BFC	550	0.75
BFCF	700	0.568
CALIPER	20	
DP	30	0
DRV	650	0
VK	420	0
PBECFP	40	0
PBEC	55	0

Figure 17: *TimePlan Worksheet. Upper: Calander or Production table. Lower left: TimePlan table. Lower right: Quantities*

4.3.3.1. Calendar of Production

The Calendar of Production table is the only input required in the TimePlan worksheet, where the number of production weeks and days of a year are defined. This is used as a source data for defining frequency of maintenance and meetings which will be more discussed under "Support Processes".

4.3.3.2. TimePlan

The table is a summary of the yearly time plans for the processes and resources, created using Power Query. To get the yearly time plans, the time per product t for all steps in the processes table are multiplied with the quantity for the retributive product. This results in the total time T per year for each step, calculated by Equation 4.20. This data is then aggregated for each process to get the different time plans.

$$T = t * Q \qquad\qquad Equation\ 4.20$$

Furthermore, the time of maintenance, repairs and meetings are aggregated and added to the table. The table is updated by pressing "Ctrl+Shift+R". Below the columns in the individual columns in the TimePlan table are presented.

- **Main Used** is the sum of T for all steps, in each individual process, were **"Main Used"** under the input columns in the processes is "TRUE". Exception is the row of "Worker", "Travers" and "Wagon" in the TimePlan worksheet. For "Worker", "Travers and "Wagon" all times T from all processes are summed if retributive input column is "TRUE" in the process worksheets.

- **Main Blocked** is the sum of T where the rows in the "Main Blocked" column is "TRUE". "Worker", "Travers and "Wagon" does not have any "Main Blocked" time.

- **Maintenance** is the sum of the time of **"Time Yearly"** column from the Maintenance worksheet for retributive process. If the Maintenance is "Outsourced" no time will be put on "Workers" in the TimePlan table.

- **Meeting** is the sum of the time of **"Time Yearly"** column from the Meeting worksheet.

- **Repairs** is the sum of the time of **"Time Yearly"** column from the Repairs worksheet.

4.3.3.3. Quantities

The Quantities table is simply the same as the two middle columns from the ProductMix table in the ProductMix worksheet and the quality loss factor from the earliest step in the processes of a product. The table is created in the Power Query and updated automatically, by pressing "Ctrl+Shift+R".

4.3.4. Materials

The materials worksheets consist of three worksheets referred to as "Raw Material", "Consumables", "Consumption" and "Kit". All of which are worksheets where one can add material cost that goes directly in to a product or as an hourly or yearly cost of a process.

4.3.4.1. Raw Material

The raw material worksheet contains one table with the same name which can be seen in

Figure 18. The cost of raw material for different products are presented in this table. Note that in the case of Faiveley and the overhaul process it is not necessary since no raw material is used, but the functionality has still been implemented to make the model as generic as possible. It takes in to consideration the quality loss in the processes to determine the added cost of raw material due to quality losses. The content of the columns in the raw material table will be explained in the bullet point below.

- **Product** is the product the raw material is dedicated to.

- **Description** is an optional input to clarify the purpose of the raw material.

- **Nominal Cost** c_{b0} is the material cost per product, exclusives of material waste and rejections, equivalent to k_B in Ståhls cost model.

- **Input Material Amount** m_{tot} is the total volume of material per part going in to the processes

- **Output Material Amount** m_{det} is the material volume in the finished product.

- **Material Waste Factor** q_B is calculated by Equation 2.5

- **Quality Loss Factor** q_{Q1} is the quality loss factor automatically collected from the Quantities table in the TimePlan worksheet. The loss factor, as previously stated, is the loss due to quality that accumulates from the last to the first step in all processes, or in other words the quality loss acting on the first step in of a products processes.

- **Cost Quality Loss** c_{bqQ} is the added cost of raw material due to the quality loss which is calculated by Equation 4.21.

$$c_{bqQ} = \frac{c_{b0}}{(1 - q_{Q1})(1 - q_B)} - \frac{c_{b0}}{(1 - q_B)} \qquad \text{Equation 4.21}$$

- **Cost Material Waste** c_{bqB} is the added cost of raw material due to the material waste factor which is calculated by Equation 4.22.

$$c_{bqB} = \frac{c_{b0}}{(1 - q_{Q1})(1 - q_B)} - \frac{c_{b0}}{(1 - q_{Q1})} \qquad \text{Equation 4.22}$$

- **Cost Loss** c_{blB} is the added cost of raw material due to the material waste factor and the quality loss factor which is calculated by Equation 4.23.

$$c_{blB} = \frac{c_{b0}}{(1 - q_{Q1})(1 - q_B)} - c_{b0} \qquad \text{Equation 4.23}$$

- **Cost Raw Material** c_b is the total cost of the raw material which is calculated by Equation 4.24.

$$c_b = \frac{c_{b0}}{(1 - q_{Q1})(1 - q_B)} \qquad \text{Equation 4.24}$$

Product	Description	Nominal Cost [SEK/piece]	Input Material Amount	Output Material Amount	Material Waste Factor
AC		100.00 kr	10	7	0.428571429
BFC		500.00 kr	50	30	0.666666667
BFCF		200.00 kr	20	15	0.333333333
Caliper		600.00 kr	40	25	0.6
DP		400.00 kr	23	20	0.15

Quality Loss Factor	Cost Quality Loss	Cost Material Waste Rate	Cost Loss	Cost Raw Material
0	- kr	75.00 kr	75.00 kr	175.00 kr
0.75	4,500.00 kr	4,000.00 kr	5,500.00 kr	6,000.00 kr
0.568	394.44 kr	231.48 kr	494.44 kr	694.44 kr
0	- kr	900.00 kr	900.00 kr	1,500.00 kr
0	- kr	70.59 kr	70.59 kr	470.59 kr

*Figure 18: **Raw Material table**, Upper: Left part of table. Lower: Right part of table*

4.3.4.2. Consumables

The Consumables worksheet consists of just one table that will be referred to as the "Consumables" table which can be seen in Figure 19. The columns are explained in the bullet points below.

- **Consumable** is the trade name of the consumable.

- **Unit-Prices** c_{up} is the purchase price of the consumable for the unit-amount ua with the unit u.

- **Unit-Amount** ua is the amount in the unit u, gotten per unit-price up.

- **Unit** u is the unit in which the Unit-Amount is specified.

- **Disposal-Cost of Unit-Amount** c_{udc} is the cost of disposal per unit-amount ua.

- **Unit-Cost** c_{uc} is the total cost of the consumable which is calculated by Equation 4.25.

$$c_{uc} = c_{udc} + c_{up} \qquad \text{Equation 4.25}$$

Consumable	Unit-Price	Unit-Amount	Unit	Disposal Cost of Unit-Amount	Unit-Cost
5-56 Aerosol	69.50 kr	1	Piece	0	69.50 kr
Actrel 3356 D	40.30 kr	1	kg	0	40.30 kr

Figure 19: *Consumables table*

4.3.4.3. Consumption

The consumption worksheet contains a table that will be referred to as the "Consumption" table, it can in full be seen in Appendix D. The columns are divided in to four different parts "Input", "Consumable Data", "Product/Process – Data" and "Output", the retributive parts can be seen in Figure 21 and Figure 22. In the consumption table, the consumption of different consumables can be defined. In the bullet points below the columns in the table are described.

- **Description** is the description of the consumption that makes it possible to distinguish.

- **Consumption by Product or Process?** Is an option to dedicate the consumption to a product or a process. If it is dedicated to a product

the cost of the consumption will go straight to a product, else if is dedicated to a process the consumption will be distributed through the time a product uses a process. For example, it is easy to measure how much paint that is necessary to paint a specific product, there for that consumption can be dedicated to a product. If on the other hand the consumption of sand in a sandblasting process would be described it would be easier to find the total amount per year and distribute it on the time a product takes to be sandblasted.

- **Process,** if the consumption is set be by process, it is possible to choose a process from a drop-down list in this column.

- **Product,** if the consumption is set be by product it is possible to choose a product from a drop-down list in this column.

- **Consumable** is a drop-down list of the consumables available which is taken from the consumables worksheet.

- **Amount** is the amount that is consumed. Depending on the option of the consumption being done by product or process, the amount is distributed to a process hour, a product piece or a full year of a process-hours or yearly quantities of a product.

- **Unit** u is the unit the amount should be specified in which is automatically looked up in the consumables worksheet. Observe that no input should be done in this column even though it is among the input columns.

- **Amount per** is a column where one can choose in a drop-down list if the consumption is per "Year" or "Process-Hour or Product-Piece". The function of it in combination with the "Consumption by Product or Process?" column is explained below in Figure 20.

    Attention! If the setting "Year" is chosen the amount will be fixed independently of the yearly quantities or process hours meaning that it will result in a fixed yearly cost. If one knows the yearly quantity it is easy to first type that amount and then change it to the amount automatically calculated in the "Cost Added" column.

Amount Per		
	Year	Product-Piece or Process-Hour
Process	The amount specified will be divided on the time plan for the choosen Process when used (not blocked)	The amount specified will be the amount dedicated to a hour of a Process specified used (not blocked)
Product	The amount specified will be divided on the Yearly quantity for the choosen Product	The amount specified will be the amount dedicated to the product specified

Consumption by Product or Process?

Figure 20: Amount per column function matrix

- **Unit-Cost** c_{uc} is automatically gathered from the consumables table for the chosen consumable.

- **Unit-Amount** ua is the unit amount the consumable is purchased in. This is automatically gathered from the consumables table.

- **Price/amount** c_{pa} is calculated by Equation 4.26.

$$c_{pa} = \frac{c_{uc}}{ua} \qquad \qquad Equation\ 4.26$$

- **Quantity or Hours Yearly** $Q\&H$ is the yearly quantity or yearly number of hours, for the retributive product or process ("Used"), collected from the TimePlan worksheet.

- **Hours or Pieces** will have the value of "Pieces" if the consumption is done by product and "Hours" if the consumption is done by process. It is a unit for the value in the cell to the left, see Figure 22.

- **Amount per Hour or Piece** a is the amount, in the unit u for the consumable in the consumption table, that is consumed in one process hour ("Used") or one product for the chosen product or process.

- **Cost Added** c_{ad} is the added cost per hour ("Used") or product piece for the specified process or product for this consumption.

- **Amount Yearly** *A* is the yearly amount of the consumption in the specified unit for the consumable in the consumption table.

- **Cost Yearly** C_{ac} is the yearly cost added of consumption and is calculated by Equation 2.7.

$$C_{ac} = Q\&H * c_{ad} \qquad\qquad \text{Equation 4.27}$$

Input							
Description	Consumption by Product or Process?	Process	Product	Consumable	Amount	Unit	Amount per
	Product		DRV	MOBILGREASE 28	0.133	kg	Process-Hour or Product-Piece
	Process	SANDBLASTING		Blästersand	3693.75	kg	Year
PreAssembly	Product		BFC	LOCTITE 243	0.2	ml	Process-Hour or Product-Piece
PreAssembly	Product		BFCF	LOCTITE 243	0.2	ml	Process-Hour or Product-Piece

Figure 21: Consumption table, Input columns

Consumable Data			Product/Prosses - Data		Output			
Unit-Cost	Unit-Amount	Price/amount	Quantity or Hours Yearly	Hours or Pieces	Amount per Hour or Piece	Cost Added	Amount Yearly	Cost Yearly
320.00 kr	1 kg	320.00 kr	974.00	Pieces	0.1330	42.56 kr	129.5	41,453.44 kr
320.00 kr	25 kg	12.80 kr	608.53	Hours	6.0699	77.69 kr	3693.8	47,280.00 kr
857.00 kr	250 ml	3.43 kr	675.00	Pieces	0.2000	0.69 kr	135.0	462.78 kr
857.00 kr	250 ml	3.43 kr	667.00	Pieces	0.2000	0.69 kr	133.4	457.30 kr

Figure 22: Consumption table. Left: Consumables data column. Middle: Product/Process – Data column. Right: Output Columns.

4.3.4.4. Kit

The Kit worksheet contains a table where one can note the cost of parts that goes in to a product, see Figure 23.

WorkSheet	Product	ART.Nr	Description	Price
KIT	AC			800.00 kr
KIT	BFC			500.00 kr
KIT	BFCF			900.00 kr
KIT	Caliper			833.33 kr

Figure 23: Kit worksheet

4.3.5. Resources

4.3.5.1. Worker

The Worker worksheet is where the workforce is defined, the average salary is calculated (which is the salary used in the model for process steps that uses a worker) and the "worker rate loss" is calculated. The worksheet contains three tables and three charts, the General Input table, the worker table, the workforce table, the "Worker Rate as function of Experience" chart, the "Worker Time Comparison" chart and the "%Time" chart. The complete worksheet can be seen in Appendix E.

The structure of this worksheet differs in one fundamental aspect from other worksheets, it is here assumed that the workforce does not strictly work with the processes defined. This means that not all the cost of the worker salary will inherently be distributed in the cost model. To monitor the number of hours used in the model and the amount available it is shown in a graph "Worker Time Comparison". If for example all processes are defined and the time in the model is different from the time available, one might have the wrong workforce setup in the workforce table or not all processes performance by the workers are mapped.

General Input table, see Figure 24, is general data input which is used for every row in the Workforce table. There are four rows which must be defined.

- **Full time hours/year** T_{FT} is the amount of work hours for a worker full-time.

- **Rate at start of employment** R_1 is the pace or rate of effiecency of a newly employed worker in comparison to an experanced worker.

- **Experience needed for full rate** E_2 is the point at which an employed reaches full pace or rate of efficiency.

- **Should the total salary cost be distributed?** The input cell can have the value of "FALSE" or "TRUE", if the value of "FALSE" is set an average salary cost per hour will be used and if it is set to "TRUE" the total salary cost of the workforce will be distributed on the time plan in the model. If not all processes that the workforce is working with are defined it is recommended that it would be set to "FALSE".

The **Learning Curve** graph see Figure 24 illustrates how the learning curve is approximated for a worker based on the values R_1 and E_2. By making the production processes more or less complex for the workers these values can be controlled to see the effect it has on the process times and costs. The values of R_1 and E_2 or the function defined as the learning curve are just approximations based on the common knowledge of that there are a learning curve for most manual work. If the work is considered very easy and monotonous the value R_1 should be raised and E_2 lowered and if the contrary is true the opposite should be done. By integrating the Learning Curve and dividing by the experience (number of employed years) the average rate r_{avg} during employment can be calculated.

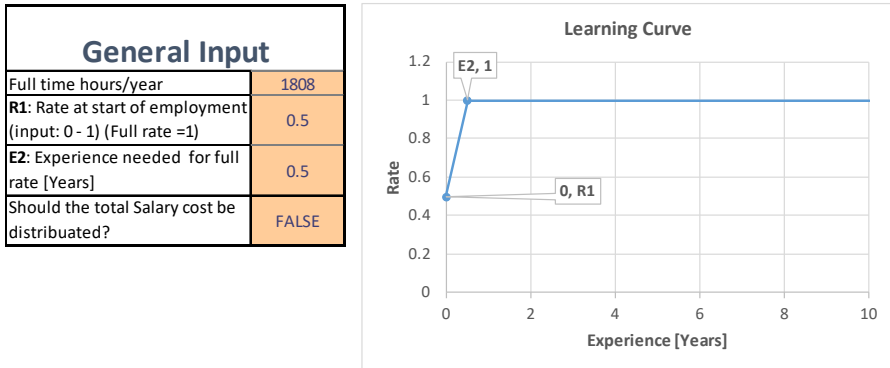***Figure 24:****. Left: General Input table. Right: Learning Curve which shows the worker rate as function of Experience.*

The workforce table in Figure 25 is where one can define the workforce, each row is an employee. The following bullet points describe the columns:

- **Name** is the name of the worker or some sort of identification.

- **Contract Type** is where one can define if a worker is employed or contracted.

- **Experience Full-Time [Years]** Ex_0 describes the number of years of experience the worker has of the work he does before the year of interest.

- **Fraction of Full-Time Present Year** Ex_+ describes the fraction of the full-time year the worker is going to be or have been working the year that is of interest.

- **Salary Hourly** cr_{sws} is the hourly salary for the worker.

- **Experience After this Year** Ex is the experience after the year of interest and is calculated by Equation 4.28.

$$Ex = Ex_0 + Ex_+ \qquad \text{\textit{Equation 4.28}}$$

- **Rate Avg.** r_{avg} is the average rate of a worker during the time of employment, after the year of interest and is calculated by Equation 4.29 if $Ex < E_2$ and by Equation 4.30 if $Ex > E_2$

$$r_{avg} = \frac{R_1 + \left(R_1 + \dfrac{1 - R_1}{E_2} * Ex\right)}{2} \qquad \text{\textit{Equation 4.29}}$$

$$r_{avg} = \frac{\left(\dfrac{1 + R_1}{2}\right) * E_2 + 1 * (Ex - E_2)}{Ex} \qquad \text{\textit{Equation 4.30}}$$

- **Rate Loss** $q_{pw.avg}$ is the average rate loss during time of experience after the year of interest and is calculated by Equation 4.31.

$$q_{pw.avg} = 1 - r_{avg} \qquad \text{\textit{Equation 4.31}}$$

- **Weighted Loss** $q_{pw.w}$ is the rate loss weighted by the fraction on the year of interest that the worker is working. This is calculated by Equation 4.32.

$$q_{pw.w} = r_{avg} * Ex_+ \qquad \text{\textit{Equation 4.32}}$$

- **Total Hours this Year** TH is the number of hours the worker in question will work the present year.

$$TH = T_{FT} * Ex_+ \qquad \text{\textit{Equation 4.33}}$$

- **Total salary cost** C_{TH} is the total salary of the worker described on a row and is calculated by

$$C_{TH} = TH * cr_{sws}$$
<div align="right">*Equation 4.34*</div>

Name	Contract Type	Experience Full-Time [Years]	Fraction of Full-Time Now	Salary Hourly	Experience After Present Year
xx1	Contracted	0	50%	400.00 kr	0.5
xx2	Employee	10	100%	300.00 kr	11
xx3	Employee	5	100%	300.00 kr	6
xx4	Employee	20	100%	300.00 kr	21
xx5	Employee	15	100%	300.00 kr	16
xx6	Employee	15	100%	300.00 kr	16
xx7	Employee	15	100%	300.00 kr	16

Rate Avg.	Rate loss	Weighted Loss	Total Hours this Year	Total salary cost
0.750	0.2500	0.1250	904.0	361,600.00 kr
0.989	0.0114	0.0114	1808.0	542,400.00 kr
0.979	0.0208	0.0208	1808.0	542,400.00 kr
0.994	0.0060	0.0060	1808.0	542,400.00 kr
0.992	0.0078	0.0078	1808.0	542,400.00 kr
0.992	0.0078	0.0078	1808.0	542,400.00 kr
0.992	0.0078	0.0078	1808.0	542,400.00 kr
			11752	3,616,000 kr

Figure 25: *Workforce table. Left part of table. Lower: Right part of table.*

The worker table, see Figure 26 is where the Worker Loss and the salary used in the Processes and support processes are calculated. It also serves as a comparison to set the values in the worker worksheet in an appropriate way. The bullet points below describe the columns in the Worker table.

- **Process** is a key word to connect it in the power query.

- **Worker Loss Factor** q_{pw} is a loss factor acting on every process step using a Worker due to the loss in rate because of inexperience in the present or in the pass. q_{pw} is calculated by Equation 4.35.

$$q_{pw} = Avrage(q_{pw.w})$$
<div align="right">*Equation 4.35*</div>

- **CostRate Salary** c_{salary} is the cost of salary per hour for a worker, that will be used in the model processes. Depending on the input in the "**Should the total salary cost be distributed?**" row in the General Input table, will the c_{salary} be calculated in different ways. If the input is "TRUE" will the c_{salary} be calculated by Equation 4.36 and if the input is "FALSE" will it be calculated by Equation 4.37.

$$c_{salary} = \frac{\sum C_{TH}}{T_{plan}}$$
<div align="right">*Equation 4.36*</div>

$$c_{salary} = \frac{\sum C_{TH}}{\sum TH}$$ *Equation 4.37*

- **TimePlan** T_{plan} is the time plan for workers in the model which is collected from the TimePlan table in the TimePlan worksheet.

- **Model Salary Cost** C_{salary} is the salary cost distributed in the model and is calculated by Equation 4.38

$$C_{salary} = T_{plan} * c_{salary}$$ *Equation 4.38*

Process	Worker Loss Factor	CostRate Salary	TimePlan	Model Salary Cost
Worker	0.0267	307.69 kr	5704.1	1,755,096 kr

Figure 26: Worker Table

The Comparison charts, see Figure 27 shows what time and cost is available based on the input in the workforce table and what is actually used in the model yearly. These charts can be used to tune the inputs in the workforce table and the general input table to get a more accurate setup. If for instance not all processes are defined that the defined workforce does, the time available and time in model will differ. The same thing applies to the cost if not the "Should the total salary cost be distributed?" row in the General Input table is set to "TRUE".

If all processes that the workers defined does, are defined in the model, it could be more accurate to distribute all salary cost in the model (by setting the "Should the total salary cost be distributed?" row in the General Input table to "TRUE"). By doing so one would include the cost of random activities such as unscheduled meetings and other unproductive time that have not been included in the processes defined, on the costs affecting the products. On the other hand, if not all processes were defined for all products, the cost would be put on the wrong products, creating a worse and more inaccurate result.
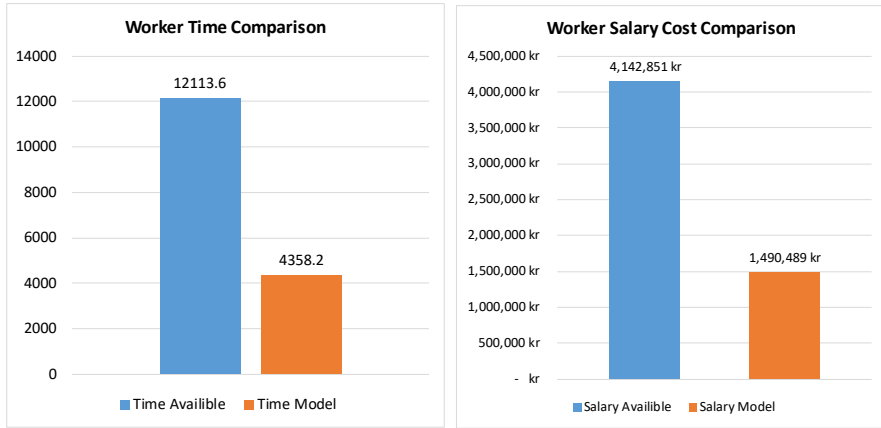
Figure 27: Comparison charts. Left: Worker Time Comparison. Right: Worker Salary Cost Comparison.

