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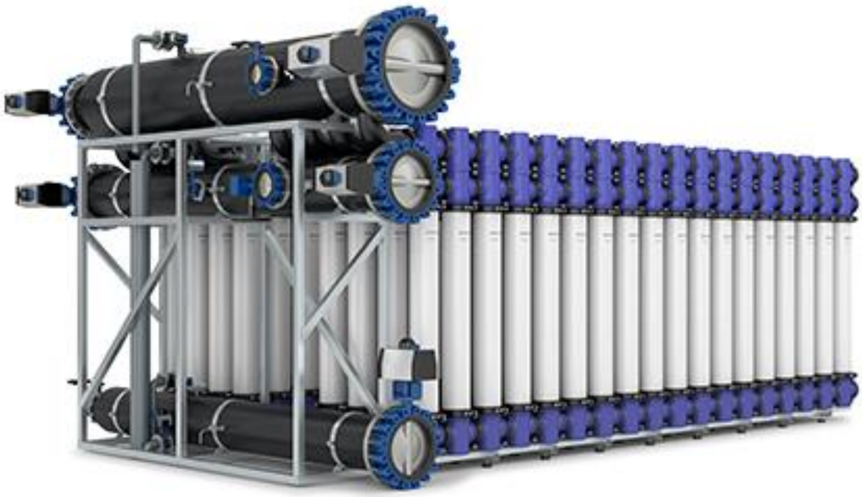
Improving process efficiency by applying lean



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Bachelor thesis industrial engineering and management

Title: Improving process efficiency by applying lean

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Due to confidentiality certain numbers in this bachelor thesis are multiplied with an unknown number, and certain parts are censored. Because of this multiplication calculated ROIs and costs/investment numbers do not always approach reality.

Management summary

problem

This research is conducted at Pentair X-Flow in Enschede on behalf of the lean department. The company produces filtration systems for several fluids. The focus of this research lays on the beer filtration product. Within the manufacturing of these products Pentair experiences inefficiency. The PCE% is unknown for these three products combined. The main research question of the thesis is: **'How to increase the Process Cycle Efficiency (PCE%) of the beer manufacturing process at Pentair by looking at the different kinds of waste according to lean?'**.

Analysis

To be able to increase the PCE% of the beer filtration products I firstly estimated a combined PCE using eVSM (Plugin for Visio). The combined PCE% of beer filtration products is estimated to be 13.37%. Secondly, I analysed why the PCE% is this low. I analysed the waste present using three different methods:

- Using the output of the VSM model
- Analysing the waste per work cell
- Analysing the waste per waste category

The three most influential wastes on the low PCE% of the beer filtration manufacturing process are the waste of waiting, waste of transportation and waste of defects. Moreover, the long cycling time(s) of the beer cell (casting cell and gluing cell) forms the bottleneck(s) of the process. It restricts the process from flowing and in combination with the waste of transportation it triggers batch-flow, which results in an increase of WIP. This batch-flow also decreases the PCE% since products have to wait for batch completion.

Solutions

The solutions generated in this research aim to solve the wastes that were identified during the analysis phase of the research or the waste in the process in general. Solutions were generated individually and by consulting stakeholders within Pentair. The solutions that specifically target the bottlenecks can be found in Table 1.

Solution	PLT decrease%	Cost saved	Surface reduction	Repair	ROI
Accelerated coating	12.72	€211,781 (one time) + €4,104 annually	34.2m^2	unchange d	0.71 < X < 0.84
Lowering coating height	6.25	€105,890 + €2,628 (annual)	21.9m^2	Likely higher	11.37
Merging the casting and gluing step	1.5	€176,282 (annually)	80m^2	36% decrease of beer repair	*
Sanding/Gluing cobot	Unknown (likely to decrease)	€408.811 (annually)	30m^2	44% decrease of beer repair	2.45

Table 1: Solutions that target the bottleneck (The two gluing solutions are multiple exclusive and can therefore not be implemented both)

Results

By combining the most promising solutions into a concept I was able to calculate the estimated impact on the PCE% and PLT using eVSM for Visio. Moreover, a sketch of the concept with all the chosen solutions was made. The following solutions form the concept:

- Accelerated coating
- Automating sanding/gluing step
- Kitting instead of prepotting
- Ensuring more quality of raw materials
- Team formation (visualization)

The KPIs and the sketch of the concept can be found in Tables 2 and 3 and Figure 1

KPIs	Current Situation	Concept situation
PCE% (in %)	13.37%	24.52%
PLT (in weeks)	4.46	2.69

Table 2: investment/return of the concept

Estimated investment costs	€900,000 to €1,100,000
Costs saved	€ 840,537.45 (one time) + €415,705.92 (annually)
Surface reduction	$80m^2$
ROI (3 years)	1.89 to 2.3

Table 3: KPIs current versus concept situation

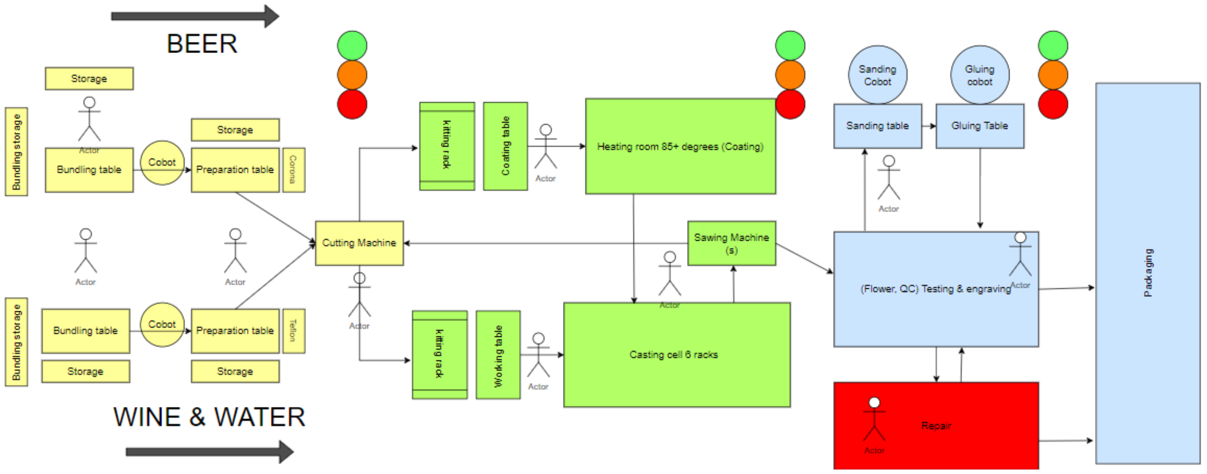

Figure 1: Sketch of the Concept

Recommendations

I advise Pentair to look into the different solutions provided in this research. Moreover, the solution can also be implemented individually and do not have to be implemented exactly like the concept in Figure 1 suggests. Another recommendation I have for Pentair would be to execute additional research into merging the casting and gluing step and to find a way to coat and cast for both sides of the model directly after another instead of having to loop through the process twice. This could simplify the process even more and therefore make it more efficient.

Preface

Dear reader,

This thesis is written with the aim to obtain my bachelor's degree for the program Industrial Engineering and Management. The research that enabled me to write this thesis has been conducted from January 2022 till June 2022 at Pentair X-Flow in Enschede.

Since my research contains a big part of case study the input of the employees at Pentair is crucial. Therefore, I would like to thank all the people at Pentair X-Flow that enabled me to execute the research to my best. I would especially like to thank Wim van Hal, my supervisor at Pentair X-Flow. He helped me to get familiar with the process and was of great influence for finding and formulating the proper research subject.

Moreover, I would like to thank Leo van der Wegen and Rogier Harmelink, my supervisors at the University of Twente. Throughout my research they provided me with plenty of feedback to improve my thesis and helped me improve my capabilities as a researcher.

Lastly, I would like to thank my family and friends for their interest in my research. Moreover, I would like to thank them for keeping me motivated throughout this strange Covid-19 period.

Ferran Harperink

20th of June 2022

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List of definitions and abbreviations

Abbreviation	Concept	Definition
CTQ	Critical To Quality	The quality specification a product or material has to fulfil for the customer
ER	Exit Rate	This is the rate at which products exit the manufacturing process
FPY	First Pass Yield	First Pass Yield is the percentage of production that does not need to be repaired or scrapped.
FTE	Full Time Equivalent	FTE equals the time an employee works per week (Full-time)
KPI	Key Performance Indicator	This is an indicator on which the process is assessed
NVA-time	Non-Value-added time	This is the time within the production lead time that there is no value being added to the product
PCE%	Process Cycle Efficiency in percentage	This number indicates how much of the total processing time exists out of value adding activities
PII department	Process Improvement Implementation department	This is a department within Pentair that focuses on process improvements and how to implement improvements.
PLT	Process Lead Time	The total time it takes a product from entering the manufacturing process till finished goods.
QA	Quality Assurance	The department within Pentair that is responsible for the quality assurance
R&D	Research & Design	This is one of the departments within Pentair which is responsible for research and design of products/processes
STW	Standard Work	Standard work refers to the amount of time an operator spends performing the task.
VA-time	Value-added time	This is the time within the production lead time that there is value being added to the product
VSM	Value Stream Map	This is a lean tool used for waste identification and analysis
WIP	Work in Progress	This is the total amount of unfinished product in the process at a certain moment.

1. Introduction

In this section I introduce the outlines of the research. First, in Section 1.1 I provide a brief description of the company. Second, in Section 1.2 I provide an extended description of the problem occurring at Pentair. After that, in Section 1.3 the problem-solving approach is introduced. In this section the reader can find the research questions used in the research.

1.1. Company description

Pentair is an American company that manufactures products to increase water quality. An example of these products can be filtration system for a pool and filtration system for beverages. They supply in a wide array of markets from spa and pool systems to biogas installations (Pentair, n.d.). For my bachelor thesis I am doing an assignment at Pentair X-flow in Enschede. At the company location in Enschede Pentair manufactures filtration products for beer, wine and water. My assignment is executed on behalf of the lean department at Pentair. I investigate the efficiency of the manufacturing of the beer filtration products. In total Pentair produces three different beer filtering products, respectively A, B and C. These products slightly vary in size and processing steps. The production plant in Enschede has two different departments, respectively "Static department" and "Dynamic department". The beer modules that my research focuses on are produced in the Static department. Next to the beer modules 'Wine&Water' and 'compact' modules are also being produced at the Static department in Enschede. The modules produced within the "Dynamic department" use different membranes and therefore have a different manufacturing process than the beer modules. This enables Pentair to use a different manufacturing process in comparison to the modules that need to be produced at the static department.

1.2. Problem description

The current manufacturing process of the beer filtration systems at Pentair is complicated. The process follows multiple different processing steps. Moreover, I observed that the workflow is not optimal and requires the products to travel long distances. The current process makes use of the cell-layout. This means that each manufacturing step is processed in its own cell. During my visits at Pentair, it became clear to me that the problem is the inefficiency. While observing the production I could see that there were a lot of products standing around waiting for their next manufacturing step. Moreover, the most produced beer module only had a PCE% of 45.14. This PCE% was retrieved by a lean specialist within Pentair in 2021. The efficiency of the process now is measured in terms of **Process cycle efficiency (in %)** which is calculated as follows (Bicheno & Holweg, 2016):

$$PCE\% = \frac{VA\_Time}{PLT} * 100$$

where:

- VA-Time = value-added time (Hours)
- PLT = Process Lead Time (Hours)

The **process lead time** is calculated as follows:

$$PLT = \frac{WIP}{ER}$$

where:

- WIP = Work in Progress (Pieces)
- ER= Exit rate (Pieces/ Hour)