The "Total Hours this Year by Contract Type" chart shows the percentage of the defined workforce work hours that are for employees and contracted workers. This chart is to help to find a good setup when defining a workforce.
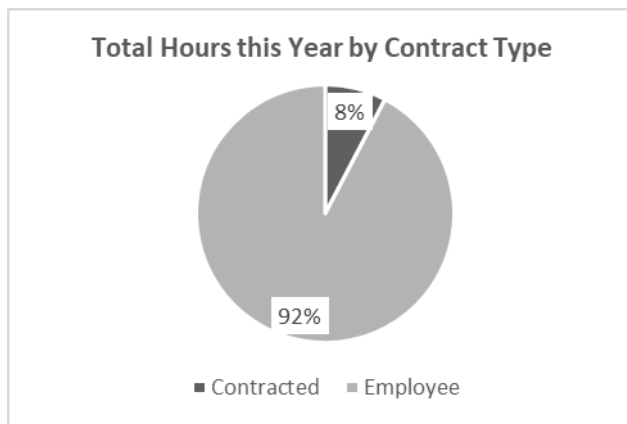
Figure 28: Total Hours this Year by Contract Type

The facility worksheet is where the parts of the facility is dedicated to different processes. There are two tables, the "Whole Facility" table and the "facility" table.

In the **whole facility** table, see Figure 29, the total yearly cost for climate, rent and any other cost associated with the facility is noted. In the second to last row the area of the facility is noted and the last row the price per area c_{Area} is automatically calculated.

The following bullet points explain the columns in the facility table, Figure 30:

- **Department** is a note to know which department the row is for.

- **Process** is the process an area to is dedicate to.

- **Area** A is the area in square meters that are available to be dedicated to processes.

- **Other cost** is an extra cost that one might want to contribute to the dedicated are.

- **Facility Cost Yearly** $C_{Facility}$ is the yearly facility cost of the area noted and is calculated by Equation 4.39.

$$C_{Facility} = c_{Area} * A \qquad \qquad \textit{Equation 4.39}$$

- **TimePlan** T_{plan} is the time plan on wich the cost of the facility should be distributed on. In the case of the facility it is the sum of the time plans for the retributive process which is automatically collected from the TimePlan table.

- **CostRate Added** cr_A is the added cost per hour on a process, in this case due to the facility, calculated by Equation 4.40.

$$cr_A = \frac{C_{Facility}}{T_{plan}} \qquad \qquad \textit{Equation 4.40}$$

Whole Facility	
Climate	2,000,000.00 kr
rent (sek/year)	10,000,000.00 kr
Other cost	0
Area (m^2)	10000
Sek/m^2/year	1,200.00 kr

Figure 29: Facility worksheet. whole facility table.

WorkSheet	Department	Process	Area	Other Cost	Facility Cost Yearly	TimePlan	CostRate Added
Facility	UH1	Travers	8		9,600.00 kr	338.1063367	28.39 kr
Facility	UH1	BFC_Dismantling	32		38,400.00 kr	856.8973453	44.81 kr
Facility	UH1	InsideWash	36		43,200.00 kr	838.3524424	51.53 kr
Facility	UH1	SandBlasting	25		30,000.00 kr	817.7833643	36.68 kr
Facility	UH1	Painting	16		19,200.00 kr	946.7288875	20.28 kr

Figure 30: Facility worksheet. facility table

4.3.5.3. Equipment

The equipment worksheet consists of three tables, the equipment table, the General input table and the CPI table. In the General input table, the cost of capital p and power cost c_{kWh} in kr/kWh is noted, see Figure 31. The CPI table consists of consumer price indexes (CPIs) for each month since January 1980. The index measures the average price trend for total private domestic consumption and is the usual measure of compensation and inflation calculations in Sweden [14]. The table is not automatically update so a URL to Statistics Sweden's website is provided in cell above the table which leads to a source were the CPIs can be copied from.

- **Equipment** is the simply the denotation of the equipment.

- **Process** is the process which the equipment is dedicated to.

- **Acquisition Cost** K is the cost of acquiring the equipment.

- **Acquisition Date** is the date the equipment was acquired.

- **Power Consumption [kw]** P is the consumption of power of the equipment, per hour, when used in a process.

- **Technical life [years]** n is the technical life of the equipment.

- **Salvage Value** S is the value of the equipment at the end of the technical life. Note that it must be inserted as present value since it does not get adjusted by inflation automatically.

- **Cost inflation Adj.** K_0 is cost of acquiring the equipment adjusted for inflation, in case an acquisition date was defined. It is calculated by Equation 4.41 were CPI_{NOW} is the most recent available consumer price index and CPI_{THEN} is the consumer price index for the month and year coresponding to the date of the acquisition. The CPIs are automatically collected from the CPI table.

$$K_0 = K * \frac{CPI_{NOW}}{CPI_{THEN}} \qquad \text{Equation 4.41}$$

- **Annuity Factor** a_f is calculated by Equation 2.4.

- **TimePlan** T_{plan} is the time plan for the specified process, which is collected from the "Sum" column in TimePlan table in the TimePlan worksheet.

- **Power CostRate Added** c_{power} is the cost of power per hour for the equipment when used, which is calculated by Equation 4.42.

$$c_{power} = c_{kWh} * P \qquad \text{Equation 4.42}$$

- **Depreciation CostRate Added** c_{dep} is the added cost per hour on a process, in this case due to the facility, calculated by Equation 4.43.

$$c_{dep} = \frac{(K_0 - S) * a_f}{T_{plan}} \qquad \text{Equation 4.43}$$

General Input	
Cost of Capital	5%
Power cost	0.22 kr

Figure 31: General Input table

Equipment	Process	Acquisition Cost	Aquisition Date	Power Consumption [kw]	Technical Life [years]
Travers1	Travers	231,000.00 kr			25
Travers2	Travers	200,000.00 kr			25
Pallställ	Receiving_Ship	60,000.00 kr			25
Truck Junghen	Receiving_Ship	100,000.00 kr			15
Truck Junghen	Receiving_Ship	100,000.00 kr			15
Pelarsvängkran	Travers	40,000.00 kr			25
Tvättmaskin Yt	PreWash	697,775.00 kr		37	20

Salvage Value	Cost Inflation Adj.	Annuity Factor	TimePlan	Power CostRate Added	Depreciation CostRate Added
	231,000.00 kr	0.0709525	271.6878932	- kr	60.33 kr
	200,000.00 kr	0.0709525	271.6878932	- kr	52.23 kr
	60,000.00 kr	0.0709525	96.20269385	- kr	44.25 kr
	100,000.00 kr	0.0963423	96.20269385	- kr	100.15 kr
	100,000.00 kr	0.0963423	96.20269385	- kr	100.15 kr
	40,000.00 kr	0.0709525	271.6878932	- kr	10.45 kr
	697,775.00 kr	0.0802426	338.2368285	8.14 kr	165.54 kr

Figure 32: Equipment table. Upper: Left part of table. Lower: Right part of table

4.3.6. Support Processes

The Support Processes consists of three worksheets, namely the Maintenance, Meetings and Repairs worksheets. The cost of the support processes cannot be directly connected to a product. Therefor the cost has to be divided by a process time plan to the be distributed on the retributive cycle times to then be put on a product. What is needed is the time of "Main Used" from the TimePlan table from the TimePlan worksheet. This time is used to distribute the cost of Repairs, Meetings and Maintenance. The reason for it to not be a cost on a process when blocked is because a process being blocked does not lead to a need for maintenance or repairs. Cost of meetings are put on the workers hourly rate when working with the processes (and not support processes) to be connected to a product.

It is important to note the difference between "Repairs" and "Maintenance" worksheet. The "Repairs" worksheet is made to specify repairs done on a specific equipment in infrequent matter, for example if a machine breaks down and needs to be repaired. These costs will then be distributed on the retributive equipment's whole technical life. Maintenance on the other hand

are the preventive maintenance that is done frequently, the costs of which ar reoccurring yearly.

4.3.6.1. Maintenance

The Maintenance table can be seen in Figure 33. Below the content of each column is presented.

- **Description** is the description of the maintenance to make it distinguishable.

- **Process** is the process that bears the cost of the maintenance. If the maintenance is done to a machine the process that should be chosen is the process that that equipment is dedicated to.

- **Worker or Outsourced?** Is an option if the maintenance is done by a factory worker or if the work is outsourced. If the maintenance is outsourced the time of the maintenance will not be added to maintenance time plan for "Worker" in the TimePlan table, just on the retributive process defined in the Process column. If the maintenance is done by the factory workers, the time will be added both to maintenance column for the retributive process and to the Worker row in the TimePlan table.

- **Time per Occasion** $t_{Maintenance}$ is the duration of the maintenance.

- **Cost if Outsourced** $C_{outsourced}$ is the total cost billed by the company which perform the maintenance if it is outsourced.

- **Frequency** $f_{Maintenance}$ is the number of times the maintenance takes place under the given period $Tf_{Maintenance}$

- **Frequency Period** $Tf_{Maintenance}$ is the period wich the frequency $f_{Maintenance}$ is defined for. The cell contains a drop-down list with the options of "/day", "/week" and "/year".

- **CostRate Salary** c_{ws} is the salary cost per hour of a worker and is automatically collected from the CostRate worksheet.

- **CostRate Main Blocked** c_B is the cost of the process per hour when blocked, which is the sum of rate for depreciation and facility for the retributive process which is automatically collected from the CostRate worksheet.

- **Cost per Hour** $c_{Maintenance}$ is the total hourly cost of the maintenance calculated by Equation 4.44.

$$\frac{C_{outsourced}}{t_{Maintenance}} + c_{ws} + c_B \qquad \text{Equation 4.44}$$

- **Frequency Yearly** $F_{Meeting}$ is the number of occasions per year the meeting is held and is calculated by collecting the value for the defined Frequency period from the Calender of Production table in the TimePlan worksheet and multiplying it with the defined Frequency, except if the chosen Frequency Period were "/year" then it is just the defined frequency.

- **Cost per Occasion** $co_{Maintenance}$ is calculated by Equation 4.45.

$$co_{Maintenance} = c_{Maintenance} * t_{Maintenance} \qquad \text{Equation 4.45}$$

- **Time Yearly** $T_{Maintenance}$ is the yearly time spent on a mintenance and is calculated by Equation 4.46.

$$T_{Maintenance} = t_{Maintenance} * F_{Maintenance} \qquad \text{Equation 4.46}$$

- **Cost Yearly** is calculated by Equation 4.47.

$$C_{Maintenance} = F_{Maintenance} * co_{Maintenance} \qquad \text{Equation 4.47}$$

- **TimePlan** T_{plan} is the time plan on which the cost of the maintenance should be dedicated to. In this case it is the number of hours from "Main Used" for the retributive process which is noted in the Process column.

- **CostRate Added** is the added cost per hour on a process, in this case due to maintenance, calculated by Equation 4.48.

$$c_A = \frac{C_{Maintenance}}{T_{plan}} \qquad \text{Equation 4.48}$$

Description	Process	Worker or Outsourced?	Time per Occasion	Cost if Outsourced	Frequency	Frequency Period
Fylla på sand och f	SandBlasting	Worker	0:05:00		3	/Week
daily maintenance	PreWash	Worker	0:15:00		1	/Day
weekly maintenan	PreWash	Worker	1:30:00		1	/Week
Change Filter	InsideWash	Worker	0:10:00		60	/Year
tömning vattenavs	InsideWash	Worker	0:25:00		3	/Year
Destilator	InsideWash	Worker	3:30:00		24	/Year
Mätning PH-värde	InsideWash	Worker	0:10:00		24	/Year

CostRate Salary	CostRate Main Blocked	Cost per Hour	Frequency Yearly	Cost per Occasion	Time Yearly	Cost Yearly	TimePlan	CostRate Added
342.00 kr	62.66 kr	404.66 kr	141	33.72 kr	11:45:00	#########	608.5347519	7.81 kr
342.00 kr	214.39 kr	556.39 kr	235	139.10 kr	58:45:00	#########	156.6872545	208.62 kr
342.00 kr	214.39 kr	556.39 kr	47	834.58 kr	70:30:00	#########	156.6872545	250.34 kr
342.00 kr	324.70 kr	666.70 kr	60	111.12 kr	10:00:00	#########	472.4864684	14.11 kr
342.00 kr	324.70 kr	666.70 kr	3	277.79 kr	1:15:00	833.38 kr	472.4864684	1.76 kr
342.00 kr	324.70 kr	666.70 kr	24	2,333.46 kr	84:00:00	#########	472.4864684	118.53 kr
342.00 kr	324.70 kr	666.70 kr	24	111.12 kr	4:00:00	#########	472.4864684	5.64 kr

Figure 33: Maintenance table. Upper: Left part of table. Lower: Right part of table

4.3.6.2. Meetings

In Figure 34 the Meetings table is shown. The content of each column is described in the bullet points below.

- **Description** is the description of the meeting to make it distinguishable.

- **Nbr of Workers** $NBR_{Meeting}$ is the number of workers that is attending the meeting.

- **Time per Occasion** $t_{Meeting}$ is the duration of the meeting.

- **Frequency** $f_{Meeting}$ is the number of times the meeting takes place under the given period $Tf_{Meeting}$

- **Frequency Period** $Tf_{Meeting}$ is the period wich the frequency $f_{Meeting}$ is defined for. The cell contains a drop-down list with the options of "/day", "/week" and "/year".

- **CostRate Salary** c_{ws} is the salary cost of a worker and is automatically collected from the CostRate worksheet.

- **Frequency Yearly** $F_{Meeting}$ is the number of occasions per year the meeting is held. This is calculated by collecting the value for the defined frequency period from the Calender of Production table in

the TimePlan worksheet and multiplying it with the defined Frequency, except if the chosen Frequency Period were "/year" then it is just the defined frequency.

- **Cost Per Occasion** $co_{Meeting}$ is calculated by Equation 4.49.

$$co_{Meeting} = c_{ws} * t_{Meeting} * NBR_{Meeting} \qquad \text{Equation 4.49}$$

- **Time Yearly** $T_{Meeting}$ is the amount of worker time spent on this meeting yearly and is calculated by Equation 4.50.

$$T_{Meeting} = t_{Meeting} * NBR_{Meeting} * F_{Meeting} \qquad \text{Equation 4.50}$$

- **Cost Yearly** $C_{Meeting}$ is calculated by Equation 4.51.

$$C_{Meeting} = F_{Meeting} * co_{Meeting} \qquad \text{Equation 4.51}$$

- **TimePlan** T_{plan} is the time plan on wich the cost of the meeting should be distributed on. In the case of meetings, it is the number of hours of the workers in the processes which is automatically collected from the TimePlan table, row "Worker" column "Main Used" in the TimePlan Worksheet.

- **CostRate Added** c_A is the added cost per production hour in the processes of a worker due to Meeting, calculated by Equation 4.52.

$$c_A = \frac{C_{Meeting}}{T_{plan}} \qquad \text{Equation 4.52}$$

Description	Nbr of Workers	Time per Occasion	Frequency	Frequency Period	CostRate Salary
mondaymeeting	4	0:30:00	1	/Week	307.6923077

Frequency Yearly	Cost per Occasion	Time Yearly	Cost Yearly	TimePlan	CostRate Added
47	615.38 kr	94:00:00	28,923.08 kr	5335.626028	5.42 kr

Figure 34: Meeting worksheet. Left part of table. Lower: Right part of table

4.3.6.3. Repairs

In Figure 35 the Repairs table is shown. The content of each column is described in the bullet points below.

- **Description** is the description of the repair to make it distinguishable.
- **Date** is the date of the repair.
- **Cost** K_{rep} is the cost of the repair.
- **Downtime** t_{rep} is the duration of downtime associated with the repair.
- **Equipment** is a drop-down list where one can choose the equipment that the repair has been performed on. The list is collected from the equipment worksheet.
- **Technical Life [years] n** is the technical life of the chosen equipment and is automatically collected from the equipment worksheet.
- **Cost Inflation Adj.** K_{rep0} is the cost associated with the repair adjusted for inflation in case a date was defined and is calculated by Equation 4.53 were CPI_{NOW} is the most recent available consumer price index and CPI_{THEN} is the consumer price index for the month and year coresponding to the date of the repair. The CPIs are automatically collected from the CPU table in the equipment worksheet.

$$K_{rep0} = K_{rep} * \frac{CPI_{NOW}}{CPI_{THEN}} \qquad \text{Equation 4.53}$$

- **Annuity Factor** a_f is the annuity factor associated with the equipment and is also automatically looked up in the equipment worksheet.
- **Process** is the associated process to the equipment and is automatically looked up in the equipment worksheet.
- **TimePlan** T_{plan} is the time plan on wich the cost of the repair should be distributed on. In this case it is the number of hours from "Main

Used" for the retributive process which is noted in the Process column.

- **CostRate Main Blocked** c_B is the cost of the process per hour when blocked, which is the sum of rate for depreciation and facility for the retributive process which is automatically collected from the CostRate worksheet.

- **Cost Yearly** C_{Repair} is what the repair cost would be if it would have been an annual cost and is calculated by Equation 4.54.

$$C_{Repair} = a_f * K_{rep0} + \frac{c_B * t_{rep}}{n}$$

Equation 4.54

- **CostRate Added** c_A is here an hourly cost that will be added to a process that uses the equipment that has been repaired and is calculated by Equation 4.55.

$$c_A = \frac{C_{Repair}}{T_{plan}}$$

Equation 4.55

- **Downtime Yearly** is calculated by Equation 4.56.

$$\frac{t_{rep}}{n}$$

Equation 4.56

Description	Date	Cost	Downtime	Equipment	Technical Life [years]	Cost Inflation Adj.
UH-nr: 116 ,UH-benämr	2015-10-20	350.00 kr	1:00:00	Blästerskåp 840	20	350.00 kr
UH-nr: 196 ,UH-benämr	2015-11-12	350.00 kr	1:00:00	Tvättmaskin Inre 593	20	361.09 kr
UH-nr: 93 ,UH-benämni	2015-11-13	600.00 kr	0:24:00	Målningsbox UH1 838	15	619.01 kr
UH-nr: 320 ,UH-benämr	2015-12-16	1,035.00 kr	0:41:24	Tvättmaskin Inre 593	20	1,066.23 kr

Annuity Factor	Process	TimePlan	CostRate Main Blocked	Cost Yearly	CostRate Added	Downtime Yearly
0.080242587	SandBlasting	608.5347519	31.67 kr	29.67 kr	0.048753796	0:03:00
0.080242587	InsideWash	472.4864684	58.93 kr	31.92 kr	0.067560016	0:03:00
0.096342288	Painting	169.650437	18.50 kr	60.13 kr	0.354435006	0:01:36
0.080242587	InsideWash	472.4864684	58.93 kr	87.59 kr	0.185380768	0:02:04

Figure 35: *Repairs table. Upper: Left part of table. Lower: Right part of table*

4.3.7. CostRate

The CostRate Worksheet consists of two tables, the CostRate table and the Worker table, none of which have any input columns. The sole purpose of this entire worksheet is to act as a source of reference to the Process and the support processes worksheets. Looking in the cells there are no calculations since all the operations to calculate the hourly rates are done in the power query.

The Worker table is the exact same table as the one from the Worker worksheet with the same name. The reason for this table also being present in this worksheet is to pass the worker loss factor through to the process worksheet. The reason for this is to not have to many instances of references and by that making the model more intuitive.

The CostRate table, see Figure 36 is were all hourly rates for the processes and resources are summarized. In general, the operation done by the power query to get the hourly rates are aggregation by the retributive processes of the "CostRate Added" columns mentioned under the other worksheets. The columns in the CostRate table are explained in the bullet points below.

- **Process** is the denotation of the process, here the resources "Worker", "Wagon" and "Travers" are viewed as processes with the same names.

- **Power** is the sum of the equipment power cost (called "Power CostRate Added" in the Equipment table), for the retributive process.

- **Depreciation** is the sum of the equipment depreciation cost (called "Depreciation CostRate Added" in the Equipment table), for the retributive process.

- **Salary** is the hourly salary cost for a worker which has its source in the Worker table in the Worker worksheet.

- **Facility** is the cost of the facility per hour for each individual process which has its source in the Facility worksheet.

- **Consumables** is the sum of the cost of consumables per hour, of consumables that are consumed by process (see chapter 4.3.4.3), for the retributive process, which has its source in the consumption Worksheet.

- **Maintenance** is the cost of maintenance per hour for the retributive process which has its source in the maintenance worksheet.

- **Meeting** is the cost of meeting per hour for the retributive process which has its source in the meeting worksheet.

- **Repairs** is the cost of repairs per hour for the retributive process which has its source in the repairs worksheet.

It is important to note that the cost of depreciation, facility and salary are costs that lay on both the processes and on the support processes. This results in some of the yearly depreciation, facility and salary costs to ends up in the maintenance, meetings and repair column. The support processes are both a source of input to- and a recipient of- hourly costs in the CostRate table.

For a specific process in the process worksheet when "Main used" is "True" the cost of the whole row for that process from the CostRate table will be subjected on that time. On the other hand, if the column "Main Blocked" is true the only the cost of the depreciation and facility will burden the time. The reason for this is simply that the cause for needing maintenance and repairs is because of wear on the equipment which is happening when the equipment is used and not just blocked.

CostRate [SEK/Hour]								
Process	Power	Depreciation	Salary	Facility	Consumables	Maintenance	Meeting	Repairs
BFCF_ASSEMBLY	- kr	10.82 kr		34.22 kr				
BFC_DISMANTLING	- kr	22.87 kr		44.81 kr				
BFC_FINALASSEMBLY	- kr	46.34 kr		27.41 kr				
BFC_PREASSEMBLY	- kr	13.24 kr		42.06 kr				
INSIDEWASH	13.64 kr	230.39 kr		51.53 kr	118.80 kr	365.27 kr		8.86 kr
BFC_TESTING	0.22 kr	149.42 kr		34.76 kr		234.56 kr		13.20 kr
GRINDINGANDINSPECTION	0.95 kr	16.77 kr		84.31 kr				
PAINTING	0.22 kr	35.49 kr		20.28 kr		11.04 kr		5.04 kr
MATERIALHANDLING				181.62 kr				
PREWASH	8.14 kr	148.79 kr		60.59 kr	54.78 kr	392.96 kr		9.66 kr
RECEIVING_SHIPPING	- kr	492.90 kr		1,516.76 kr				8.70 kr
SANDBLASTING	0.29 kr	26.49 kr		36.68 kr	86.26 kr	78.05 kr		0.64 kr
SANDWASH	3.08 kr	15.74 kr		32.96 kr	37.40 kr	42.93 kr		5.09 kr
WORKER			307.69 kr	5.68 kr			5.42 kr	
WAGON	- kr	2.89 kr		2.11 kr				
TRAVERS	- kr	98.84 kr		28.39 kr				

Figure 36: CostRate table

4.3.8. Product Overhead

The Product_Overhead worksheet contains one single table were costs that will be distributed as overhead on the products total cost except overhead can be noted, see Figure 37.

WorkSheet	Description	Cost per Year
Product_Overhead	Chefer	1,000,000.00 kr

Figure 37: Overhead worksheet

The overhead rate OHR is calculated by Equation 4.57, were OHC is the sum of the overhead costs per year and $TCBOH$ is the total cost before overhead. The total manufacturing cost tmc of a product is the calculated by Equation 4.58 were $tmcbo$ is the product piece cost before overhead.

$$OHR = \frac{OHC}{TCBOH}$$
<div align="right">*Equation 4.57*</div>

$$tmc = tmcbo * (1 + OHR)$$
<div align="right">*Equation 4.58*</div>

4.3.9. Result

In the result worksheets all data is aggregated and shown graphically in different types of charts, here the content of these worksheets will be presented. To get an overview of all the different results worksheets they are presented on the original format in Appendix F. Not all charts from the result worksheets will be shown here and the ones being presented have been modified to only show the graphical aspects and not all data that they originally contain. As stated in the beginning of this chapter (4), the data shown in the graphs are not the correct data for analyzing Faiveley current situation.

In the result pages one can observe and compare different costs, products, processes, consumptions, consumables, process times and much more. This information makes it possible for management to make strategic decisions, for production planning to plan the production, for production development to find areas of improvements, for quality department to find the biggest quality issues, for purchasers to determine the yearly amounts of different consumables and so forth.

4.3.9.1. Profit_Revenue

The Profit_Revenue worksheet consists of three charts, the Revenue chart, the Product Revenue chart, and the One Piece chart. The Revenue chart shows the total revenue and cost of all products being sold in one stacked column chart. The Product revenue chart, Figure 38, displays the revenue for the individual products in stacked columns divided in a section of profit and a section of cost. Also in the table below, the profit margin for each product is shown. The same is displayed in the One piece chart, Figure 39, as in the Product revenue chart, but for one piece of each individual product. The profit margin has here been excluded in the table below since it would be redundant.
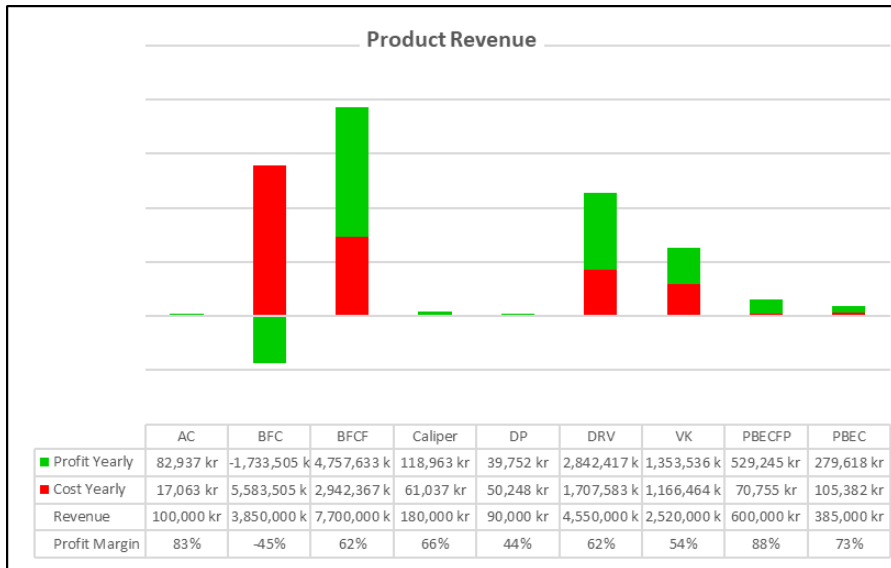

Product Revenue

	AC	BFC	BFCF	Caliper	DP	DRV	VK	PBECFP	PBEC
■ Profit Yearly	82,937 kr	-1,733,505 k	4,757,633 k	118,963 kr	39,752 kr	2,842,417 k	1,353,536 k	529,245 kr	279,618 kr
■ Cost Yearly	17,063 kr	5,583,505 k	2,942,367 k	61,037 kr	50,248 kr	1,707,583 k	1,166,464 k	70,755 kr	105,382 kr
Revenue	100,000 kr	3,850,000 k	7,700,000 k	180,000 kr	90,000 kr	4,550,000 k	2,520,000 k	600,000 kr	385,000 kr
Profit Margin	83%	-45%	62%	66%	44%	62%	54%	88%	73%

Figure 38: Profit Revenue chart

Figure 39: *One-Piece chart*

4.3.9.2. Product_Cost

The Product_Cost worksheet consists of two charts, the Product Cost chart and the Product Process Cost chart. The Product Cost chart, Figure 40, shows the total cost of the different products in stacked columns consisting of overhead, raw material, consumables and process cost. The Product Process cost chart, Figure 41, shows the total cost of the processes in stacked columns where the different stacks are the different processes.
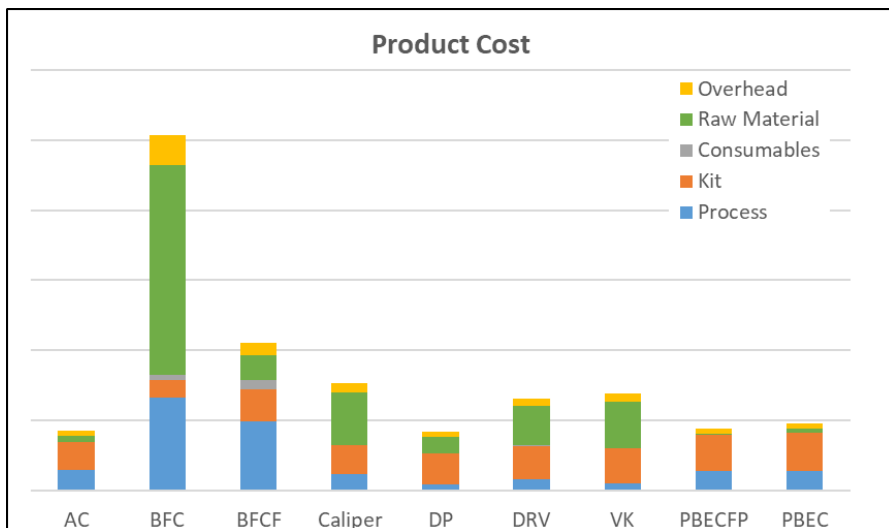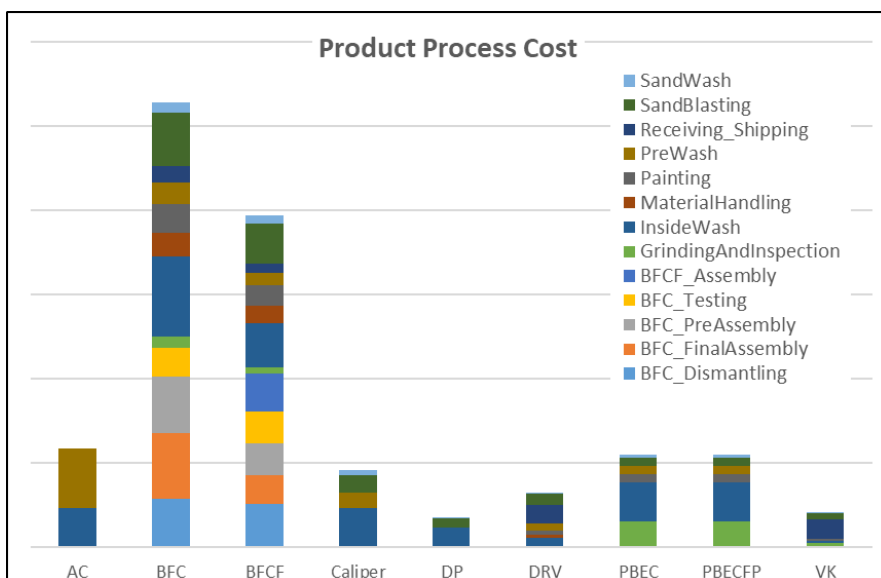
Figure 40: *Product Cost Chart*

Figure 41. *Product Process Cost chart*

4.3.9.3. Process

The Process worksheet consists of four charts that are grouped in two pairs of charts with one stacked column and one pie chart in each group. The two pairs are x-product Processes chart and the x-product x-process chart, where the x-product and x process can be chosen via two slicers, see Figure 42. The x-product Processes chart are displayed in Figure 43 were the x-product is set to BFCF. The chart shows the cost of every individual process that goes in to a specific product and what usage of resources that goes in to that cost. It also shows, in the pie chart, the total percentages of different resources contributing to the total process cost. The x-product x-process chart looks the same as the x-product Processes chart but shows only one process and each individual step in that process, for one product.
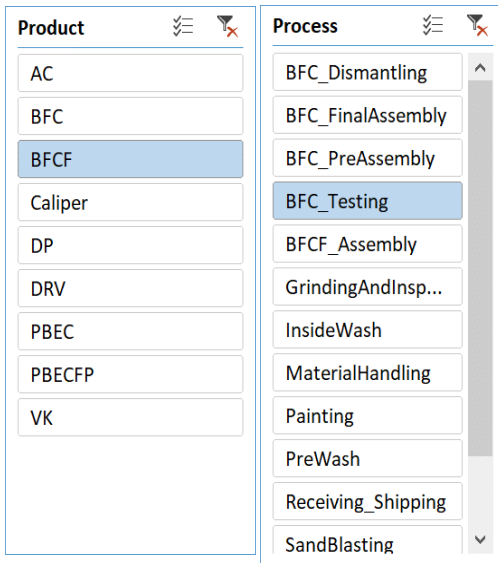

Figure 42: *Slicers in the Process worksheet. Left Product-slicer. Right: Process-slicer*
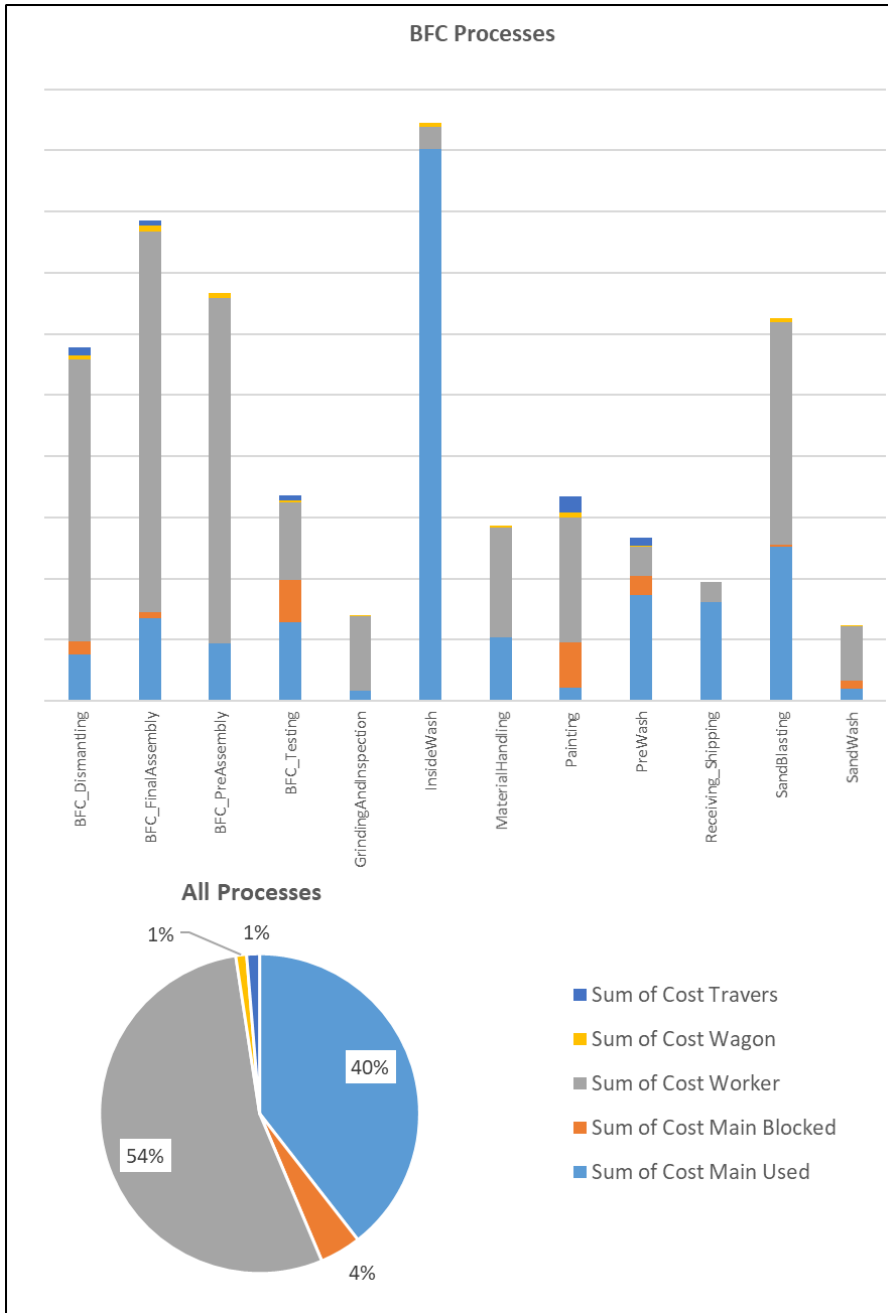
Figure 43: *x-product Processes chart*

4.3.9.4. Losses

The Losses worksheet consists of four charts, the Total Process Cost chart, the Total Raw Material cost chart, the product-x process losses chart and the product-x detailed losses chart, were product-x is chosen with a slicer. The charts illustrate the cost of the losses for different products and processes. The Total Process Cost chart shows the cost of the processes that goes into one piece of the different products. The cost is showed in stacked columns which is divided in to two parts, cost of loss and nominal cost, see Figure 44. The Total Raw Material Cost chart, Figure 45, is similar to the Total Process Cost chart but shows the cost of raw material for different products. The columns are divided in to losses and nominal cost to give and understanding of what cost the different loss factors contribute to. The product-x process losses chart shows the nominal cost and cost of losses for each product for a specific product chosen in the slicer. The product-x Detailed losses chart show the cost that each loss factor contributes to in a process the product chosen in the slicer.
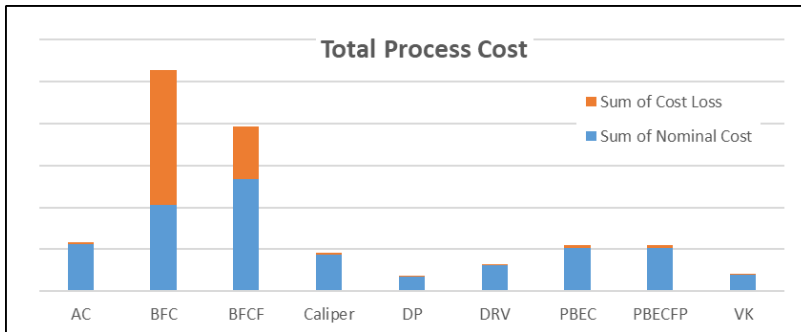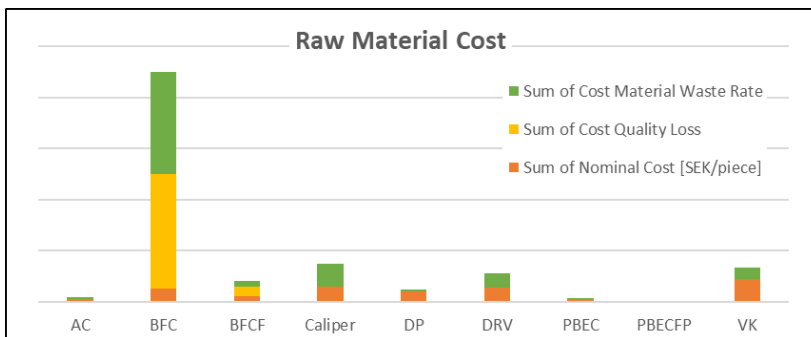

Figure 44: *Total Process Cost chart*

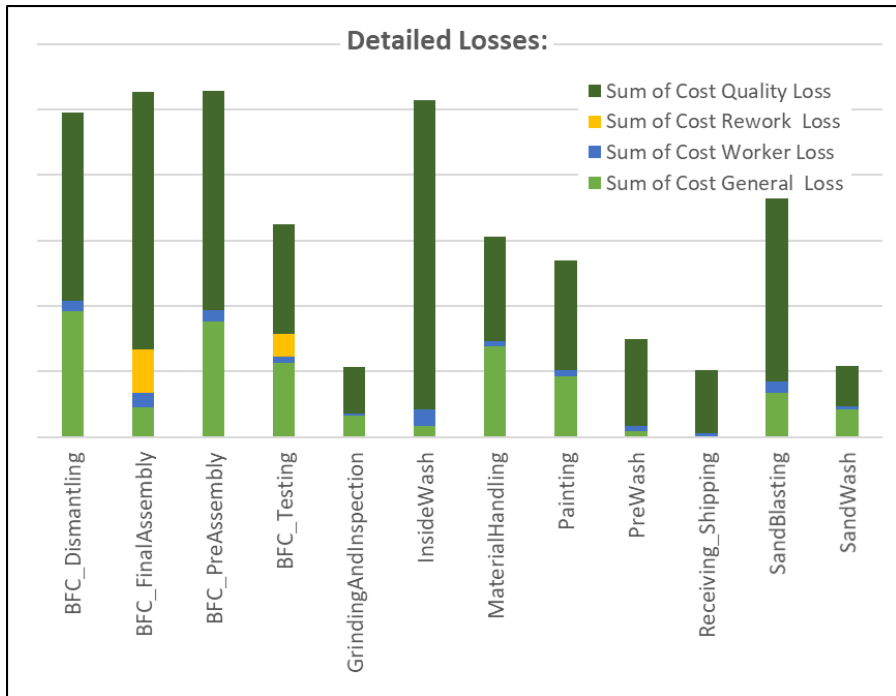**Figure 45:** *Total Raw Material Cost chart*

Figure 46: *Detailed Losses chart*

4.3.9.5. Time

The Time worksheet consists of three charts two of which controlled by a product-slicer as seen in Figure 42. The three charts are the Time Yearly chart, the Time One Piece chart and the Worker Time per Process chart. The charts visualize the time needed for different products, in processes and by workers and can amongst other things be used for planning purposes and to analyze utilization of different resources. In Figure 47 the Time Yearly chart is shown, and it illustrates how much time is needed by different resources and what activities the time is spent on. In Figure 48 the Time One Piece chart shows the process time that is needed for different products divided in stacked column that show how much time is needed by a worker and how much time that is needed without.
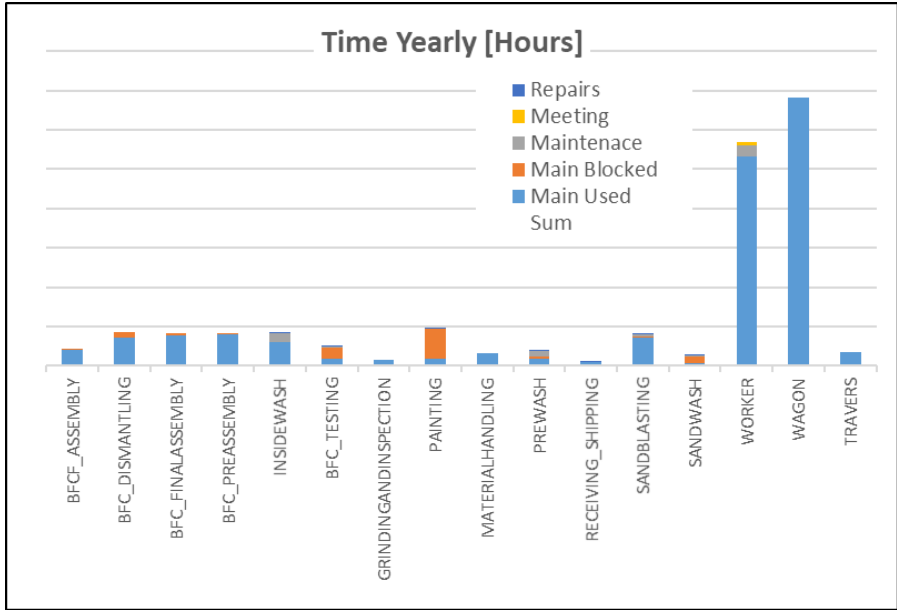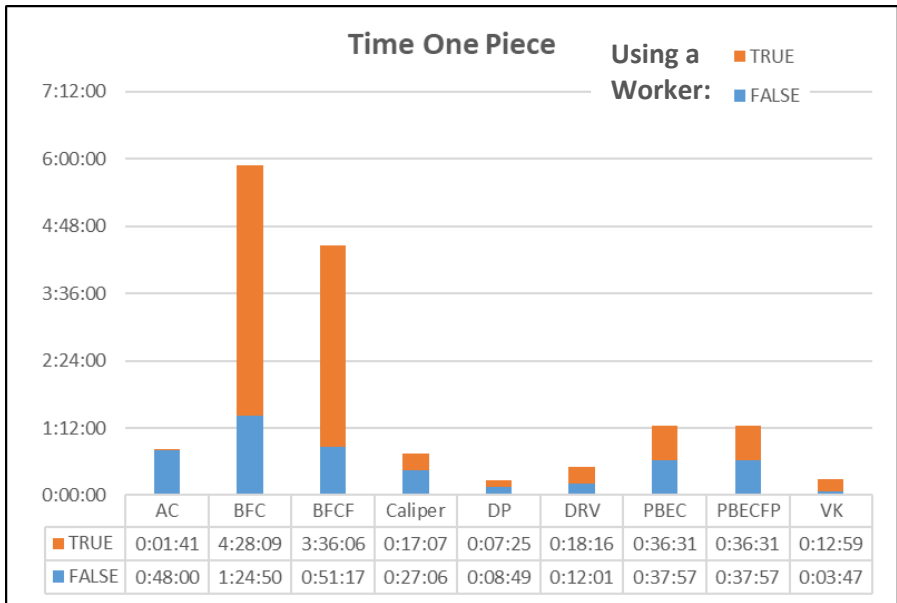
Figure 47: *Time Yearly chart*