The current **PCE%** for Product type C equals 45.14%. Type C is the beer module that is produced the most within the Static department of Pentair. This number indicates that the amount of non-added value time is bigger than the time there is value being added, since it is lower than 50%. The **PCE%** can never be 100% since that would mean that a product is being produced in a perfect way. Moreover, I also do not count moving products through the process as a value-added activity.
The question whether this calculated PCE% of product type C is valid remains, since it is calculated using an ER. Nevertheless, because of a push flow and repair within the manufacturing process, this ER is unstable and unknown. Moreover, the PCE calculations do not take into account the influence of other product types that are also produced at the same work cells that product type C is produced at. Therefore this 45.14% shows the reason for this research, but is not a fully valid estimation of the PCE% of product type C. Throughout the report I investigate and provide the actual PCE% of beer filtering products types A, B and C combined. The research question is therefore:

How to increase the Process Cycle Efficiency (PCE%) of the beer manufacturing process at Pentair by looking at the different kinds of waste according to lean?

The inefficiency of the current process causes several problems within the company. First of all, from a financial perspective Pentair is losing a lot of money because of the inefficiency. There are too many unfinished products in the process. This also increases the chance of quality loss in between the processing steps. Second, since the process is inefficient, it makes planning production difficult. Because there is inefficiency in the process, the lead times become unpredictable. A third aspect is that inefficiency can also result in demotivation. Since the current inefficiency causes products to not hit the first-time right standard, the operators must do a lot of unnecessary handling.

To solve the inefficiency, Pentair needs to change certain things which will be found out during this research. The core problem of this research is therefore an action problem. An action problem is, as it says itself already, a problem that requires action to be solved (Heerkens & van Winden, 2017). To be able to solve this action problem I will answer certain knowledge problems throughout this bachelor report, since I first have to know how high the combined PCE% will be and what is causing it to be low. These knowledge problems form the base for the research-questions. The first part of the research will therefore be explanatory. The research will find out why and how the process is inefficient and look for solutions to solve this. Moreover, in the end of the research solutions will be generated and a concept will be created.

1.3. Problem Solving Approach

Research must be planned and structured well. To make sure I will succeed at what I intended achieving at the beginning it is essential to start while keeping in mind the desired outcome (Covey, 2010). Therefore, a proper problem-solving approach is of great importance for my research.

To ensure that I can answer the research question of my bachelor thesis, ***how to increase the Process Cycle Efficiency (PCE%) of the beer manufacturing process at Pentair by looking at the different kinds of waste according to lean?*** as good as possible I structured the research. The problem-solving approach that is used for this report is inspired by the Managerial-Problem-Solving Method (Heerkens & van Winden, 2017). This problem-solving method consists out of the 7 phases shown in Figure 2.

Figure 2: MPSM Cycle

1.3.1. Research questions

To be able to understand the current manufacturing processes I answer the first research question of this report:

1. *What does the current beer filtration membrane manufacturing process look like?*
    - *What processing steps does the overall process consist of?*
    - *How much time do all these steps take?*
    - *What is the layout of the processing line?*

To answer the first question, I talk to the operators at Pentair and observe the production process and steps myself. Moreover, I use the data that is already available and is valid for the current situation, for example current processing times and operator times. These times are retrieved by executing "Standard Work" timings. The answer to this first question forms Section 2 of this bachelor thesis.

2. *What is lean manufacturing?*
    - *What kinds of waste exist according to lean manufacturing?*
    - *Which lean tools exist and can be used at Pentair?*

To answer the second question, I introduce the theoretical framework to the reader. In Section 3 of my bachelor thesis, I provide the information about lean management and the different kinds of waste. This enables me to apply the theory on the case of Pentair in Section 4 of this bachelor thesis. To answer the research questions below I will conduct additional literature research.

3. *What types of waste are the most present at Pentair and why do they occur?*
    - *What are the values of the KPIs (PCE%, WIP, PLT) in the current situation?*
    - *What wastes are most present at Pentair and how do they influence the PCE%?*
    - *Which work cells do contain or cause the most waste in the process?*
    - *What does cause all this waste?*

After I introduced the problem, the process and mention the theoretical framework, it is time for me to bring the two different topics together. I identify the different types of waste at Pentair. Which of the different lean wastes are occurring and which types of waste are of the biggest influence on the efficiency of the process? The answers on these research questions form Section 4 of this bachelor thesis. I investigate the waste that is present in the process as one thing and within the processing steps itself.

4. *What solutions can eliminate the waste currently present at Pentair?*
    - *What will be the impact of the solutions?*
    - *What will be the investment costs of the solutions?*

Once I identified the waste at Pentair, I enter the phase of solution generation. To come up with solutions I will perform interviews with the R&D department at Pentair and the employees at Pentair that are responsible for testing new manufacturing possibilities. Moreover, I contact the supplier of workbenches and machines to get to know the feasibility of my solutions. The solutions will be modelled in eVSM to calculate a corresponding PLT and PCE% change. The answer to this question forms Section 5 of this bachelor thesis.

5. *How can the generated solutions be merged into one concept?*
    - *What will be the impact of the concept on the PLT and PCE%?*
    - *What needs to be kept in mind while implementing the solution?*
    - *Who needs to be included during implementation?*

After research question 4 is answered, a concept is formulated that contains the most promising solutions from question 4. This will be done by using a weighted impact effort matrix. Once I identify this, I merge the chosen solutions into a concept. And I include an implementation plan that describes who has to be involved and what should be focussed on in a short term and during a long term. The answers to these question form Section 6 of this bachelor thesis

1.3.2. Conclusion and recommendations

Once all research questions are answered a conclusion is made including recommendations to the management team of Pentair, together with a discussion of the research the conclusion and recommendation form Section 7.

2. Description of the current situation

In Section 2.1, I introduce the different manufacturing steps and provide a brief description of the beer filtration product manufacturing process. In Section 2.2, I provide descriptions of the individual manufacturing steps. In Section 2.3, I elaborate on which products there are, and which manufacturing steps the different products require. Moreover, I show how long all the manufacturing steps take for each product type. In section 2.4, I introduce the layout of the Static department.