Figure 48: *Time One Piece chart*

4.3.9.6. Rates_Processes

The Rates_Processes worksheet consists of two charts; the Rates chart and the Processes Yearly Cost chart. The Rates chart, Figure 49, is simply a chart of the values in the CostRate table from the CostRate Worksheet. The Process Yearly Cost chart, Figure 49 shows the yearly cost accumulated by the processes by different products. It is simply the aggregation of the different steps from the processes table multiplied with the yearly quantities for the retributive products. It can be observed that it does not have to be the process with the highest rate that has the highest yearly cost. A high rate can simply be an implication of a process not being used as much as other processes.
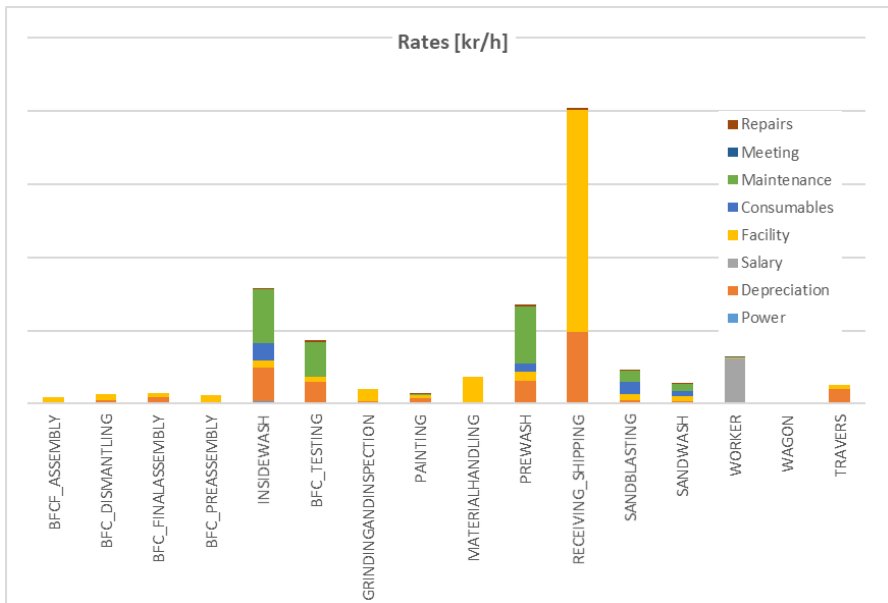

Figure 49: *Rates chart*
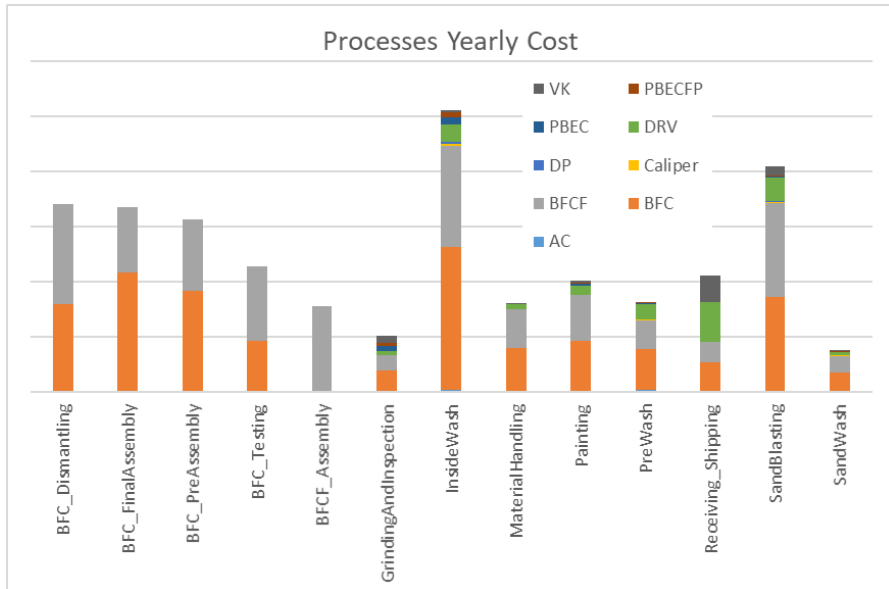
Figure 50: *Processes Yearly Cost chart*

4.3.9.7. Consumables

The Consumables worksheet consists of three charts; the Total Consumption chart, the Product-Piece Consumption cost chart and the Process-Hour Consumption cost chart. The charts display the cost of consumption of consumables from different angles, the Total consumption chart displays the total cost of the different consumables and the total cost of all consumables on a yearly basis. The Product-Piece consumption chart show the consumption of consumables dedicated to products, see Figure 51. The Process-Hour Consumption cost chart, Figure 52, show the cost of consumption of consumables dedicated to processes.

Figure 51: *Product-Piece Consumption cost chart*

Figure 52: *Process-Hour Consumption cost chart*
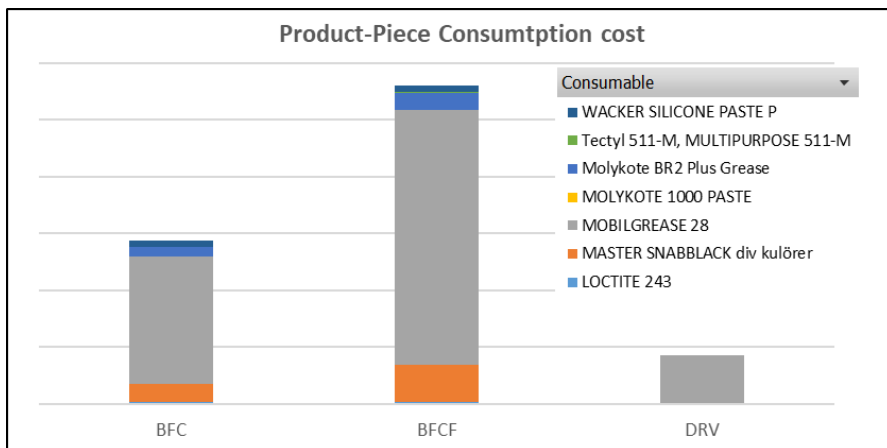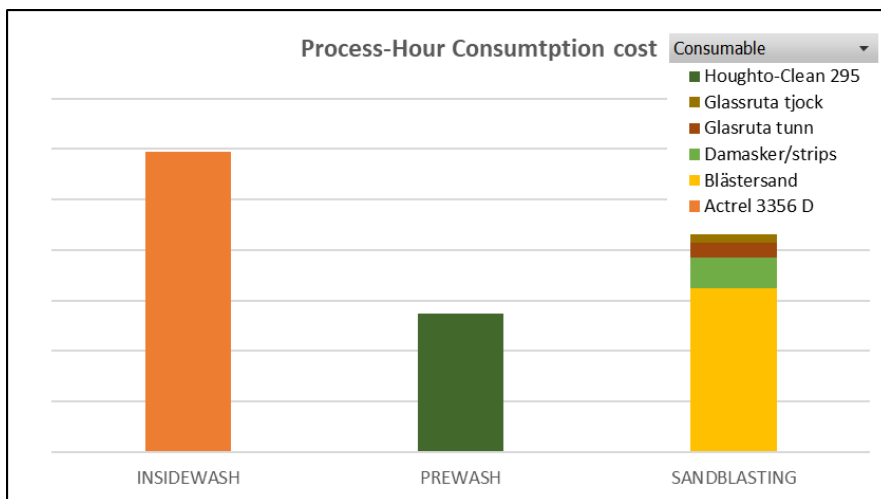
5. Data Gathering and Refinement

In this chapter, the data gathering proceedings, sources, and refinements are presented. The data is the underlying source of input to the Cost Model System described above. The data gathered comes from multiple sources and entities at Faiveley. Not all aspects or data gathered will be presented since some of the data was confidential. Since the focus of this thesis are the products BFC and BFCF, data regarding these products have gotten the most attention but since these products share processes with other products, these other products were also taken into consideration.

A general observation regarding data and thereby administration at Faiveley is that there are quite a few administrative systems used at the moment. The ERP-system, which was implemented only a few years back but already then was over 10-years-old, is described by employees as a big step forward from the old one although the choice of system can be questioned. It has to be mentioned that this decision was made on the highest level in the company and was not something that the Landskrona site had mush say in. Regardless the ERP-system is not intuitive and seems to have deficiencies in regards of its search engine. Multiple employees' states that it is not used correctly, or it does not support the functionality needed at Faiveley. To create the functionality needed there are multiple support systems, access files and excel spreadsheets. Furthermore, there is a program for keeping track of maintenance and equipment, a program for purchasing, one for the bookkeeping, one for clocking in and out, and so on. All serves a purpose, but few of these systems work well together and communicate automatically. Very few people at the Faiveley seemed to have a clear view of how all systems work together. This made the data gathering tedious and complex. It was also observed that random things and miss communications happened very frequently. This seemed to lead to delays for customers and "firefighting". Many conflicts were observed between departments and people, which were clearly a cause of all this. In turn this seemed to make people bitter and to work in their own functional silos. It also disabled people from working with continuous and lasting improvements.

5.1. Time Study System

No time studies had been done before this thesis of the overhaul process for the BFC and BFCF products. To assist the work of conducting a time study a tool called "Time study system" was created in excel with a VBA program. The tool eliminates the need of stop watches and makes it easier to keep track of multiple processes at a time. Below in Figure 53 the interface of the program is displayed, in the background the worksheet with the table ought to be filled can be seen.

The program works by using the built-in clock of the computer and when the "Start" button is pressed it puts that time in a cell for the retributive process. After this the button switches color to red and caption to "Stop". If pressed again it sets the current time in a cell next to the start time. The duration is then calculated automatically by simply taking the difference of the two. In extension to this, sub process can be added and be used to take time of a process within another. This can for example be handy if a particular issue occurs worth to be noted. By pressing the turquoise button, a new, so-called time recording is added, in Figure 53 two of these have been added. For each of these there can be a description, a process, an operator, a class and so forth, specified. When a time recording is done, the needed fields are filled, and the times are stopped, the time recording can be closed by pressing the button "Done!". In Figure 53, it can be observed that one time recording (ID00001) have been completed and closed.

Figure 53: *Time Study System Interface*

5.2. Time Study

The time study was mainly conducted on one type of BFC and BFCF. Because of limited time and resources, conducting a time study of all, close to 50 variants were deemed impossible. The variants subjected to the time study are types that are overhauled in vast amounts yearly and are there for a good basis for BFCs and BFCFs in general. On the other hand, by only looking at one type of BFC and BFCF the issues with the great variations of products handled in UH1 is not seen in the numbers. Problems as not having the right instruction manual, parts and/or tools were frequently emphasized by the personal, but this is not seen in the times since the product that were in question in case of the time study did not have these issues. Another aspect, in the same regard, is that the workers knew how the overhaul should be done. This eliminates the influence of the workers having to learn the overhaul procedure.

It has to be taking in to account that the overhaul process is not as an ordinary production process of new products. In an overhaul process of old and used products, different issues and problems occur continuously. Adding to this the setup of the workshop at Faiveley can be viewed more as a functional workshop than a process flow production. The different processes conducted on a product have a specific order, but what the workers choose to do has not. A worker might make one product from start to end or he might sandblast many products from the same batch. He can also choose to start the washing on one batch wile he works on dismantling another. All this makes the overhaul process complex and therefore making a time study of the overhaul process complex as well. The time study system was partially created to help with these issues, making it easier to administrate and take time, but still, errors occurred. Errors in starting and stopping the time often created a delay, but this is deemed negligible since errors in the beginning are approximately in the same proportion as the error at the end which mean that the time was both started and stopped to late. Also, since the workers seek to gain time by doing tasks like starting or loading a machine while passing it, it is somewhat hard to distinguish the tasks and to figure out what the workers do without intervening in the work.

The indeterministic nature of the overhaul process made the cleaning and structuring of the data from the time study a challenging task. All data consisting of approximately 300 individual times, needed to be structured and grouped in to the right processes and steps. For each step, the average time and a shortest time were used in the cost model. Some recordings, such as the nominal cycle time of the washing machines could be directly taken

from the setting on the machines. The output after the cleaning and grouping the data were approximately 134 processes steps that could be inserted to the Cost model system. From the time study, the time of some of the maintenance work could also be used in the cost model.

The observer effect has a big influence when doing a time study like this, it takes quite some time before the workers on the factory floor becomes convenient with the study. It is important to interact and clearly explain the reasons for doing the study. The reasons here were to get an as accurate understanding of the processes as possible, to use the data to be able to argue and explain in other entities of the company what the issues really are on the factory floor.

For the Cost model system to work in an accurate way, all or at least most cycle times for products that shared processes with the BFCs and BFCF would be needed. To deal with this, old time-studies on other products were relied up on. These did though not have an as thorough work behind them. For most of these only one observation of the process cycle times usually was observed, which makes the average and nominal time to be set to the same in the time study system. This was also emphasized by the workers, whom stated that when time studies usually were conducted they were only done on one piece and by that the issues that occurred were generally not observed. On other products and processes, were no time study had been conducted at all, estimates were made if the particular time were deemed to have a big influence on the results in the cost model system.

5.3. Consumables

A list was made of most of the consumables consumed in UH1. This list was partly extracted from a software used at Faiveley for risk assessing and emergency information regarding chemicals and partly made by observing and writing down the different consumables used. The list was handed to a purchaser of consumables that partly filled it with unit-prices and unit-amounts. Those consumables remaining were gathered from other employees as the consumption of which were added in the cost model.

The consumption of the consumables was apprehended in two different ways; by measuring the consumption directly as is occurred or with help of an employee, going through the order history of a full year and adding up the consumption for a particular consumable. The measuring was done by using a scale and measuring the weight of the can or tube for the retributive consumable before and after consumption. A couple of repetitions were

made, and the average was used. These consumptions were directly dedicated to products in the model. The yearly consumptions from the order history were in general dedicated to processes in the Cost model system, meaning that the cost of which is laid on products based on how much time they use a process a consumable is dedicated to.

5.4. Quantities

Two scenarios with yearly quantities were created, one based on order history denoted S1 and one based on future estimates S2. For the first scenario, the order history was gathered from the ERP-system by the supply chain department. Orders were categorized and aggregated by product family for the most previous full year. The following product families were used: BFC, BFCF, Caliper, AC, DP, VK, PBECFP, PBEC and DRV. The quantities for the retributive product families and scenarios can be seen in Figure 69.

5.5. Equipment

Equipment data were gathered by first listing the equipment observed to be used in the overhaul process. The acquisition values of the equipment were then gathered from the bookkeeping, and for those not found, estimations were made. For some of the equipment there were an identification number. In some few cases this could be used to find the receipt or the quotation, but most often the numbers and denotation were found to be inconsistent. The main reason for this seems to be that there are many administrative systems that are to be used when an investment is to be made and these systems are not interlinked. When an investment is to be made there are mainly three systems to my knowledge that must be used. First the AM-system that keeps track of the maintenance, repairs and equipment. Here the identification number is generated. Then to approve the investment another system is used. Last the equipment have to be registered in the bookkeeping. It quickly becomes obvious that it is not strange that mistakes are made, and inconsistencies occur. For instance, if an equipment was bought it should get an identification number but sometimes this number has been forgotten or not communicated to the financial department that does the bookkeeping. This leads to it not being possible to know what equipment's in the bookkeeping is the equipment in the factory.

The power consumption per hour by the machines were collected by observing the specification on the name plate. This is of course not the consumption but sets it at least in the right ballpark.

The technical life used in the Cost model system were in most cases estimates but in some cases based on the current age of the equipment. It was not noted when this data was collected, which dates that the equipment was acquired on. Since this data were excluded in the Cost model system, there are no adjustments of costs because of inflation. This results in the costs of depreciation being lower than what it would have been otherwise.

5.6. Facility

The yearly cost of the facility and the area of it were provided by the financial department. A map of the facility was provided by the production technology department were the UH1 factory floor were divided in to the different processes seen below. The area in white is dedicated to other processes that are not used by the BFCs and BFCFs and are therefore not included in the model.

Figure 54: Factory floor overview

5.7. Power and Climate

A draft of power bills spread out over the year were supplied by the financial department. On these bills electrical and power for climate were specified. The cost of climate was calculated by taking the average monthly cost from the bills and multiplying it with 12. The cost for electrical power were calculated by summing the cost of power from bills spread out over the year and dividing by the total power used specified on the same bills.

5.8. Test rig data

Each BFC and BFCF is tested in a test rig and the results of each test is logged in a database. Any old test results for that product, that is from previous overhauls or from the time it was first manufactured, will be removed. However, there can be multiple tests for one overhaul logged, for instance if a test failed. By analyzing the data, it can be used to calculate the amount of rework done in the testing and assembly processes.

The given values for the tests were not initially side by side in the spreadsheet with the test results, but provided in a separate spreadsheet by the technology department. To be able to know which errors that occurred when a test failed the test results were connected and compared with the given values. The given values consisted of a table were there were multiple given values with different review dates for a single product. To couple the given values with a test, the given values with a review date closest before a test, were used.

When a test is performed it will not complete the test process if it fails at any subtest. By knowing which error that have occurred and the cycle time of each individual test within the testing cycle, the rework can be calculated more precisely. The rework for the testing step will simply be the total time of failed test divided by the total testing time. The consequences of failed tests on other process steps were discussed with personal with long experience and summarized in a Figure 55. The orange columns denote the type of error and each row is a process step. If the value is "TRUE" in for example the "Al" column for the loading step in the testing process it means that the error "Al" leads to rework in that step. The rework loss factor for all steps in Figure 55, except the testing step, were then calculated by taking the amount of errors that lead to rework in a step divided by the total amount of tests. The resulting rework loss factors are summarized in Figure 56.

A few sources of errors in this analysis can be noted. First, since the actual error and the time for correcting it is not noted in the test results it is hard to determine how much rework is needed. Secondly, the testing data did not distinguish overhauls from reclaims and reparations. This is an aspect that have a negative influence on the result since all reclaims or reparations are tested twice, once when they arrive and once after they have been repaired. But since the vast majority of the tests are done on overhauls the data are deemed valid to use as a source of estimating rework. Furthermore, the pairing of the given values and the test results were based on the date and article number. Some were not possible to pair because of wrong article

number or missing given values and were therefor eliminated from the source of this analysis.

A few issues were noticed regarding the test rigs. A major issue was that there was no id to directly connect the given values with the test results. This data should preferable be stored alongside with the measured values. At Faiveley there are multiple test rigs, both the hardware and software of which are in many cases out of date, often the degree that they are no longer supported by the suppliers of the retributive systems. To make things worse, there are no standard for which it-systems that should be used. Multiple employees described the maintenance of the system and test rigs as very costly and time demanding. It was also emphasized that data could be corrupt and that the issues with the it-systems possibly creates problems with traceability. Since the testing is of brakes for trains, that in many cases transport human beings, it is a great risk for Faiveley if the databases were audited.

Process	Step	Product	AI	As	F1	F2	FF	FL	L
BFC_Testing	Loading	BFC	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_Testing	PrepTest	BFC	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_Testing	Disconnecting	BFC	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_Testing	Unloading	BFC	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_Testing	Testing	BFC	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE
BFC_Testing	Loading	BFCF	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
BFC_Testing	PrepTest	BFCF	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE
BFC_Testing	Disconnecting	BFCF	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
BFC_Testing	Unloading	BFCF	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
BFC_Testing	Testing	BFCF	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
BFCF_Assembly	UnLoading	BFCF	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE
BFCF_Assembly	BFCF_Assembly	BFCF	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE
BFC_FinalAssembly	Loading	BFCF	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	LoadingFbrake	BFCF	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	UnLoading	BFCF	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	BFC_FinalAssembly	BFCF	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	Loading	BFC	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	UnLoading	BFC	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
BFC_FinalAssembly	BFC_FinalAssembly	BFC	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE

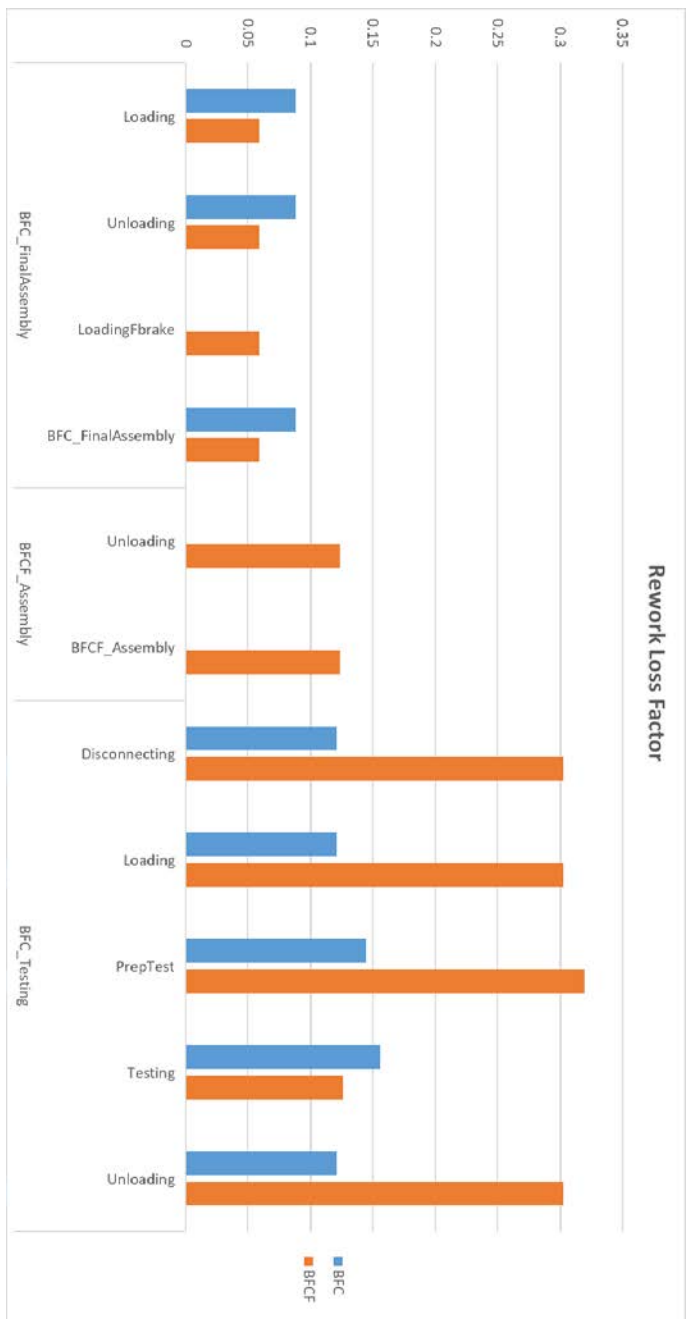**Figure 55:** *Test results consequences on process steps*