2.1. Description of the manufacturing process

In Figure 3 the manufacturing process of the beer filtration products is illustrated. As can be seen the manufacturing process consist out of in total thirteen different steps of which some are performed twice due to manufacturing constraints. Overall, the products mainly follow the same process, Figure 3 helps to quickly identify where the products differ from each other.

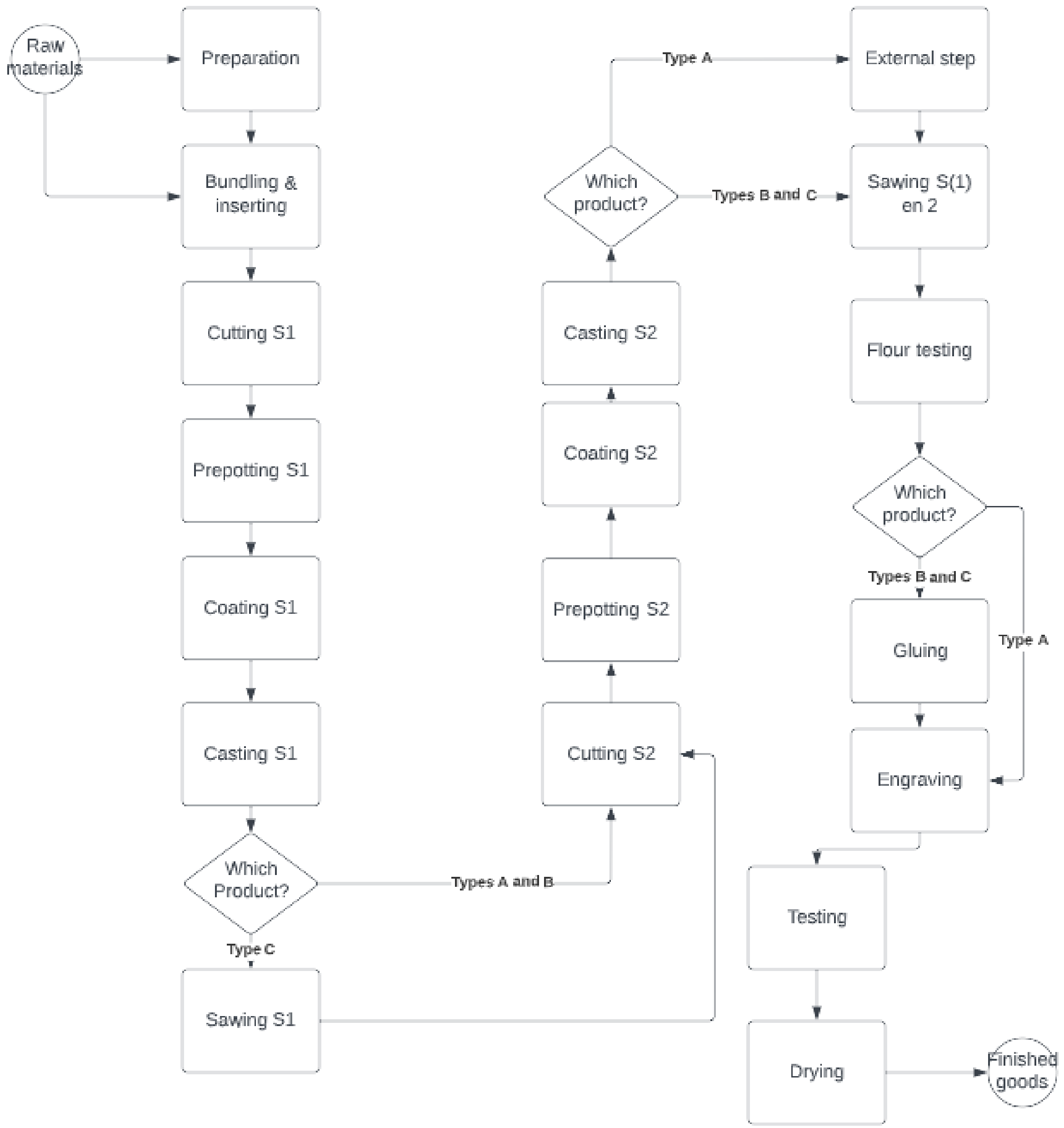

Figure 3: Map of the beer filtration product manufacturing process

As you can see in Figure 3 the raw materials arrive to at the preparation and bundling steps. Housings and spacers are delivered to be prepared. Once the housings and spacers are prepared, they move on to the bundling operator. This operator bundles smaller bundles into bigger bundles and inserts the bundles into the housing/spacer. After that the first side of membranes is being cut. Then prepotting casting and coating happens. This sequence is performed twice since these manufacturing steps cannot be performed horizontally. Once the product has looped through there twice, product type A is prepared for the external step. The next step is sawing of the module, for product type A and B the both sides are sawn at the same time. Type C is sawn side by side. Once the product is sawn product type B and C have to be glued. Product type C does not have to be glued and will immediately move onto testing of the product. If the product passes the test, it is dried and packaged. A more extensive explanation of these manufacturing steps can be found in Section 2.1.1.

Currently at the static department of Pentair operators are assigned fixed manufacturing steps. This means that there are operators that spend the whole day cutting products or bundling and inserting. Nevertheless, at the moment operators that are assigned to the beer cell perform the manufacturing steps from prepotting until flour testing. Moreover, the manufacturing step gluing has 2.5 fixed FTE assigned to it. The external step for product type A takes around 1 to 2 weeks. Moreover, the preparation for this step is performed by the operator that is also responsible for the preparation of the housings/spacers. Another thing to keep in mind is that several operators that work on the manufacturing of beer filtration products at the moment are also producing wine and water filtration products. The following operators produce wine, water and beer filtration products:

- Preparation operator
- Bundling operator
- Cutting operator
- Testing operator

The demand for wine and water filtration products is lower than the demand of beer filtration products and therefore only covers a small part of the operator time.