Figure 56: *Rework Loss Factor Summary*

5.9. Maintenance and repairs

To keep track of maintenance and repairs on the equipment and facility, a system called AM has been implemented at Faiveley. This system helps to keep track of the costs and time spent on maintenance and repairs, both done inhouse by the own personal and outsourced to other firms. It reminds employees when a particular maintenance task needs to be done. It is also possible to register errors on equipment and make requests. As of today, it is mainly used to help the inhouse workshop personal that implements changes and repairs in the factory to keep track of their tasks. It is not registered what hourly rate that is put on this inhouse maintenance, just the time. The outsourced repairs go the other way around, here it is just the cost that is registered. Of course, both aspects could be registered for both outsourced and inhouse maintenance and repairs and would if so were done be a great resource for determining time and money spent on it. This system has just recently been implemented and because of lacking history of maintenance it is hard to distinguish which maintenance that occurs frequently and which that only are one-time occurrences. Despite this, it could be determined through discussions and rough estimation which costs that only were one-time occurrences, and which occurred frequently. The frequently occurring activities will be referred to as maintenance and the ones only occurring on single occasions will be referred to as repairs, as it is in the Cost Model System. The few registrations of data that corresponded to maintenance done by production personal was removed since this data were gathered through interviews with production personal together and routines from internal documents which were deemed to be a more accurate source. To estimate cost for the inhouse maintenance and repairs, the same cost for production personal is assumed and multiplied by the maintenance or repair duration. Since the duration of outsourced work is not specified in the AM system, to get an approximation of the duration of the outsourced maintenance or repairs the hourly rate was set to 1500 SEK and the total cost of a maintenance or repair was divided by that rate to get the number of hours spent on a maintenance or repair. The only year with complete data on maintenance was the year of 2016, which was then used as a source for the yearly maintenance. The aggregated data for maintenance is shown in Figure 57. The data on repair was directly inserted to the Cost Model System unaggregated.
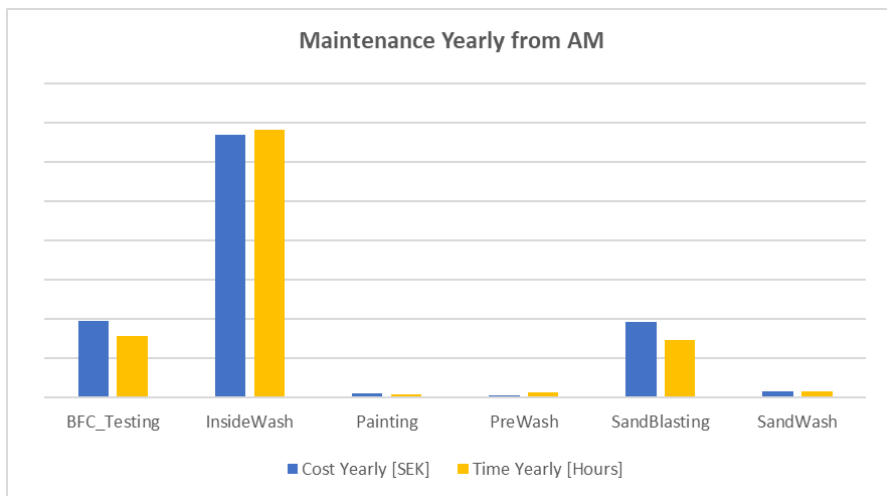
Figure 57: *Maintenance Cost and Time Yearly by process*

5.10. Worker Information

Information regarding salary was not provided more accurately or detailed than what rate was used to calculate product prices. The amount specified was the same irrespectively of the workers were contracted by another firm or the employed personal was used.

Since not all processes for all products processed by the UH1 department were defined, the setting "Should the total salary cost be distributed?" row in the General Input table on the worker worksheet were set to "False".

Rate at start of employment, used as a parameter in the cost model, which is the pace or rate of efficiency of a newly employed worker in comparison to an experienced worker was arbitrarily set to 0.5 based on discussions and with personal with long and wide experience. Experience needed for full rate (in years), which is another parameter used in the cost model was also set to 0,5. The justification of this is that the complexity of the overhaul process due to big variations conditions of products and big variety of products, creates losses in rate in all manual processes. Mitigating this effect can for example be done by limiting the variety of products or simplifying the processes.

The employees working on the floor in UH1 are in a mixed age and experience. Some have been working at Faiveley for many years and knows

the products in and out. Some of the key player for the overhaul process of various processes are close to retirement and will be hard to replace without loss of production rate.

6. Current Situation

In this chapter, the current situation of the UH1 department at Faiveley will be described and evaluated. As previously stated the BFC products are mainly of interest but since processes are shared with other products, those products must be taken in to consideration in regard to those processes.

The processes that are dedicated to BFCs are denoted with "BFC" as a prefix and processes dedicated to BFCFs have "BFCF" as a prefix. As all BFCFs are a version of the generic product group named BFC, so all BFCFs go through the BFC processes, but not all BFCs go through the BFCF processes. Some of the process steps have been disregarded in the description below such as collecting parts for the assembly steps and administrative steps which occur in multiple steps along the processes. The movement of pallet wagons and wash wagons between processes have here been described inside the processes, but in the cost model system all these processes have been grouped under a process denoted "MaterialHandling". The receiving and shipping processes are described as one and the same process in the cost model system since both uses the same resources and area in the facility.

6.1. Value Stream Map and Process description

The value stream map, illustrates a generalized overview of the overhaul processes of BFCs. Since the processes are for overhauls of old and used products, the condition of those products makes the processes and their cycle times differ a lot. Adding to the variation is that there are more than 50 variants of the BFCs. What has been chosen to be described in the value stream map is the processes for a specific type of BFCs that are overhauled in vast quantities and is valid for most BFCs. It is important to note that the workload and lead-times for various parts and processes varies a lot, from hours to days. This, in turn makes the lead-times through and between the processes vary a lot. For this reason, the lead-time is not shown for the waiting on parts but instead lead-times showed are simply the cycle times for the processes.

The setup of the factory floor in UH1 can be described as a functional layout, were all the work of more or less all processes are done by the same workers. Consequently, the description of the processes below describes the flow of a BFC and not the order the work is done by a worker. Depending on workload and the number of workers the structure of the work varies. Also, since some of the processes are done automatically by a machine, like the washing

processes, the workers sometimes do other tasks on other products and/or processes while he waits for one of the automatic processes to get done.

The information flow surrounding the overhaul process can be described as a quite complex process in itself. Often random products show up that should be overhauled but no tools, manuals or spare parts are present. To not make the value stream map too complicated the information flow has been disregarded. Furthermore, since it is an overhaul process the usual flow of raw material coming from supplier, being processed and then the ending up at a customer is not valid. Rather, the supplier of the products intended to be overhauled is the same as the customer, as can be seen in Figure 58.

Below the value stream map is explained, the numbers in the list correspond process number in Figure 58:

1. All Products that are ought to be overhauled are received and stored on pallet racks. When the overhaul of a batch is to be performed the products are loaded to a pallet wagon. (The Leadtime of this step is not included in the value stream map.)

2. The following is a description of the Prewash process steps for BFCs. The steps are similar for other products.

    a. Eight BFCs are moved on a pallet wagon to the Prewash process.

    b. Four BFCs are loaded using a floor mounted crane, to a platformed that can be moved inside the washing machine.

    c. The BFCs on the platform are masked and inserted to the washing machine.

    d. The BFCs are washed automatically in the machines during which the worker can do other tasks.

    e. The BFCs are taken out of the washing machine, the masking is removed and the BFCs are loaded back to the pallet wagon.

    f. The pallet wagon with 8 BFCs that have been washed id moved from the prewash to the BFC Dismantling.

3. BFC Dismantling

    a. One BFC is loaded to a pillar and locked into position.

  b. The BFC is dismantled and the parts are put in a basket on a wash wagon.

  c. When the dismantling is complete the wash wagon is moved to the Inside Wash.

4. Inside Wash

  a. The basket on the wash wagon is loaded to an electrically powered roller table, with room for three baskets, that automatically loads the washing machine. The wash wagon with no basket is moved to the other end of the roller table.

  b. The Basket first in line on the roller table is loaded in to the washing machine, washed and loaded back to the roller table.

  c. The basket first done with the washing is unloaded from the roller table to a wash wagon and moved to wagon area 1 next to the prewash area.

5. Grinding and Inspection

  a. A wash wagon is collected from wagon area 1 next to the prewash area, and brought to the grinding inspection area were part are inspected some are loaded to a pallet wagon.

  b. Some parts are taken to the grinding machines and grinded.

  c. The wash wagon with the remaining parts in it is moved to the sandblasting. While the pallet wagon is left in wagon area 2 next to the grinding and inspection area.

6. Sand Blasting

  a. The BFC parts are loaded inside the sandblaster and blasted

  b. The parts are cleared of sand by using an air blow gun and unloaded from the sandblasted back to the wash wagon.

  c. The wash wagon is moved to the sand wash.

7. Sand Wash

  a. The parts are loaded from basket on the wash wagon to a platform that can be moved in to the washer.

  b. The platform is pushed inside the washer and the washer is closed and started.

    c. The washing machine washes the parts for approximately 2 minutes.

    d. The parts are unloaded from the washer in to a wash wagon and moved to the painting.

8. Painting

    a. The parts are loaded from a wash wagon on to the paint both.

    b. The parts are masked and hanged on hooks or put on stands.

    c. The parts are painted and then left for a while for drying.

    d. The parts are loaded back to the wash wagon moved to wagon area and loaded to a pallet wagon.

9. BFC Pre Assembly

    a. A pallet wagon is received from the wagon area and brought to the Preassembly.

    b. Some of the parts are greased and assembled.

    c. The assembled parts are loaded back to the pallet wagon and moved to either BFCF assembly or the BFC final assembly depending if it is a BFCF or not.

10. BFCF Assembly

    a. The BFCFs F-brake part is assembled and put back in the pallet wagon to be moved to the final assembly.

11. BFC Final Assembly

    a. A pallet wagon is gathered from the BFC preassembly or the BFCF assembly.

    b. The BFC is assembled and loaded back to a pallet wagon which is moved to the test rig or loaded straight on to the test rig by travers.

12. BFC Testing

    a. The BFC is prepared and the test is started.

    b. During the test, administrative work is done and if the test is successful it is disconnected.

    c. The BFC is loaded back to a pallet wagon using a travers.

d. If the test fails, depending on the error the test is run again and or the BFC is sent to the one of the assembly processes where it is repaired and then retested.

13. Shipping. The lead time of this process is not included in the value stream map.

   a. When the testing is done and a pallet wagon is filled with 8 BFCs and the pallet wagon is collected using a forklift.

   b. The Pallet wagon is brought to the shipping area and the pallet is unloaded from the pallet wagon.

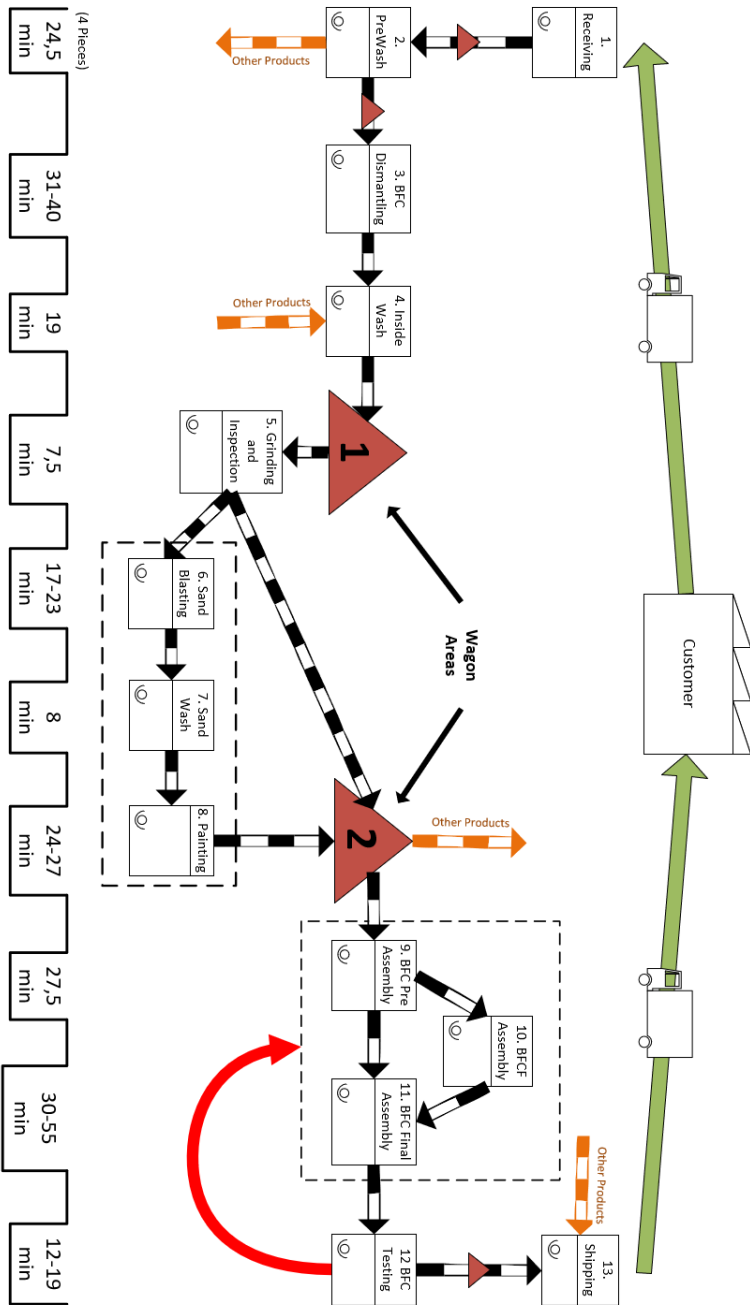   c. The pallet is fitted witch an extra pallet collar, a lid and the sealed using a plastic strap.

Figure 58: *Value Stream Map of the current situation*

6.2. Cost Model System Results

In this chapter the results from the cost model system is presented for the current situation in the scenario denoted S2 described in chapter 5.4. Not all charts from the results worksheets in the Cost model system will be presented and some key figures have been removed from the charts, as requested by Faiveley.

6.2.1. Profit_Revenue

Not all processes for all products have been included in the CMS, nor have all kits, consumables or overhead costs. This is not only important to note when looking at the product revenue chart presented below but also when working with the CMS. The costs that are included for each product can be seen in Figure 60 and Figure 61. Surely, as more data on processes and other costs would be registered in the cost model, the cost of each product would increase.

It can be observed in Figure 59 that the BFCs stands for the biggest part off the revenue when it comes to overhauls. It comes as no surprise that some of the other products show a better profit margin since not all their processes have been mapped in the Cost model system. Despite this, the products VK, PBEC and PBECFP show a lower profit margin than BFC and BFCF. This can either be explained that wrong process times have been registered, the wrong costs for kits, the wrong sale price in the cost model system or it can simply be that the products are less profitable. A more thorough analysis and more data would be necessary to evaluate this fully for every product. If so were to be done and more variant were to be introduced in the model, it is likely that some products would show to not be profitable enough and should then either be removed from the portfolio or have a higher sale price.
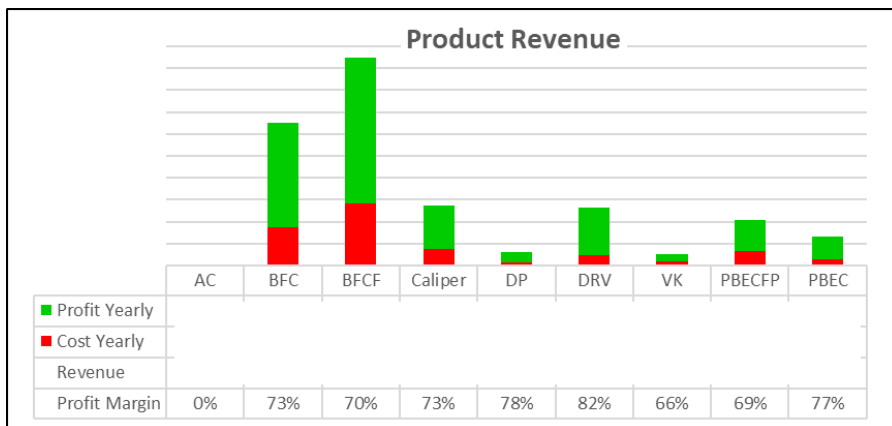
Product Revenue

	AC	BFC	BFCF	Caliper	DP	DRV	VK	PBECFP	PBEC
■ Profit Yearly									
■ Cost Yearly Revenue									
Profit Margin	0%	73%	70%	73%	78%	82%	66%	69%	77%

Figure 59: *Product Revenue chart*

6.2.2. Product_Cost

In the Product cost chart, Figure 60 it can be seen which costs that have been included in the Cost model system for the different products. No overhead cost or raw material is included, and cost of consumables have only been noted for BFC and BFCF. Furthermore, what is showed is a generalization of different product families, when there actually different costs depending on which variant. The cost of kit for example, is noted for the variant that is most commonly occurring in UH1, but in reality, this varies quite a lot.

In the Product Process Cost chart, Figure 61 it can be seen which products which processes have mapped in the cost model system. The products that are of most interest for this analysis, the BFC and BFCF, have the most processes mapped. Among the shared processes the cost of the inside wash is in general high for all processes. The cost of Sandblasting, grinding and inspection is also quite high. Looking at the BFC and BFCF their dedicated processes (with "BFC" or "BFCF" prefix) are all relatively expensive, in particular the dismantling for the BFCF and the final assembly for the BFC.

A source of error when comparing the different processes is that the process steps might have been defined differently by different people that have gathered data for the model. As an example, if data from time studies made by different people are used, one person might choose to include the material handling in a particular process and another person choses to define it as a separate one. This can give the impression that a process is more expensive for one product than another, when in reality, it is not.
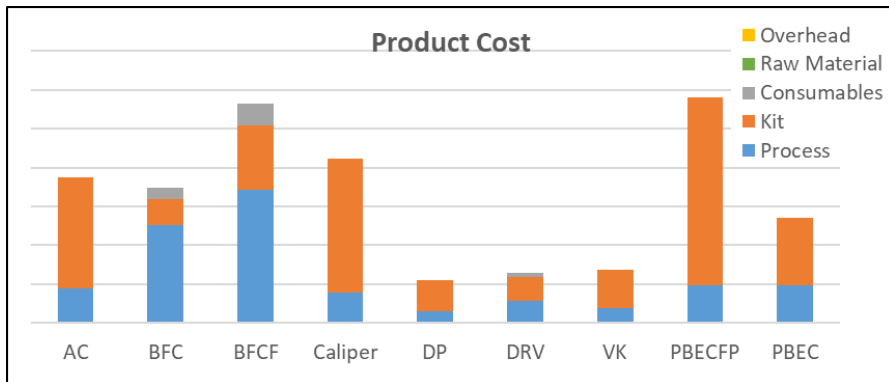
Figure 60: Product Cost chart
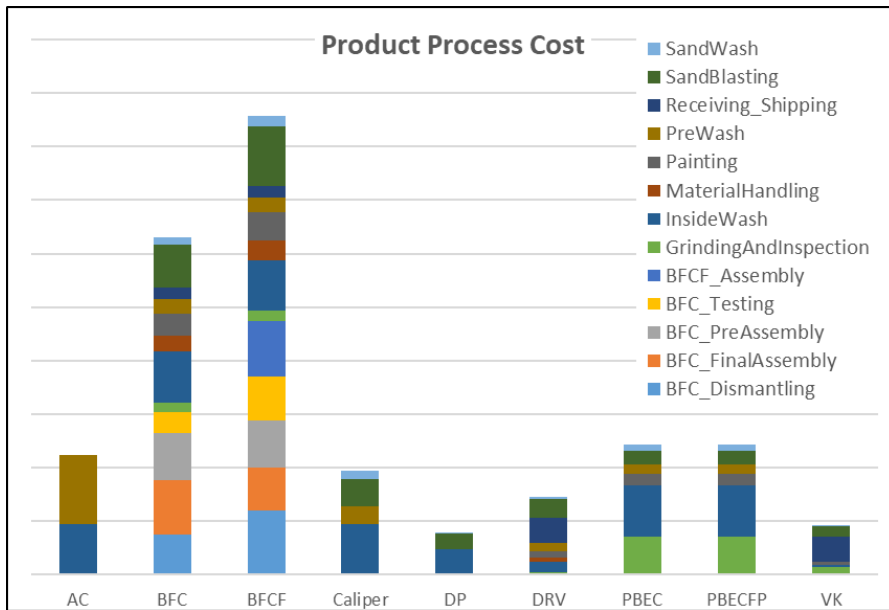
Figure 61: Product Process Cost chart

6.2.3. Processes

In Figure 62 it can be seen which process steps that are the most expensive for a BFC. Steps that occur in multiple processes are here aggregated. The Sandblasting, PreAssembly, InsideWash and the BFC_FinalAssembly steps are particularly expensive, even though they are steps only occurring once, still this was expected since the duration of them are quite long. Next to those

are the steps Loading and Unloading. This can be explained by that they are steps occurring in multiple processes, which individually are not expensive but aggregated, they are. This is here exemplified by showing the BFC, but the same thing is true for most other products overhauled in UH1.

Figure 62: *Process Steps BFC*

6.2.4. Losses

In Figure 63 the total cost of the processes that goes into the different products (one piece) are shown in stacked columns which are divided in nominal cost and cost of the losses. It can be seen that the losses are a significant part of the cost for the BFC and BFCF. The reason the other products show a lower cost and lower fraction of losses is that not all the processes have been mapped, and the ones that have been mapped are not done as thoroughly as for the BFC and BFCF.
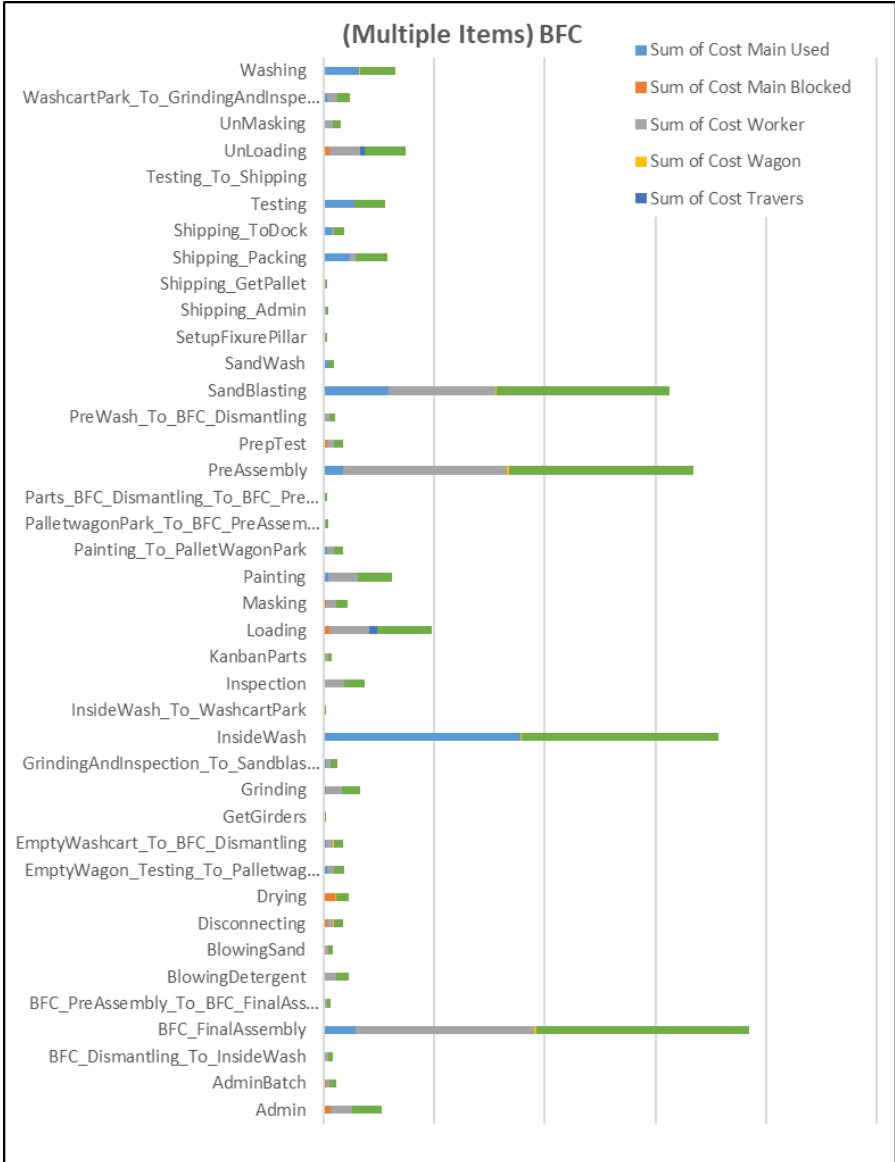
In Figure 64 and Figure 65 the different types of losses are shown for the various processes for the BFC and BFCF. The losses are predominantly of the type "general loss", which are losses due to general variations in the production which makes the production pace slower. There are many reasons for this type of loss being as big as it is. One is that since most of the processes are manual, the cycle time will vary depending on which worker that does the work. Depending on what condition the products were in when received it might take longer to overhaul. For example, if the product is rusted it can take twice as long to take apart, to grind and to sandblast. Furthermore, if a part would break when dismantling or already were broken, (assuming it is not a part of the standard replacement kit) a new one would have to be ordered. To get replacement parts can take long time and in many cases, this leads to extra work since the products must be put aside to let other products get through. This together with the fact that there are many different products being processed at one time leads to a lot of congestion in the workshop. The most common and frequently observed issue in regard to availability of parts were the cylinder sleeves. The cylinder sleeves are not changed on all BFC and BFCFs, but all are checked and if there are deep scratches on them they are replaced. Mostly this was done in the final assembly step but should have been done as early as in the inspection step, the postponement is probably because of the administrative burden. When in the final assembly step and in need of a new cylinder sleeve, the workers scout the wagons with other BFC and BFCFs, from the same batch, for sleeves that are okay so the BFC or BFCF currently being assembly can be finished. The reason it is not just ordered and waited for is that it takes about 1-3 hours to get it a new sleeve, even though they are literally a few meters away in the warehouse of the factory. If waited for, it would implicate extra work of unloading and loading another BFC or BFCF. This issue would be easy fix by making the cylinder sleeves be available on a shelf in this part of the factory, or by making it a standard replacement part that would be

included in the replacement kit. It can be concluded that the processes are all but deterministic, more standardization and automation would help to get the processes to go more smoothly which would reduce the cost.
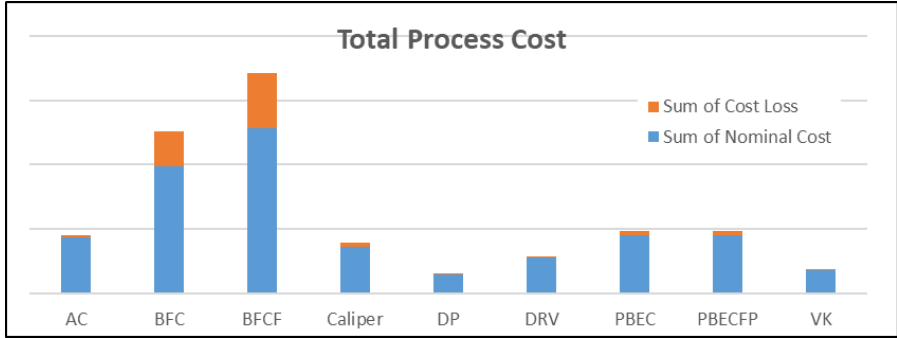
Figure 63: *Total Process Cost*
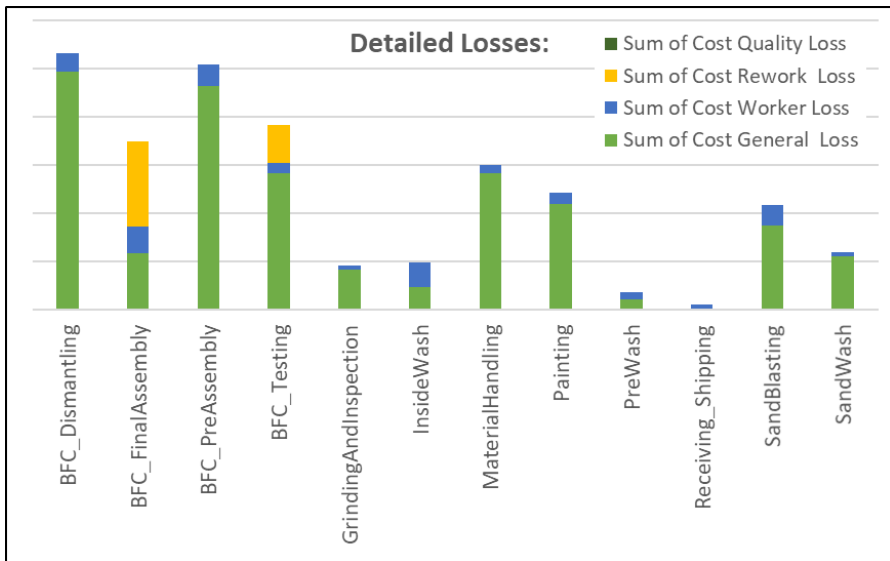
Figure 64: *BFC Detailed Losses*
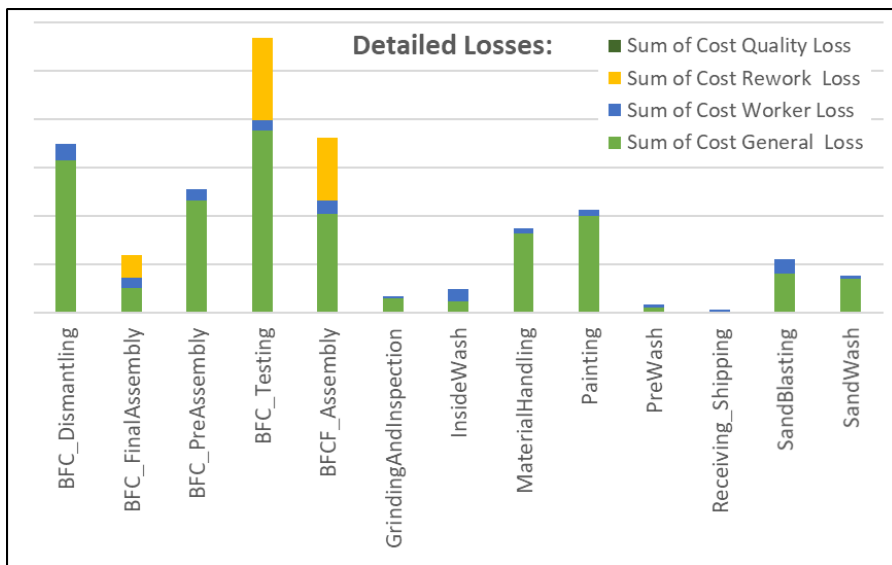
Figure 65: *BFCF Detailed Losses*

6.2.5. Time

The total time spent yearly on the processes and resources can be seen in Figure 66. It can be observed that for the InsideWash a big portion of the time is spent one maintenance. The hours on the Painting process is mostly due to it being blocked, which can be explained by the time that the paint is drying. The high amount of time consumed by workers and wagons is simply a result of that there are multiple workers and wagons that can be used at the same time and that these resources are used in most processes.
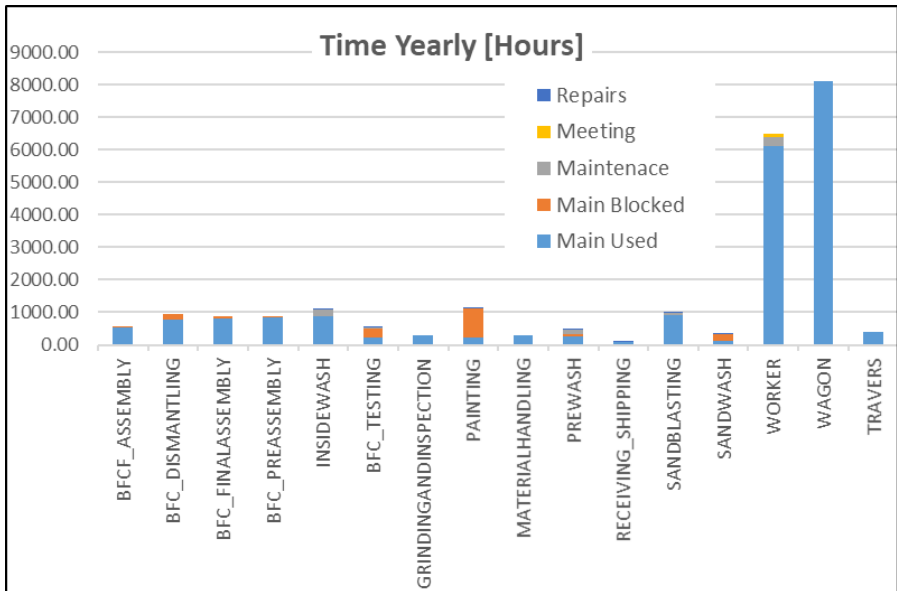
Figure 66: *Time Yearly*

6.2.6. Rates_Processes

As explained in chapter 4.3.9.6, it can be observed in Figure 67 together with Figure 68 that it does not have to be the process with the highest hourly rate that has the highest yearly cost. A high rate can simply be an implication of a process not being used as much as other processes. For instance, Receiving_Shipping have a high hourly rate but it is not the most costly process. This can be explained by multiple reasons, not all time it is used is registered in the cost model system or the time it is used might be short which possibly makes it time efficient. Contrary, some rates might be low while the processes in total of costs of a product are high, like dismantling or assembly processes. This can be explained by that the process takes long time and/or it uses multiple resources at a time, like a worker, wagon and/or traverse, which makes the rates add up.

It can be observed that the hourly rate of the Inside Wash is high, and the biggest chunk is from maintenance. Which leads to the question; is it used right, too much or is it old and worn down? Since much of the cost is maintenance, repairs and consumables it is possible that these costs would be lower if the machine were used less. The cost of depreciation would on the other hand be higher if it were used less, but it is possible that this would also mean that the technical life would increase and by that compensating the shorter yearly time plan for that equipment. The chunks of rates for the prewash are in the similar proportion as the inside wash but in total much smaller. The biggest chunk of the rates for sandblasting is consumables and maintenance, adding to that it is a 100% manual process which adds the rate of a worker to the process. It can be observed in Figure 68 that the most expensive processes are the InsideWash and the SandBlasting. The grinding part of the GrindingAndInspection process is something that for many of the products are done because of the sandblasting not being efficient enough, it could be viewed as a part of the sandblasting process, this would then be the most expensive process.
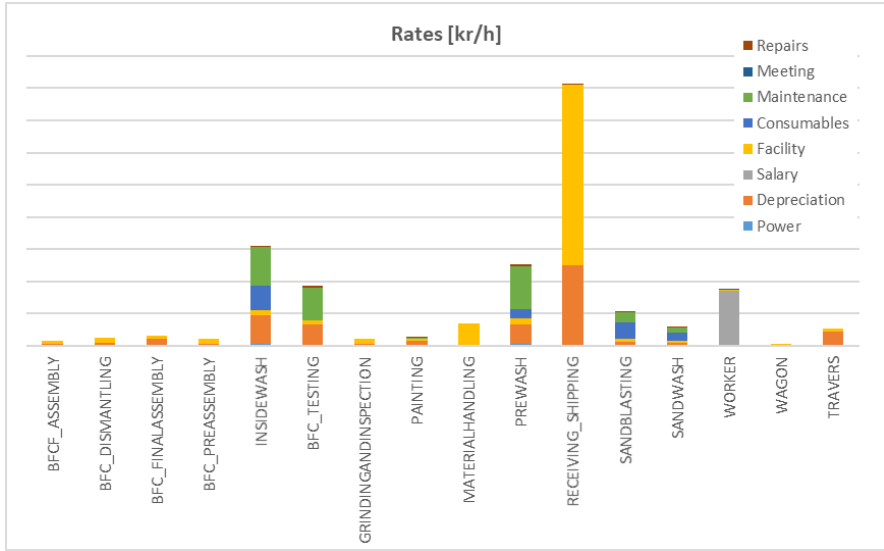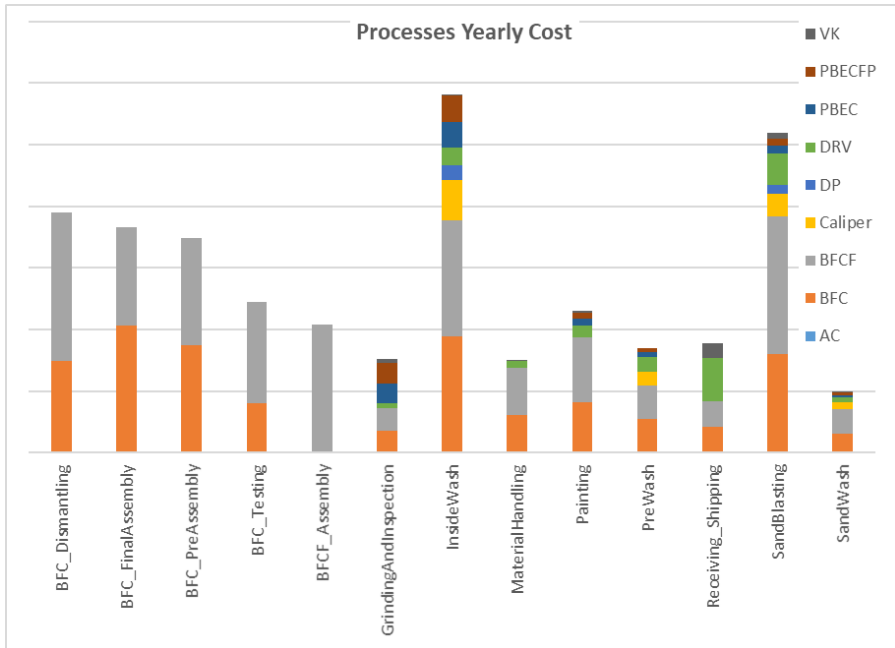
Figure 67: *Rates*

Figure 68: *Process Yearly Cost*

6.3. Current situation evaluation

A very apparent issue in the processes is the congestion on the factory floor. This can in part be seen in the losses in the material handling process, that is moving the different products between the processes. The obvious solution to handle the congestion would be to increase the floor space, making more room to move through the factory floor. But the same effect can be achieved in other ways. By shortening the lead time for overhaul of the various products, less products would be in the system at the same time, as commonly known from littles law from queuing theory i.e. the relationship among WIP, cycle time CT, and throughput TH, see Equation 6.1 [15].

$$WIP = CT * TH \hspace{3cm} Equation\ 6.1$$

This could be achieved in multiple ways, but an obvious one would be to make spare parts that are needed, available when needed. As a suggestion, parts as the cylinder sleeves, as discussed above could be made available by keeping a small stock in the UH1 area. Another way is to eliminate some of the many product variants that are overhauled. The many variants create a lot of setup time, a lot of time to find the right tools and manuals and also long time to get the spare parts needed. At the moment, this is handled by putting products to the side to wait for parts after being dismantled, sandblasted and inspected. When spare parts arrive, it goes quick to assemble, but the process of putting the products away and resuming the work later consumes both time and space. All the variation makes the overhaul process very complex which in turn makes it hard for new employees to learn which makes the process times longer. Both because they must learn but also because other workers must teach them how to do it. If more new employees would be hired it would show in the cost model that the worker loss would get bigger, the cycle times would get longer, and overall cost would increase. If the floor space were to be increased, it would reduce the cost of the material handling both in regards of BFC and BFCF but also the other products. This could be analyzed in the cost model system by adding space to processes and appreciating the reduced cycle times for various processes. But since doing an extension of the facility have great effects on other products as well, it does also need a lot of more data to show the real possible effect and if it would be beneficial.

The process steps loading and unloading which are reoccurring in multiple processes are steps that naturally are wished to be reduced or removed. This could possibly be done by changing the equipment used for material handling and the traverse. By having some sort of conveyor system that is connected

to the different processes and perhaps can even pass through them, without the products having to be loaded and unloaded, could have a great impact on both the steps mentioned but also the material handling. An issue with this idea, that have to be mentioned, is that the great variation of products and processes makes it hard to create and implement a system like this since it is not as adaptive as the wagons used today are. If this were to be further evaluated, the obvious processes to consider would be the shared processes like the sandblasting and painting or any of the washes. When and if this would be done, other processes could one by one be connected.

The state of the equipment in UH1 is in general old and quite worn. Looking at rates for the inside wash it can be observed that the cost for maintenance and repairs are high for the machine. The reason for this are due to multiple aspects, one could be that it is not used correctly in the sense that the products that are washed are dirtier than the equipment is intended for. Or, it could simply be that the machine is worn. The Inside Wash is observed to be a high cost in other aspects as well, such as consumables and depreciation. It is shared by multiple products so improving this process would have great synergetic effects. It can be noted that the reason for the setup today, where parts are washed before sandblasted is because one cannot sandblast greasy parts. The sandblasting cabinets used today are leaking significantly both contaminating the air and making the floors slippery around the equipment. The reason for them leaking is partly because the ventilation and filter system used for the machines are too small (it was made for two cabinet but now there are three), partly because the pipes for the ventilation of the cabinets leak and last because the cabinets are worn. The blasting agent is glass beads, which seems to be the best option but according to Occupational Safety and Health Administration (OSHA), (an agency of the United States Department of Labor) has potential to cause lung damage [16]. The leaking is also a contributor to cost since it results both in waste of glass beads, maintenance in refilling glass beads and time in cleaning up the floors. Furthermore, the sandblasting is also physically demanding, many heavy lifts in and out of the cabinets, moving the parts around in the cabinets and standing in a fixed position for long times which could cause repetitive strain injuries. As seen in Figure 68 it can be noted that sandblasting is the second most expensive process yearly, after the inside wash. One improvement, that could reduce the cost of the sandblasting and to some degree also the painting, would be to go through the different parts of the products being overhauled, and instead of sandblasting and painting some of the parts they could instead be replaced with new ones. This could easily be analyzed in the cost model

system by testing to add cost to the kit and to reduce the cycle times for the retributive products.

A sensitive question, but of most importance to discuss, is the moral, attitude and culture at Faiveley. It was observed many times that the different departments had widely different opinions on how and whom that should do what. Furthermore, there seemed to be a distrust between different departments and especially between the office and the factory floor personal. It was obvious that many in the office did not realize the issues that lays in the hand of the workers on the factory floor. Often products would get delivered to the UH1 department that there were no manuals, tools or spare parts to do the overhaul with. Since this has happened frequently for many years the personal on the factory floor have become quite bitter, which has a big effect on moral on the factory floor. This obviously has a great implication on the cost of products, which has a root in the losses. If further evaluated it could be proven in the CMS that cost could be reduced by improving the relations between the different departments, without including the obvious fact that the bad communication obviously leads to delays for customers. Also, it seemed as the upper management seldom went out in the factory and talked to the worker and tried to understand the real issues and how the workers felt about the situation. This could possibly be a first and simple step to change the attitude and culture at Faiveley.

7. Experimental design and Evaluation

There are many possible improvements that can be done to reduce the cost of the overhaul process, some of which have been mentioned and briefly discussed in the previous chapter. Not all of them will further be evaluated in the cost model system. What have been chosen to look deeper in to are simply the most expensive processes which if improved can have the great impact and synergetic effect on all products that are overhauled in UH1. Among other processes, the sandblasting is one of the most expensive processes, which also have issues regarding the working conditions. Consequently, this is one process that have been focused on for a further evaluation.

7.1. Experimental design

three different improvement suggestions, described below in chapter 7.1.2, 7.1.3 and 7.1.3 were chosen to be evaluated in two scenarios, with different yearly quantities. In Figure 69 the two scenarios S1 and S2 are shown. S1 are based on quantities from the most recent full year and S2 are future estimated quantities.

The experiments are being limited to only look at UH1 as an isolated entity and does not consider that the changes suggested might could create more value for the customer. For instance, if lead-times are reduced the customers might would except a price increase of products. If this would be considered the result could show to be even more promising.