2.2. Description of the manufacturing steps

In this section a more extensive description of each manufacturing steps of the beer filtration products is provided.

2.2.1. Preparation

This phase of the production is about setting up the beginning. The different modules use either spacers or housings. Before the operator starts working on the module, they must check whether the spacer or housing is of good quality. They have to check whether there are scratches or colour differences on the housing. If the quality is as expected the operator cleans the inside and outside of the housing with ethanol. If the product contains a spacer the operator also has to check whether the spacer contains damage or colour differences. To prepare the spacer the operator has to sand it as straight as possible. This has to be done since the supplier does not sand it with enough precision. In the next step the operator has to apply the backflush plates on the spacer. Lastly, the operator has to attach the fixation set on the spacers. All these processing steps to the spacer are precise and therefore are rather time consuming. Once all these tasks are done, the products move on to the bundling cell.

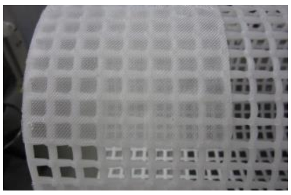

Figure 4: Spacer wit backflush protection

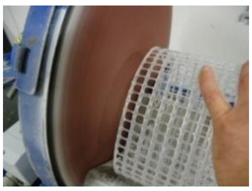

Figure 5: Sanding Spacer

Figure 6: Checking the Internal

2.2.2. Bundling

In the bundling cell the operator checks the membranes and gets rid of the membranes that are broken, nodded or dirty. If there are two or more membranes that need to be removed per bundle, the operator will replace the exact number of membranes by other proper ones. If there is only one bad membrane a replacement membrane is not needed. When the operator made sure the bundle is of good quality, the bundle will be inserted. Depending on the product type this process is different. For product type B, the operator bundles the membrane bundles into one big bundle in a gutter and then inserts it into the spacer. If the product uses a housing instead the operator has to put the bundles into an inside compartment. Once they are in the compartment the operator applies clips to fixate the membranes in the compartment. After this is done the operator inserts the compartment (including the fixated membranes) into the housing. When the membranes are inserted into the housing or the spacer, the operator applies isolation tape at both sides on the membrane. While applying this 38mm isolation tape the operator must be cautious that the sticky side of the isolation tape does not touch the membranes, since this could damage them. This isolation tape is applied to keep the ends of the membranes together to enable the operator to cut as straight as possible in the next production step.

Figure 7: Bundling

2.2.3. Cutting

In this stage of the process the operator cuts off parts of the membranes that are hanging outside of the housing or spacer. Depending on the product type there is a certain length of membranes that must stick out of the module. A cutting stop ensures that the bundles are cut on the appropriate length. When the operator cuts the membranes, it is key that they focus to cut it as straight as possible in order to make the upcoming steps in the manufacturing process as easy as possible. The membrane bundle has to be laid properly in the spacer and is then taped to the spacer. Moreover, a foam is used to align the bundle for cutting. The membranes are cut in several goes, after each cut the operator turns the module 90 degrees, this helps to cut as straight as possible. Once the operator finishes cutting there are still several tasks they must execute before the product can go on to prepotting. After cutting there is a lot of residue left on the module. In order to clean the module, the operator blows minimum compressed air on the product. For product type C the operator must glue a permeate-stop into the conus. Since product type C uses a housing instead of a spacer there is no fixation set applied yet, therefore after cutting the operator mounts a hang-clamp on it for the prepotting/coating racks.

Figure 8: Cutting Stop

Figure 9: Cutting Machine

Figure 10: Hang-Clamp

2.2.4. Prepotting

During this stage the modules are hung on a prepotting/coating rack. The operator has prepared a prepot substance on a plate. This plate is pushed onto the end of the membranes to close them. The operator gets the plate of the membranes by using a slight twisting technique. Once the plate is removed the operator checks whether all the membranes are actually closed by the prepotting substance. If this is not the case, they will close the ones that remain open with their hands. This prepotting substance reaches temperatures of 40-50 degrees Celsius. The heating of the prepotting takes around 2 hours for the three beer filtration products. During this process it is important that the operator makes sure that the prepot does not stick the membranes together, for this a spatula is used to keep them moving. This ensures that the membranes fill the module properly and do not stick the membranes together. Before the module can continue to the next processing step it has to cool down. This takes at least half an hour.

Figure 11: Operator applying Prepotting

2.2.5. Coating

The coating step is performed in batches of five or ten. At the beginning the operator puts the raw materials into a bucket that will form the coating. After that the bucket is put under a stirring machine which mixes the raw materials into a smooth coating. This process takes the machine around 10 to 15 minutes. Once the coating is mixed properly, the operator holds the membranes in the bucket and applies the coating for 45 seconds for all the product types. Depending on the different product types, the height of the applied region of the coating differs. After that the membrane bundles have to leak out for 60 seconds. Once the obsolete coating substance has drained the operator pats the membrane bundle dry with a paper towel. After that the membranes have to dry, which takes around 2 hours. The operator has to make sure during these 2 hours that the bundles stay loose. To ensure the membranes stay lose and do not stick together they use the same kind of spatula that is also used during the prepotting step. After these 2 hours the insert has to dry for an additional 40 hours for product types A and C, and 12 hours for product type B. Product type A and C are heated at a temperature of 40 degrees Celsius, product type B is heated at a temperature of 75 degrees of Celsius. After the drying of the insert, it has to cool down for 2 hours. Once the module is on room temperature it is checked and ready for the casting processing step.