Product	S1 Quantity Yearly	S2 Quantity Yearly
AC	10	0
BFC	675	1000
BFCF	667	1000
Caliper	4	350
DP	29	250
DRV	974	750
VK	534	250
PBECFP	37	225
PBEC	27	225

Figure 69: Yearly quantities scenario 1 and 2.

7.1.1. Pressurized blasting cabinet PBC

To reduce the cycle time of the sandblasting, reduce the amount of blasting beads being spilled and improving the ergonomic situation slightly, one consideration is to replace the blasting cabinets with pressurized blasting cabinets. A pressurized blasting cabinet can be seen in Figure 70 which looks more or less the same as suction blasting cabinets but works in a slightly different way. Instead of picking up the blasting beads by suction which takes a lot of energy, the blasting beads are pressurized in a vessel to blast through a nozzle [17]. A schematic of the on the two different types of blasting systems are shown in Figure 71.

Suggestions on how much cycle times will reduce using a pressurized blasting cabinet from different equipment manufacturers range from 50% to 75% [18], [19]. It will be assumed that the cycle times can be reduced by as much as 50% when changes are applied in the cost model system. Otherwise, the only differences will be a less maintenance since it is expected to not leak or break as much as much as the old cabinets. The costs of outsourced maintenance are assumed to be 8000 SEK and take approximately one work day of 8 hours.

An offer has given for a pressurized blasting cabinet of approximately 150000 SEK. If the capacity is approximately twice of the capacity of the currently used blasting cabinets, it can be assumed that two is needed to replace the current three cabinets. Some of the old machines will be possible to sell which mitigates the investment with approximately 20000. Installation of two new cabinets is estimated to 35000 SEK, making the total investment 315000 SEK.
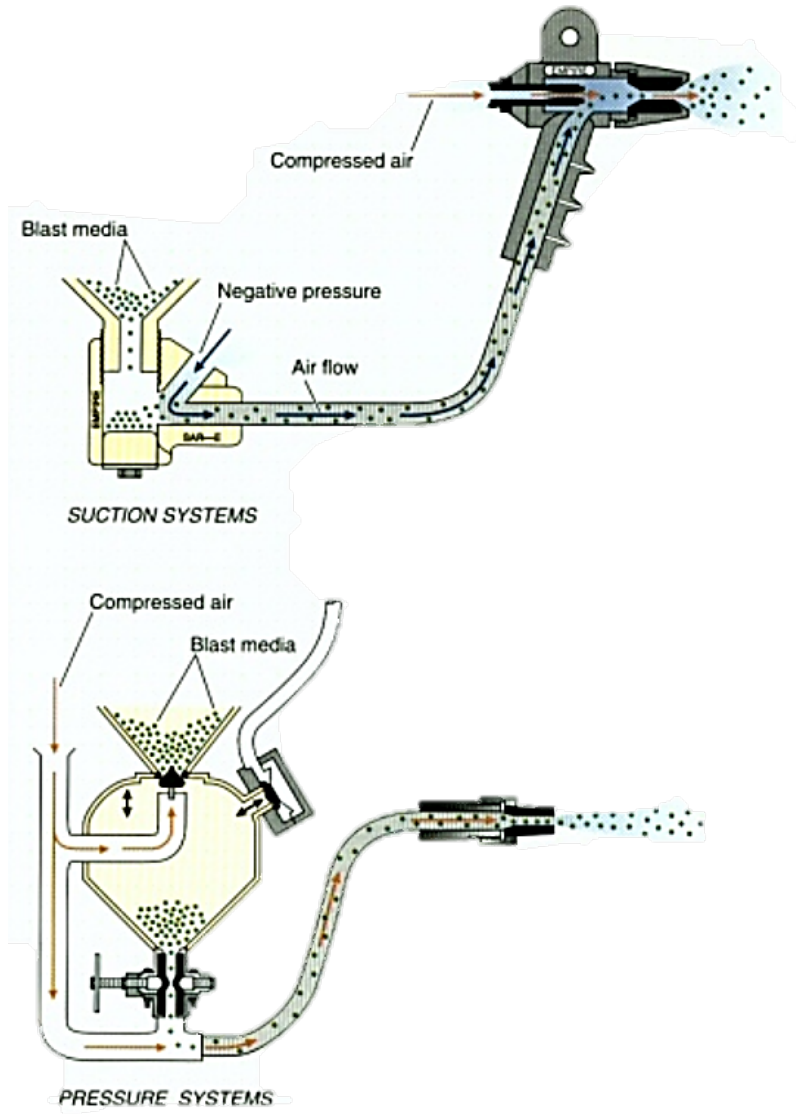

Figure 70: *Pressurized blasting cabinet [20]*

Figure 71: *Schematic of suction and pressurized blasting [18]*

7.1.2. Hangar blasting machine HBM

An improvement suggestion that has being considered even before this thesis was initialized was to use an automatic sandblasting machine instead of sandblasting manually as it is done today. The machine that were most thoroughly looked in to and seemed to be most promising was a hanger blasting machine, see Figure 73.

The hanger blasting machine have ha large hanger suspended on a rail on to which parts are loaded and then pushed inside the machine. The Y-track configuration that can be seen in Figure 73, allows one batch of workpieces to be loaded while another batch is in the machine and being processed.

Some of the advantages pointed out by the equipment manufacturer are listed below [21]:

- Self-contained, fully equipped shot blast machine

- Installed without the need for further exhaust ducting

- Quick turnaround, easy assembly and commissioning

This machine will reduce the time of sandblasting and only needs manual work in the loading and unloading steps. The machine will also eliminate the hazardous aspects regarding sandblasting currently present in the factory. The changes in the processes apart from sandblasting are only that the grinding will not be necessary since it is no problem for the machine to take care of thicker rust or contamination, as long as it is dry.

A visit was conducted to a manufacturing site to see and test this equipment. A comparison of before and after a part that was blasted in the machine can be seen in Figure 72. The results were promising, all paint and rust was removed. The cycle was very short during the test since only one part were inserted. But, it was appreciated to take approximately 5.5 min if it was fully loaded, which is much faster than today. It is assumed to be able to be loaded with 2 BFC at a time. Loading, unloading, masking and unmasking of two BFCs will approximately be 3 minutes. Other products can also be grouped together and blasted in one cycle, which makes the process very quick.

An offer for this machine has been given of 479000 SEK. On top of that it is estimated that installation, masking equipment and other costs, not included in the investment of the machine will be approximately be 110000 SEK. Some of the old machines will be possible to sell which mitigates the investment with approximately 20000. The final investment ends up to 569000 SEK.

The running cost, such as cost of maintenance is assumed to be similar to the current situation, but slightly reduced since the hangar blaster can be assumed to not leak which means that it does not need to be refilled with blasting beads as much as the old blasting cabinets. But since the type of beads being used will be more expensive the cost of is assumed to remain the same. The preventive maintenance done by the own personal is assumed to be an hour a week and costs of outsourced maintenance is assumed to be 10000 SEK and take approximately one work day of 8 hours.

Figure 72: Comparison of before and after blasting in the hanger blasting machine. Left: Before. Right: After

Figure 73: Hanger blasting machine. [22]

7.1.3. Slurry blaster machine SBM

An equipment that could significantly improve the overhaul process for most products in UH1 is a so-called slurry blaster or wet sandblaster, see Figure 75. The machine washes, wet-sandblasts, and washes again, with a cycle time of approximately 15 minutes. With a machine like this some processes can be completely eliminated, and some can be reduced. The grinding, the sandblasting and sand wash would be removed completely, and the usage of the inside wash would significantly be reduced. The spinner hanger slurry blaster work in the same way in aspect of loading and unloading as the hanger blasting machine and therefor the same cycle times for loading, unloading masking and unmasking will be used assumed for this machine. The reason for that the inside wash cannot be completely removed is because some of the parts cannot be wet-sandblasted since they are too fragile, and still would have to be degreased. But, there are only a few parts that would need to be washed in a separate process and if using the inside wash, many of them could be grouped to one basket and therefor reducing the cycle time for each product. An overview of a future scenario value stream map with a slurry blaster can be seen in Figure 76.

Since the inside wash would be used less the technical life would possibly increase, which would reduce the cost of the yearly depreciation. In the Cost model system, it is assumed to increase with 5 years. Adding to this, the amount of maintenance and chemicals that would be needed would reduce, which is a big cost presently. The maintenance and the chemicals needed by the Inside wash is assumed to be reduced by approximately 50%.

Some of the advantages pointed out by the equipment manufacturer are presented listed below [23]:

- No dust – No need for a dust collector
- Does not require pre- and post-cleaning processes
- Closed-loop process – both detergent and media are recycled
- Does not require compressed air for blast motive force
- Very clean and dust-free part surfaces
- Can process wet, oily, and greasy parts.

An example image of parts, before and after being processed in the machine, have been supplied by the manufacturer and can be seen in Figure 74. The upper image of the gearbox housing before and after shows the result of a

very greasy part going through the machine, and the lower image shows of a very rusted turbo-housing going through the machine. [24]

Furthermore, since the machine does not create any dust it would improve the hazardous conditions today with leaking blasting cabinets, and since much time on both loading in and out of the processes will not be needed with a slurry blaster both cost of labor and risk of repetitive strain injuries can possibly be reduced.

By email correspondence with the equipment manufacturer an approximated investment cost of 330,000 CAD for the spinner hangar slurry blaster was estimated. On top of that it is estimated that installation, masking equipment and other costs, not included in the investment of the machine will be approximately 130000 SEK. Some of the old equipment could possibly be sold mitigating the costs by as much as 25000 SEK. In total the investment ends up, with the current (2017-09-20) exchange rate to be 2241600 SEK.

The running cost, such as preventive maintenance, changing the blasting agent and chemicals is assumed to be similar to the situation today, but the maintenance cost is slightly reduced since it can be assumed to not leak which means that it does not need to be refilled with blasting beads as much as the old blasting cabinets. But since the type of beads being used will be more expensive the cost of is assumed to remain the same for consumables. The preventive maintenance done by the own personal is assumed to be an hour a week and costs of outsourced maintenance cost is assumed to cost 15000 SEK and take approximately one work day of 8 hours. The cost of detergent or chemicals is assumed to be twice as much as the chemicals sand wash consumed, the specific type has yet to be determined.

Figure 74: Before (left) and after (right) slurry blasting. Upper: Gearbox housing. Lower: Turbo housing. [24]
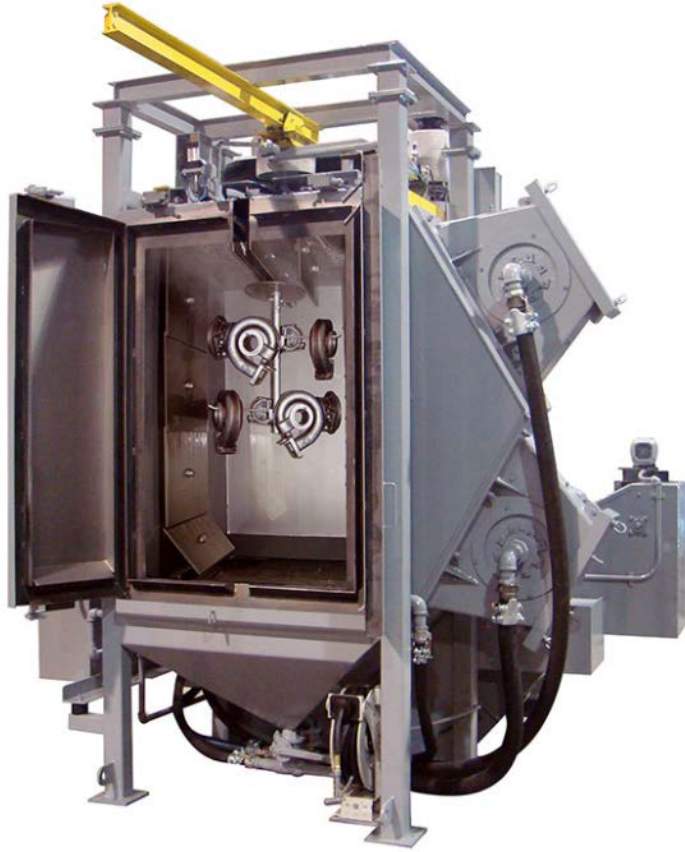
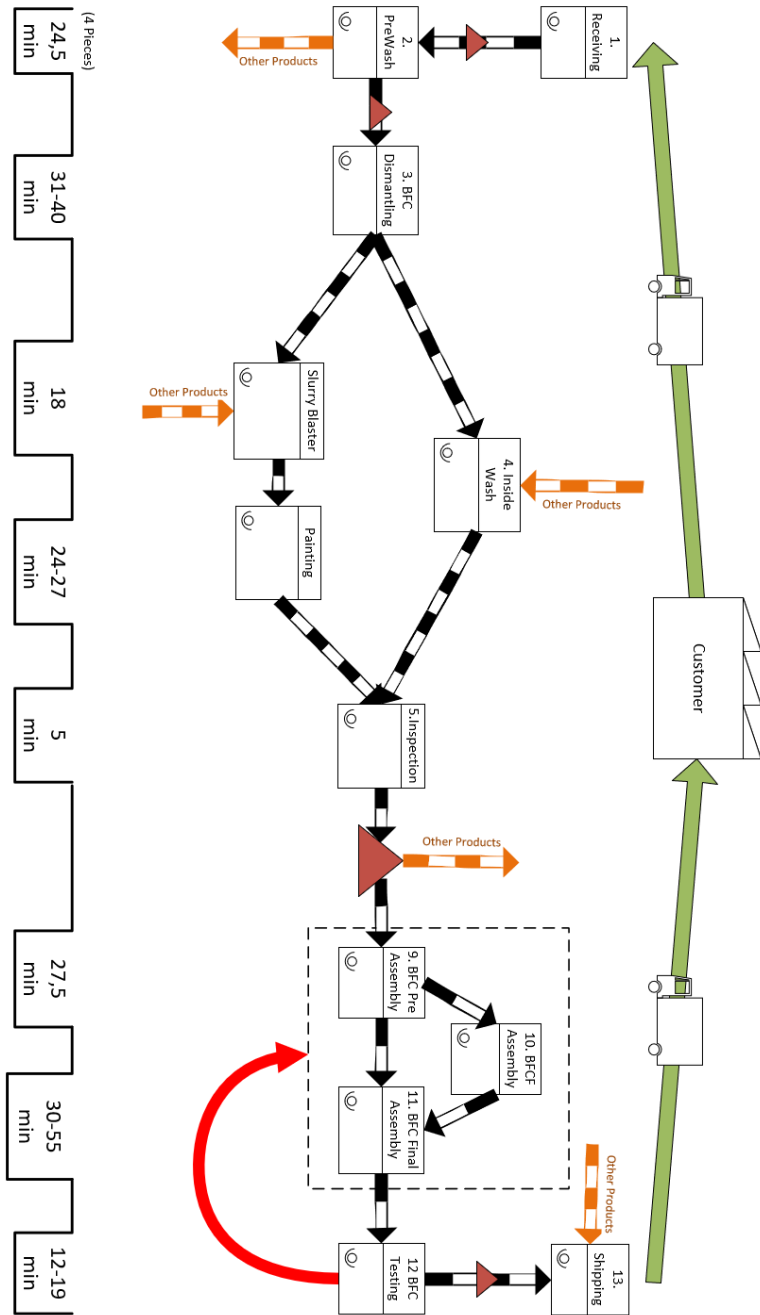***Figure 75:*** *Spinner hangar slurry blaster.* ***[24]***

Figure 76: *Value stream map with slurry blaster*

7.2. Final Results and Evaluation

In this chapter the results of the different improvement suggestions in the different scenarios will be demonstrated. The results will also be evaluated and result in recommendations for Faiveley to go further. Some values are not included in the various charts out of request of Faiveley, instead they are shown graphically in charts.

7.2.1. Final Results

In Figure 77 the yearly cost and yearly cost reduction, for both situations, S1 and S2, for each of the investments suggested above is presented. It can be observed that independently of which scenario, S1 or S2, the Slurry blasting machine SBM shows the largest possible cost reduction from the current situation. The reason that the scenario S2 shows the greatest cost reduction is simply because that since the scenario has the greater quantities and therefor the fixed costs will be divided on more parts and hours.

By dividing the yearly cost reduction by the retributive investment, a measure is given for cost reduction for every invested SEK. A comparison of this measure for both scenarios and the three different experiments can be seen in Figure 78. It can be observed that for this measure the PBC shows the best possible results in scenario S1 and HBM in scenario S2. This measure is good to compare different options in case capital is scarce since looking at the yearly costs directly already have taken the investment in to account.

In Figure 79 the cost of one overhaul of a BFC and BFCF is shown together with the cost reduction percentage the different investments would imply in the different scenarios. It is clear that the second scenario S2 shows the most promising results independent of investment, and that the slurry blasting machine SBM is the investment that will reduce the cost the most of overhauling a BFC or BFCF.

In Figure 80 the yearly time plan for the manual tasks demanding a worker is shown, together with the reduction that the various investments would imply, in the two different scenarios. The slurry blasting machine SBM shows the greatest possible reduction in the time plan. Figure 81 shows the process time for a BFC and BFCF for the different investments together the possible time reductions. The result shows also here that the slurry blasting machine SBM, shows the most promising possible reductions.

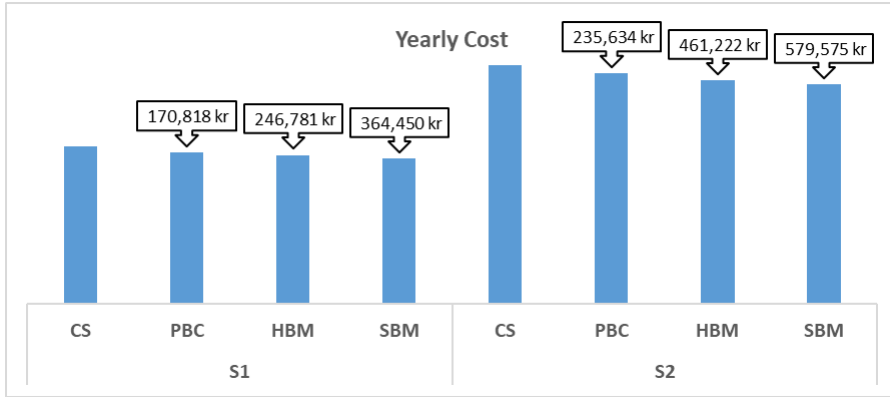***Figure 77:*** *Yearly cost (Columns) and yearly cost reduction (Callout boxes)*
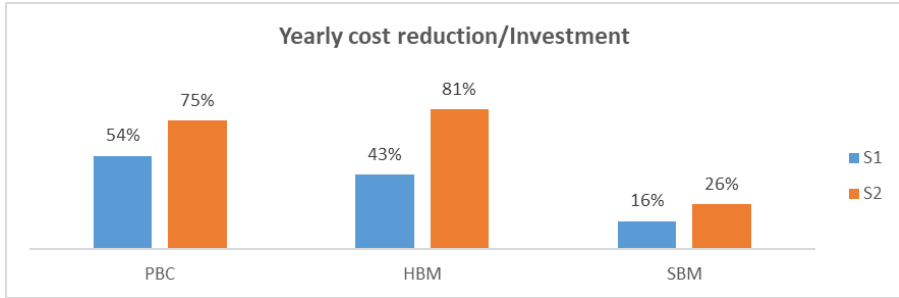

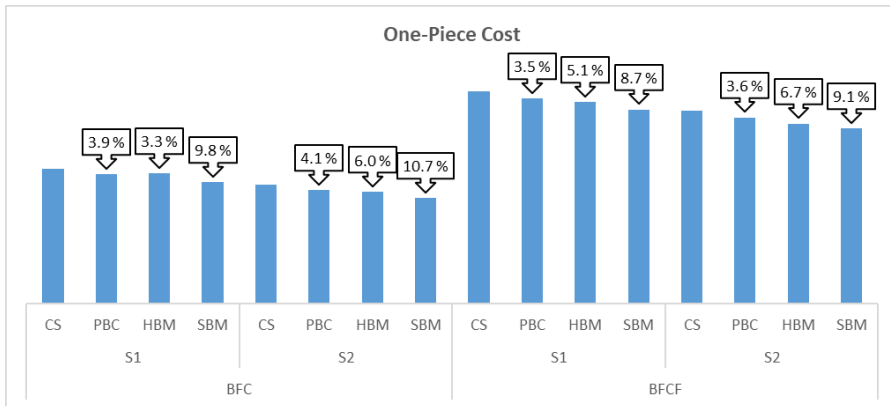***Figure 78:*** *Yearly cost reduction/Investment*

Figure 79: *One-Piece cost (Columns) and percentage cost reduction (Callout boxes)*
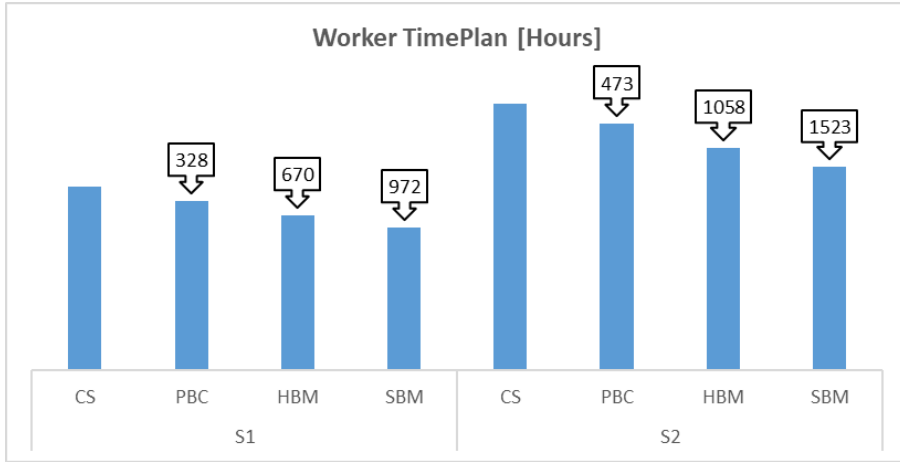
Figure 80: *Worker Time plan yearly (Columns) and time reduction (Callout boxes)*
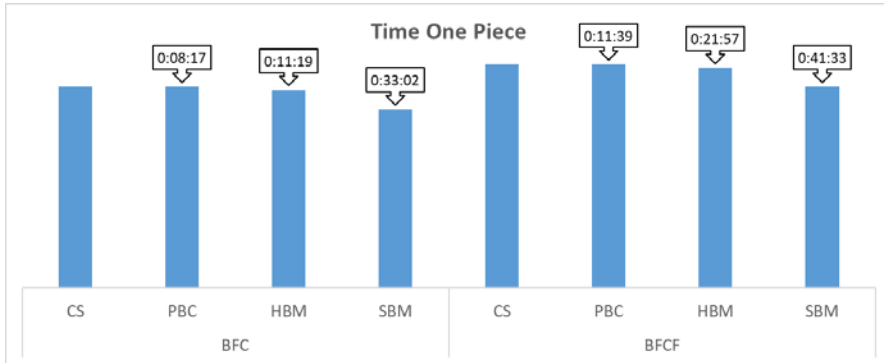
Figure 81: *One-Piece process time (Columns) and process time reduction (Callout boxes)*

7.2.2. Evaluation

Whatever option previously suggested is chosen to further evaluate, it is quite clear that significant cost reductions are possible. The pressurized blasting cabinets are the cheapest solution and definitely improve the situation, but only slightly. It is still manual and does not open for many other improvements or is a system that can be built up on. The issues with loading and unloading remain. It reduces the cycle times and the needed man hours, but not close to the level of the other options. It is a solution that is great if the strategy of Faiveley is not to continue doing overhauls for many years to come or capital is very scarce, otherwise it should not be chosen.