Figure 12: Operator applying Coating

2.2.6. Casting

This manufacturing step is executed in the casting cell in batches of 5 or 10, since all cups on one rack share the same temperature program regulator (HB-Therm). This casting cell has to have a certain humidity and temperature to ensure the quality of the casting substance. Every day the ratio and the temperature of the substance has to be checked. In the casting cell the operator makes use of casting cups where the modules are put on. Before the modules can be inserted onto this cup the operator has to check whether there is damage and if necessary clean it. Then the cups and the hose are greased with vaseline. The hose connected to the cup is used to regulate the temperature during the casting. The temperature is set to 20 degrees Celsius for the beginning of the temperature program. Besides the casting cups the modules also need to be prepared before the operator can start the casting process. At the beginning the operator checks the prepotting, if not all membranes are closed this still needs to be fixed. Once the operator checked the quality of the prepotting and coating, they attach the module onto the casting cups and fixate it. When they are attached and on the proper temperature the operator can start the casting process. The operator taps the casting substance into a PE-pot. This pot is put on to the pouring hose that is attached to the casting cup. Depending on the product type the casting process has to be done in multiple steps. Table 4 shows the number of times that a new PE-pot has to be put onto the casting cup during the temperature program.

Product Type	**Times of casting**
A	3
B	2
C	2

Table 4: Times of casting per product type

Once the first time of casting is done the operator gets the PE-pot of and inserts a new one. At the end of the casting the operator gets the module of the casting cup. When this does not go easy enough the operator heats the cup again. Moreover, the pouring hose is disassembled from the casting cup. The casting in this tube hardens and therefore this tube is considered waste and thrown away. After all these processing steps the product is able to move on to the next step.

2.2.7. Sawing

The two modules that use spacers instead of a housing are put into a mould. This mould is cleaned with ethanol before usage. Once the module lays in the half of the mould the operator closes the two halves together and closes it with a lock. They check whether the module lays correctly and fixates it afterwards. There is a length measuring system used to make sure the module is cut into the proper size. All of the products are sawed in the same Conrad machine. Once sawing is done the membranes at the sawed side should be open again. A vacuum cleaner is used to suck out the open membranes.

2.2.8. Flour testing

Now that the product is sawed, it is time to test whether all membranes are open. One of the tests all the product type must undergo is flour testing. The operator applies flour on one of the membranes ends side. Then they blow pressured air from the other side to see if all the membranes are open. If one of the membranes still has flour on it, this means that the membrane is still closed and has to be opened. To open it they insert a pin in the closed membrane. This test is performed on both sided. If on both sides not more than 1 membrane remains closed the operator may assume that it is the same one. However, if it is more than one, they have to find the closed ones at both sides which is rather time consuming. If too many membranes are still closed, leaking or too short the product will be set on hold. If the product passes the flour test it is ready to move on to gluing or qc-testing, depending on the product type. Product type A is not glued and therefore can be tested, the other two product types have to be glued first.

Figure 13: Flour testing

2.2.9. Gluing

Only product type B and C are being glued. Product type B makes use of a PES-ring that is glued on while product type C gets a flange bushing glued on, both processes are mainly the same. The PES-ring and the flange bushing need to be roughened. Besides that, the module compartment also needs roughening on the part that has to be glued. Because of that the glue will stick the two better together. The operator afterwards makes sure that the module is clean. Once all the parts are rough and clean the operator starts applying the glue. The glue is applied in two layers on both the flange bushing or PES-ring and the module. While adding these layers the operator must make sure that the glue is applied tight and therefore does not create any air bubbles. Moreover, the operator has to wait 5 to 10 minutes between applying the different layers. After that the flange bushing or PES-ring is pressed onto the module tightly, using a turning motion. The operator lets the glue dry between 5 and 15 min, during this waiting they press the component onto the module more tightly two to three times. Once the glue is dry the obsolete glue is removed. After that the operator will remove the crepe tape. For product type C the operator glues a permeatport into the conus. the operator will put a centration mould on the permeatport that is used to level it out. The glue needs to dry one night until the centration mould can be dissembled. At the end of the gluing step, the operator cleans the whole module one more time with ethanol. Product type B needs 16 hours for drying the glue properly. Once the products spent this time drying it can move on to the next processing step. As you can see in Table 7 on these steps require a lot of operator time, especially for product type C.

2.2.10. Engraving

After product type B and C glue is dry, the operator has to engrave them. Product type B is put in a mould and put under the engraving machine. The operator programs the machine in such a way the serial number on height of the backflush protection. Engraving is readable from the spacer side. For product type C the same machine and mould are used. Product type A is engraved by hand by one of the operators.

Figure 14: Engraving Machine

2.2.11. QC-Testing

During the first phase of qc-testing the operator checks the quality of the product one more time. The operator must check whether all the forms are filled in correctly. Moreover, they perform a visual inspection of the product. This also includes checking the identification of the product. During this phase of qc-testing the products are tested in water. Since the products are wet, they are very vulnerable and have to be put into a hydrate or test housing. First of all, the three product types have to undergo a vacuum-humidification and leak out on a leaking card. After that a pressure test will be applied to the products. For this test a machine is used that closes off the product and puts pressure onto the products. This pressure varies per product type. This tests whether the product can handle the pressure that it should be able to handle for the customer.

If the test results of the palltronic test are all good the operator will label the product with a green tape. Forms are filled in and the test results are added to the computer file of the product. If the test result is suspicious or divergent the operator will perform a leaking-test in addition. This test is executed in the water basin. The membranes get filled with water, after that the product is connected onto the testing machine. This machine puts pressure on the product and enables the operator to identify leaks. After testing the operator removes the machine and gets the pressure of, while the product is still laying in the water basin. After that the products are picked out of the water and put on a leaking cart. The products need an hour to leak out after that the products are checked sufficiently and are ready to move on to the drying step.

2.2.12. Drying

After testing the products are still wet. To be able to pack the products Pentair has to make sure that the product is dry. When the products are not fully dry, they are more prone to become damaged. The products are put onto a cart. With one side the products will be connected to a drying machine. This drying takes around 12 hours. Once the operator thinks the product is dry the weight of the module will be measured. The product is allowed to weigh a maximum of 10 grams more than last time it was weighted (just before flour-testing). By doing this the operator makes sure that the product is dry enough. If during the testing phase leaks were found, these will be fixed after the product is dried. After the repairs the product must go through testing and drying once more before it can be packed.

Figure 15: Modules attached to the drying machine

2.2.13. Packaging

The packaging step deviates per product type. For product type A, the operator will check the specification of the product. After that the product is packed in vacuum seal bags. The packing process of product type A is mainly the same as the one of product type B

For product type B, the operator will get rid of fixation blocks and the transport housing that is used for transporting the product from cell to cell. All specifications of the product are checked one more time. After that the operator packs the product in a vacuum seal bag. For this they use a machine which does not vacuum pack it but packs it air free. The seal bag should be as close as possible to the epoxy head. After this the operator puts the module number on the packaging and puts six finished products of type B into one box. The products are protected by using fitting foam within the box.

For product type C, the operator only still has to put sticker onto the housing of the module. Once the stickers are on the products are put on a transportation cart. After this an operator from the warehouse will pick up the finished products.

2.3. Types of products and processes

During this research I investigate the production of the beer filtration membranes. These membranes are produced at the Static department at the production plant in Enschede. Pentair produces three different beer filtration membrane systems, respectively filtration Product type A, Product type B and Product type C. In Table 5 you can see the size and specifications of the different membranes that are used for the manufacturing of beer filtration products.

	Di (mm)	**Number of membranes per module**	**Min. Length (cm)**
MF02 (B)	1.5*2.35	4085	185
MFO8 (B)	1.5*2.35	4080	185
(A)	1.5*2.35	2700	126
(C)	1.5*2.35	2880	100

Table 5: Specifications of the different membrane per product type

As you can see the filtration membranes differ in the number of membranes and the length at which they must be cut off. The diameter of the different membranes is much alike. Since these products only differ slightly in specifications the manufacturing processes are mainly the same with exception on a few processing steps. The modules being produced at the Dynamic department use different membranes and therefore also have a different production process.

Looking at Table 6 below you can see that the most manufacturing steps are required to develop the product types. This also has to be the case since the three different products are being manufactured on the same production line. Since the products are fairly similar it makes sense to elaborate on the different process steps. First of all, Product type C does not require the spacers to be prepared since it simply does not use any spacers. Instead of this spacer product type A make use of a housing that needs to be prepared. Product type B makes use of a fixation set on the spacer, the two other products do not require a fixation set on the spacer or housing of the module. Moreover, you can see that product type C first gets sawn on side 1 and then undergoes the whole process for side 2 after that. For product types A and B the 2 sides are sawn at once before the modules head on to testing.

Beer filtration modules						SIDE 1									SIDE 2																
Producttype	Preparing Spacers	Preparing Housing	Placing Spacers	Preparing Bundles	Inserting Bundles	Cutting	Prepotten	Drying prepot	Literate	Coaten	Drying coat	Checking	Casting	Sawing	Cutting	Prepotten	Drying prepot	Literate	Coaten	Drying coat	Checking	Casting	Preparing for Y	Sawing	Flourtesting	after-processing	glueing	engraving	QC Testing	Module Drying	Packaging
A																															
B																															
C																															

Table 6: Processing steps per product type

To get a clear understanding of the process it Is important to know how long each step takes. First of all, Pentair acquired operator times throughout observations. A minimum of 5 observations were executed last year to come up with the average operator times per processing step. The average operator times can be found in Table 7. In Appendix A I provide a figure with the highest and the lowest observation. You can see that the operator time per product type strongly differs. Type A requires way less operator time to be produced than the other two, since this product type does not have to be glued. Average drying/hardening times can be found in Table 8.

Operator time	*(In Minutes)*			
	Product type	A	B	C
	Preparing spacers	5:25	19:03	N/A
	Preparing housing	N/A	N/A	7:11
	Preparing bundles	6:10	10:00	6:10
	Inserting bundles	11:35	9:02	15:41
SIDE 1	Cutting	6:55	13:54	4:40
	Prepotting	3:05	3:05	3:05
	Literate	1:00	1:00	1:00
	Preparing coating	1:30	1:30	1:30
	Coating	2:05	3:05	2:05
	Checking	1:53	2:54	1:53
	Preparing casting	2:21	1:44	2:26
	Casting	2:18	1:56	3:40
	Getting of the cups	1:27	0:36	1:46
	Sawing	N/A	N/A	3:29
SIDE 2	Cutting	4:39	7:21	1:48
	Prepotting	3:05	3:05	3:05
	Literate	1:00	1:00	1:00
	preparing coating	1:30	1:30	1:30
	Coating	2:05	3:05	2:05
	Checking	1:53	1:53	1:53
	Preparing casting	2:26	2:26	2:26
	Casting	3:40	3:40	3:40
	Getting of the cups	1:12	1:12	1:12
	Sawing	11:12	12:07	3:29
	Flourtesting	6:50	13:32	3:50
	After-processing	5:40	N/A	3:00
	Glueing	N/A	17:12	42:54
	QC test & drying	8:11	12:45	13:57
	Packaging	5:48	5:23	1:51
Total OP Time	*(In Minutes)*	**01:44:55**	**02:34:00**	**02:22:16**

Table 7: Operator times per processing step

Activity	**Correspond drying/hardening duration (in hours)**		
	Product type A	**Product type B**	**Product type C**
Prepotting	1.5*	2.5*	1.5*
Coating	44*	19*	44*
Casting	19*	18*	20*
Gluing	0	19	21
Drying after testing	12	12	12
Total of all activities	**141**	**110**	**174**

*Table 8: Waiting times after/during manufacturing activities (activities with a * are performed twice)*