The hangar blasting machine is major step towards more automation in the overhaul process. It changes the sandblasting process significantly and removes some of the unergonomic and work intensive tasks. Loading and unloading will be simplified and can be outside of the machine while another product is being processed. The rail system leaves room for further improvements and can possibly be connected to other processes too. For example, if the sandwash were to be changed to a type that allows for a hanger on a rail to go through it, the loading between the sandblasting and sandwash processes could be eliminated and reducing the cycle times significantly.

The slurry blaster machine shows very promising results on many areas. It reduces the costs, the process times and the man hours needed yearly significantly. Furthermore, it eliminates much of the lifting and loading of multiple processes which improves the ergonomic situation of the workers. However, the results that are shown above can be deemed to be quite modest. It is not unlikely that the inside wash might not be needed at all or could be replaced with another smaller and simpler machine. Since the slurry blaster, simplifies the process flow and shortens the lead-times significantly for all products, improvements are likely to occur in other processes as well, due to less congestion and complexity. Furthermore, the rail system has the potential of being extended to other processes so that loading and unloading could be eliminated even further. As an example, the rail could be extended to reach the painting booth, so the products could be painted on the hanger directly, eliminating even more loading and unloading. It could also be connected to the dismantling steps before so that loading could be done from that process directly to the hangars. Furthermore, the escalating cost of repairs and maintenance of the inside wash is a warning that something should be done about it. Purchasing a slurry blaster could help on this point also.

It could be argued that the hanger blasting machine is cheaper and similar to the slurry blasting machine. It does create a significant improvement but for a much smaller investment. But it should not be forgotten that the slurry blaster creates many significant improvements, for many processes through just one upgrade. It reduces the complexity significantly and is compact. For the hanger blasting machine to reach the same results, as the slurry blasting machine does, many more investments must be made and many other systems built and connected, which very likely when all is done, will reach a higher cost.

Both the hanger blasting machine and the slurry blasting machine takes the overhaul process forwards becoming more automated. This is important for many reasons. Some of the workers in UH1 are in just a couple of years about to retire, they will be hard to replace, and if so is done the rate will be significantly lower because of the complexity in the processes. By automating some of the processes the impact of less experienced personal will not be as significant and the experienced personal can focus on the most complicated tasks. Furthermore, at the time this was written, it was already clear that the quantities that have been used in the different scenarios are probably smaller than what will excepted in the year ahead. As an example, the AC was deemed obsolete but has been decided to be reintroduced. Big orders are expected on the PBEC and PBECFP and more variants in big quantities. Furthermore, there is nothing that shows that the quantities of DRV will be less. This future, that is close ahead would enable for a bigger investment in UH1. But before doing so, the quantities should be updated and the scenarios of this should be tested in the cost model to do a further evaluation.

8. Discussion

The challenges set out at the beginning at this thesis were at the end confirmed to be true. Variations in the condition of the products, the vast amount of product variants, the supply of spare parts and last finishing this thesis in the intended time frame, were all proven to be difficult and not completely possible to overcome. The influence of the conditions of the products being overhauled have been considered for the type of BFC and BFCF that are overhauled mostly, but there are several other variants, often in worse conditions, that have not. If data were collected on these variants it could show in greater detail which BFCs and BFCFs that have the biggest issues and from that, prices could be adjusted accordingly. The influence of spare parts, though outside the scope, had a big influence and was therefore not completely disregarded. It is an area that Faiveley can be suggested to look further into, and could offer much cost reductions, as already have been discussed from the results from the Cost model system. What would be needed to be done in the cost model system to perform this analysis further, is to add a module or worksheet that looks at cost of inventory and service levels. What it would enable, is to analyses what effect a change in inventory would make on the cost and process time of a product.

One aspect of the purpose of this thesis was "to investigate the process all the way from receiving to delivery". Though most process were investigated, the processes receiving, and delivery were not fully investigated, mostly because of time limitation. This can in part be seen in that the hourly rate of "Receiving_Shipping" process is very high. To get a more accurate picture, more time studies will have to be made and the data regarding the equipment and stock levels in the retributive areas must be added in the CMS.

There are many explanations to why the time frame was overrun, one of which, that was a challenge in itself, was the data gathering. Since there were very much complexity in the overhaul processes and multiple products sharing the same equipment, it was not possible to get trustworthy results without much data having to be collected. Adding to this, as data was collected it was brought to one's attention that the administrative systems are a big burden for the company. Though much is documented, the documentation is not well structured, and information is hard to find. The many systems, documents, folders and files often did not work well together, which makes denotations and connections to disappear along the way of doing administration. One got the sense that people working at Faiveley were overwhelmed with this situation and since it was like this in many areas, often the easiest way to collect data was simply by directly measuring,

observing and listening to the employees, to get the facts straight. For Faiveley to get control of this issue it can be suggested to look for administrative systems that can replace many, to start cleaning up some of the legacy systems that seems to accumulate for every year that passes.

The creation of the cost model system also consumed more time than originally intended and doing a generic cost model, for a one-time analysis might not be effective, but doing so allows for fast analysis of improvements in the production for the future ahead. It can be noted that when the model was completed, and the data was gathered and inserted, the analysis was easily and quickly done since it is very easy to change some values, update the model and view the results. It is suggested for Faiveley to go further with this method to in a systematic way develop the production and to get an effective method for pricing products more accurately. As mentioned in the beginning of this thesis, the way Faiveley calculate their costs are simply with a fixed hourly rate for all processes, but as seen in Figure 67 this is clearly inaccurate. Despite that the purpose of this thesis was not to analyses the way Faiveley do their costing, it must be noted that this is clearly an issue that creates many negative effect for the company. If the wrong costs are showed for the products and processes, wrong priorities are made, both internally and by customers.

As one studies a company to the degree as is done in this thesis, one comes to greater insights about the greater issues of that company. At Faiveley there have shown to be top down management, bureaucracy, departments working in functional silos and so on. It is quite clear there are grudges between departments, but the issue is not just at the site of Landskrona, it seems also to be between the different Faiveley entity's in other countries. Many employees described that there is a culture of not sharing information among each other and not responding to each other's needs. Comparing Faiveley to what gets thought at the university it is easy to say that Faiveley is far behind in multiple areas. The production, production development, company culture, IT, supply chain, automation, quality and so on. There are many areas of improvements and looking at the view of production development at Faiveley it seems to be outdated. Faiveley like many other companies focuses on old principles from lean like value stream mapping, 5s, 5-whys and QRQC. Though these things are all good, a renewing of traditions would help to get Faiveley to focus on the important issues and prioritize the right things. A question that comes to mind is whether Faiveley are susceptible to a system such as the CMS? If the CMS were to be used, it could be used by multiple departments and would have a great possibility to take them in to the 21:th century and enable the management to get an overview of the costs

and processes in the company. It can be used as in this thesis, for production development but furthermore, for strategic decisions, planning, analyzing quality issues, pricing and much more. The CMS can be used by multiple instances of the company from planning and economics and sales departments to production technology department and purchasers. Having one entity were the data is merged to show a complete overview of the production, enables an analysis that could possibly get a company like Faiveley aligned, or in other words, get their priorities straight. Many people have probably wanted, suggested and tried to make changes at Faiveley, but not succeeded. One gets the feeling that people are tired bitter and disappointed to the slow and improvements that are made. I see this as a big barrier of implementing the cost model system or making significant changes at Faiveley. While implementing the cost model system could bring the truth to light so real improvements can start to happen, I don't believe Faiveley, being as conservative as it is, will consider it… However, I would like to be proven wrong.

In regards of theory, Ståhls cost model has served a major influence on the approach undertaken for this thesis. With that being said, not without any challenges and modifications having to be made to it. Though is easy to apply to a theoretical case with just one cell, it was not easy or completely explained how to be used for multiple products that share many of the resources, in a practical case. All the conditional dynamics that is encountered in real life is not something that the cost model by Ståhl generically takes care of. For this to be achieved demanded great number of algorithms had to be added. The time plans used is in the cost model system are calculated and have many dependencies in regard to how a resource is used. In Ståhls cost model the time plan, is simply assumed to be known. The cost of renovations is set as a fraction of the investment of the retributive machine in Ståhls cost model. Though this is convenient when looking at costs in theoretical case, it is not in a practical one. What is known in a practical one is the real cost and when it happened. Formats of the worksheets in the cost model system were made with the data sources in mind so that data would easily be inserted to the model. Breaking down every aspect in its individual part makes the problems of putting data in the model an easy task. Furthermore, the concept of using a so called "learning curve" which adds losses on manual tasks depending on what workforce is used, extends the cost model by Ståhls. This tool makes it possible to find an optimum combination of employed and hired workers in a factory and, more importantly, it shows the value of having experienced personal since the opposite adds to the losses. It can be concluded that Ståhls cost model served

as an effective model to use as a base for calculating costs of products and processes. The methodology, that was influenced by multiple sources, but strongly by Banks Simulation steps, showed to be a good and systematic approach to find possible production improvements and other issues, at least at Faiveley.

In general, the approach undertaken for this thesis have shown to be an effective and systematic approach for production development. It did go over the intended timeframe, but while it created more work here right now, it could save a lot of work in the future. Building the cost model system did consume a lot of time, but now when it is done the cost model system allows for fast analysis of improvements, both big and small, in more or less any manufacturing company.

What a cost model enables is to compare apples and oranges, time and waste, consumables and spare parts. The path towards creating it will demand that costs are put directly or indirectly on everything. This in turn gives a tool to systematically prioritize based on value. It is often stated than "one can't put a price on everything". But regardless of one choses to prioritize with or without putting a price or not, it is inevitably done. One must realize that when one priorities one option over another, one has decided what has the most value. What looking at costs enables is making this process of prioritizing less arbitrary. Money is not just a tool for trading goods and services, it is a system for normalizing and comparing everything, which for this case, the cost model system made possible.

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Appendix A

The dependencies of the power query

Appendix B

The Processes worksheet.
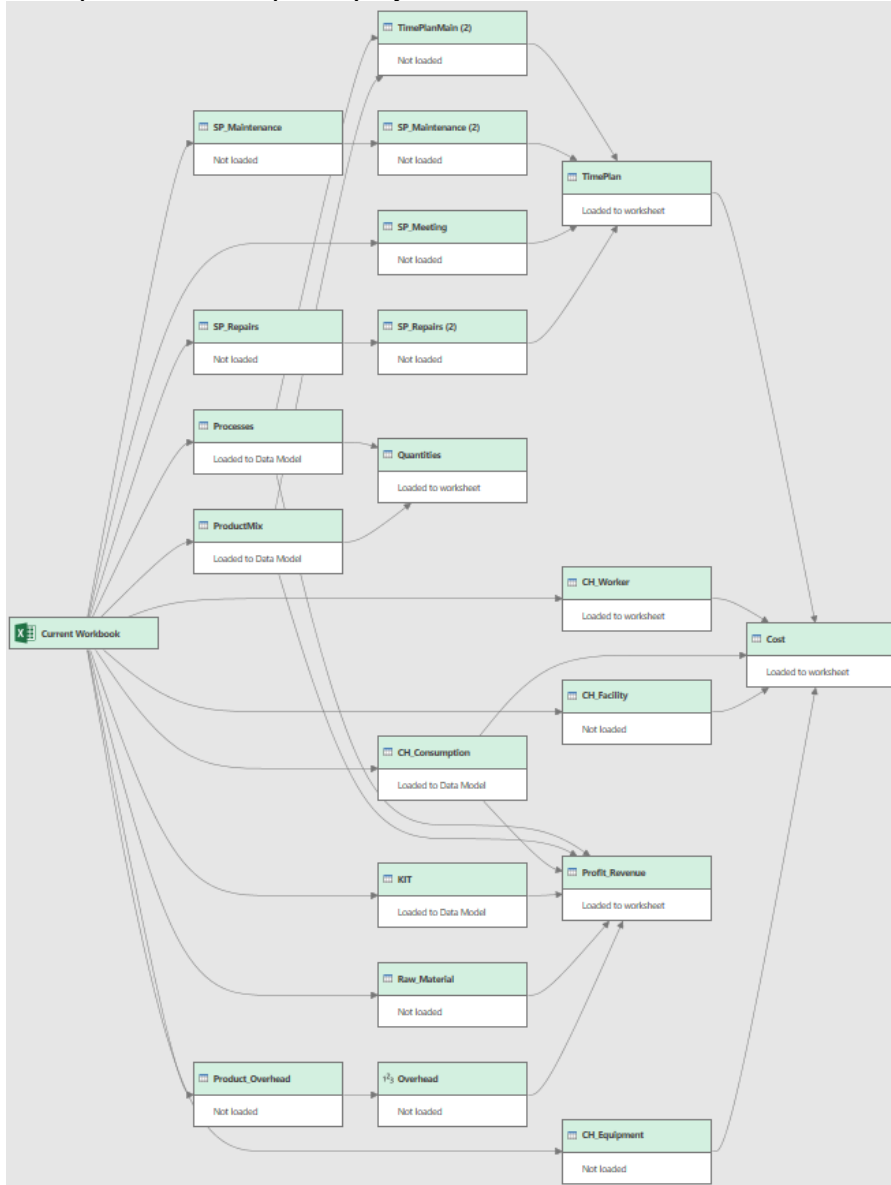
Appendix C

Prof that the general loss, the worker rate loss, the rework loss and the quality loss cannot be summed by simple addition to get the total loss. For it to be true the following would have to be equal to 0:

$$
\frac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} -
$$

$$
\left(\begin{array}{c}
t_0 + \dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} - \dfrac{t_0}{\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} + \\[2ex]
\dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} - \dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} + \\[2ex]
\dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} - \dfrac{t_0}{\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} + \\[2ex]
\dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right)} - \dfrac{t_0}{\left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)}
\end{array}\right)
$$

$$
=
$$

$$
1 - \left(1 - q_{pg}\right)\left(1 - q_{pw}\right)\left(1 - q_{pr}\right)\left(1 - q_Q\right) - \left(q_{pg} + q_{pw} + q_{pr} + q_Q\right)
$$

The last row is the residue which is only zero if three or four of the loss terms are zero.

Appendix D

Consumption table.

Description	Consumption by Product or Process?	Process	Product	Consumable	Amount	Unit	Amount per	Unit-Cost	Unit-Amount	Price/amount	Quantity or Hours Yearly	Amount per Hour or Piece	Cost Added	Amount Yearly	Cost Yearly
	Input							**Consumable Data**			**Product/Prosses - Data**	**Output**			
											Hours or Pieces				
Product		DRV	MOBILGREASE 28		0.133 kg		Process-Hour or Product-Piece	320.00 kr 1 kg	320.00 kr	974.00 Pieces	0.133	42.56 kr	129.5	41,453.44 kr
Process	SANDBLASTING		Blästersand	3693.75 kg		Year	320.00 kr 25 kg	12.80 kr	608.5 Hours	6.069	77.69 kr	3690.0	47,280.00 kr
Pre-Assembly		BFC	LOCTITE 243	0.2 ml		Process-Hour or Product-Piece	857.00 kr 250 ml	3.43 kr	675.00 Pieces	0.200	0.69 kr	135.0	462.78 kr
Pre-Assembly		BFCF	LOCTITE 243	0.2 ml		Process-Hour or Product-Piece	857.00 kr 250 ml	3.43 kr	667.00 Pieces	0.200	0.69 kr	133.4	457.30 kr
Total		BFC	MOBILGREASE 28	0.35 kg		Process-Hour or Product-Piece	320.00 kr 1 kg	320.00 kr	675.00 Pieces	0.350	112.00 kr	236.3	75,600.00 kr
Total		BFCF	MOBILGREASE 28	0.7 kg		Process-Hour or Product-Piece	320.00 kr 1 kg	320.00 kr	667.00 Pieces	0.700	224.00 kr	466.9	149,408.00 kr
Final-Assembly		BFC	LOCTITE 243	0.2 ml		Process-Hour or Product-Piece	857.00 kr 250 ml	3.43 kr	675.00 Pieces	0.200	0.69 kr	135.0	462.78 kr
Final-Assembly		BFCF	LOCTITE 243	0.2 ml		Process-Hour or Product-Piece	857.00 kr 250 ml	3.43 kr	667.00 Pieces	0.200	0.69 kr	457.30 kr
BFCF-Assembly		BFCF	LOCTITE 243	0.1 ml		Process-Hour or Product-Piece	857.00 kr 250 ml	3.43 kr	667.00 Pieces	0.100	0.34 kr	66.7	228.65 kr
Pre-Assembly		BFC	MOLYKOTE 1000 PASTE	0.00016 kg		Process-Hour or Product-Piece	676.00 kr 1 kg	676.00 kr	675.00 Pieces	0.0002	0.20 kr	0.2	116.89 kr

Appendix E

Worker worksheet

Appendix F

The Results worksheets shown in the following order:

1. Profit_Revenue
2. Product_Cost
3. Process
4. Losses
5. Time
6. Rates_Processes
7. Comsumables

Product Revenue

	AC	BFC	BFCf	Caliper	DP	DRV	VK	PBECFP	PBEC
Profit Yearly	82,937.48 kr	-1,733,595.21 kr	4,757,632.86 kr	118,963.02 kr	39,751.51 kr	2,842,417.00 kr	1,353,535.91 kr	529,244.80 kr	279,618.02 kr
Cost Yearly	17,082.52 kr	5,583,905.21 kr	2,942,367.14 kr	61,036.98 kr	50,248.49 kr	1,707,583.00 kr	1,166,464.09 kr	70,755.20 kr	105,381.98 kr
Revenue	100,000.00 kr	3,850,000.00 kr	7,700,000.00 kr	180,000.00 kr	90,000.00 kr	4,550,000.00 kr	2,520,000.00 kr	600,000.00 kr	385,000.00 kr
Profit Margin	83%	-45%	62%	66%	44%	62%	54%	88%	73%

One Piece

	AC	BFC	BFCf	Caliper	DP	DRV	VK	PBECFP	PBEC
Profit	8,293.75 kr	-3,151.83 kr	6,796.62 kr	5,948.15 kr	1,325.05 kr	4,372.95 kr	3,222.70 kr	13,231.12 kr	5,083.96 kr
Cost	1,706.25 kr	10,151.83 kr	4,203.38 kr	3,051.85 kr	1,674.95 kr	2,627.05 kr	2,777.30 kr	1,768.88 kr	1,916.04 kr
Sale Price	10,000.00 kr	7,000.00 kr	11,000.00 kr	9,000.00 kr	3,000.00 kr	7,000.00 kr	6,000.00 kr	15,000.00 kr	7,000.00 kr

Revenue

	Total
Profit Yearly	8,370,595.38 kr
Cost Yearly	11,704,404.62 kr
Revenue	19,075,000.00 kr

1.

Product Cost

	AC	BfC	BfCF	Caliper	DP	DRV	VK	PBECFP	PBEC
Overhead	145.78 kr	867.35 kr	359.13 kr	260.74 kr	143.10 kr	224.45 kr	237.29 kr	151.13 kr	163.70 kr
Raw Material	175.00 kr	6,000.00 kr	694.44 kr	1,500.00 k	470.59 kr	1,100.00 k	1,350.00 k	80.00 kr	114.58 kr
Consumables	- kr	143.35 kr	275.00 kr	- kr	- kr	- kr	- kr	- kr	- kr
Kit	800.00 kr	500.00 kr	900.00 kr	833.33 kr	883.33 kr	933.33 kr	983.33 kr	1,033.33 k	1,083.33 k
Process	585.47 kr	2,641.12 k	1,970.15 k	457.77 kr	177.92 kr	326.71 kr	206.68 kr	554.42 kr	554.42 kr
Cost	1,706.25 k	10,151.83	4,203.38 k	3,051.85 k	1,674.95 k	2,627.05 k	2,777.30 k	1,768.88 k	1,916.04 k

Product Process Cost

	AC	BfC	BfCF	Caliper	DP	DRV	PBEC	PBECFP	VK
SandWash		61.78 kr	44.23 kr	30.89 kr	3.09 kr	8.83 kr	20.63 kr	20.63 kr	3.09 kr
SandBlasting		312.61 kr	242.50 kr	103.36 kr	56.73 kr	110.07 k	52.01 kr	52.01 kr	37.82 kr
Receiving_Shipping		96.76 kr	53.76 kr			66.19 kr			115.28 kr
PreWash	349.27 kr	133.55 kr	119.41 kr	87.32 kr		42.41 kr	43.66 kr	43.66 kr	10.60 kr
Painting		74.19 kr							
MaterialHandling		167.29 kr	102.00 kr			25.88 kr	48.79 kr	48.79 kr	1.30 kr
InsideWash	236.20 kr	143.27 kr	262.45 kr	236.20 kr	118.10 kr	14.63 kr	236.20 kr	236.20 kr	9.45 kr
GrindingAndInspection		472.40 kr	40.08 kr			47.24 kr	153.12 kr	153.12 kr	29.17 kr
BfCF_Assembly		70.07 kr	222.65 kr			11.46 kr			
BfC_Testing		168.34 kr	192.83 kr						
BfC_Preassembly		333.85 kr	185.47 kr						
BfC_Finalassembly		392.49 kr	170.14 kr						
BfC_Dismantling		288.70 kr	260.45 kr						

2.

3.

Total Process Cost

Total Raw Material Cost

BFC   Losses:

BFC

4.

Time Yearly Processes and shared Resources [Hours]

Time One Piece

Using a Worker:

Worker Time per Process: BFC

6.