2.4. Layout of the production Plan

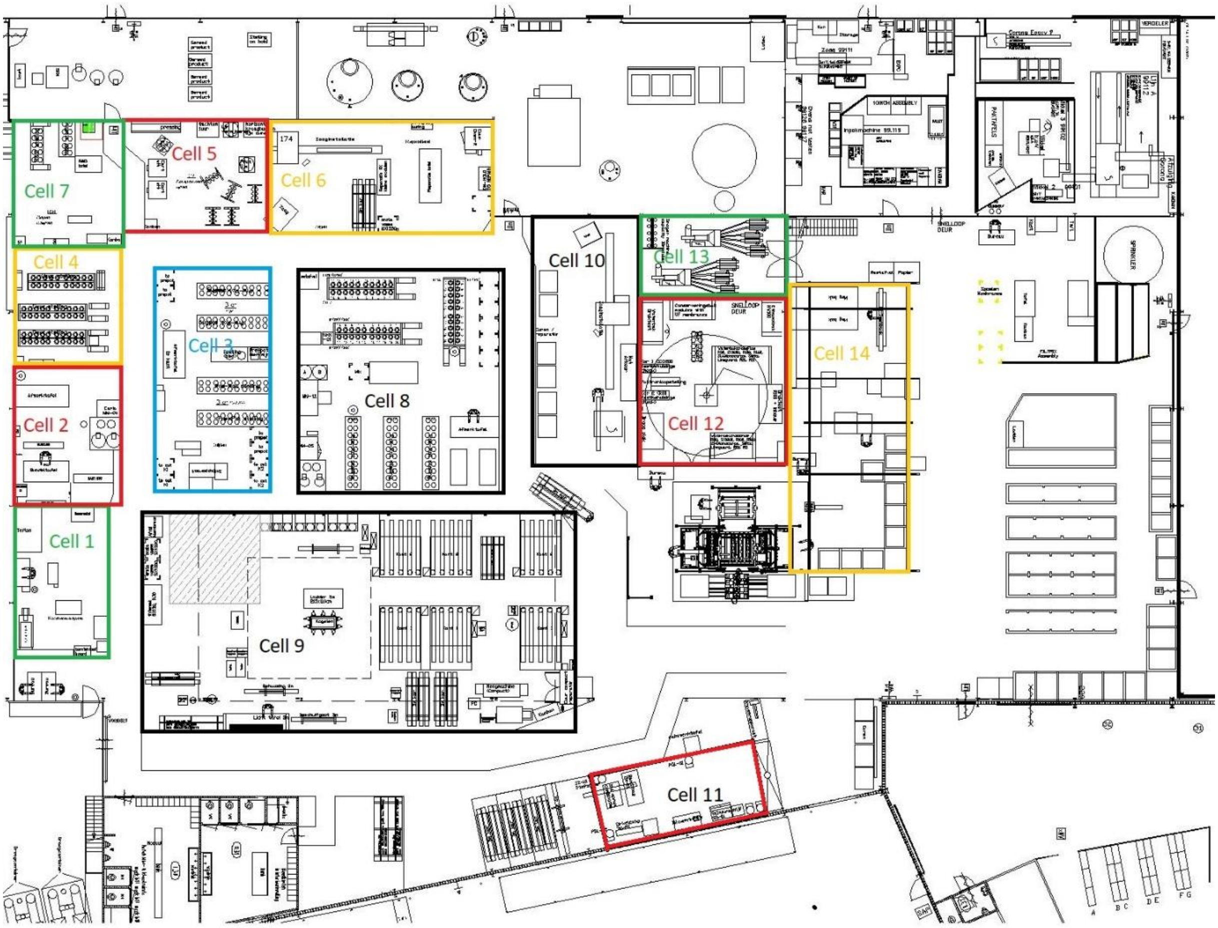

Figure 16: layout of the manufacturing plant

Another important aspect of the current situation is the manufacturing layout that is used at Pentair. As you can see in Figure 16 the current layout of the production plant is ordered in work cells. In this way the products flow from cell to cell. To make it easier to get a clear picture of what is done where, I gave each work cell a number. Moreover, in Appendix H (confidential) you can find figures of the work cells with their corresponding cell number.

Cell number	**Cell Name**
1	Preparation cell
2	Bundling cell
3	Beer cell
4	Casting cell
5	Gluing cell
6	Sawing cell
7	Gluing/R&D cell
8	Wine cell
9	Compact cell

10	Sawing cell (Dynamic)
11	Sanding cell
12	QC-Testing cell
13	Drying cell
14	Packaging cell

Table 9: Cell types

The entrance of the production plant is in the left bottom underneath cell 1. Moreover, in the left bottom the changing rooms are located for operators.

2.4.1. Allocation of the work cells

As you can see in Figure 16, cell 1 is closest located to the entrance of the plant. This is the preparation cell. In this cell the first steps of the process are performed, respectively the preparations of the housings and spacers. In the cell housings and spacers are located, there is a small extraction room for the appliance of Teflon and there is a table for the operators to work on. When the products are processed by the operator in the preparation cell, they move on to cell 2. Between these cells a fixed cart is located which is currently used as supermarket inventory. A sidenote to this cell is that product type A must return later in the value stream again to undergo the preparation for transportation to the external step.

Cell 2 is called the bundling cell. In this cell there is a table on which the operator bundles and checks the membranes. Moreover, there is an ionization clamp in which the operator can hang the membrane bundle for checking and straightening out the bundles before inserting them. In this cell there is also a storage vessel for the raw materials that form the casting substance. Once the products are processed by cell 2, they move on to cell 3.

Cell 3 is called the beer cell. In this cell they perform three processing activities. In the bottom of the beer cell the membranes are cut on in length by a cutting machine. Moreover, there are also storage spaces for clamps and permeate stops that need to be assembled to product type C. Once the product is cut it is ready to be prepotted and coated. These processing activities take place in the upper part of the beer cell. As you can see there are three racks that all contain 20 cups for these activities, which means that the current capacity of the cell adds up to 80. Moreover, in the middle of the racks in the beer cell, there is a storage vessel for the prepot/coating substance. Lastly there is a preparation/finishing table at which the coating of the modules is checked before it moves on to the casting cell.

Cell 4 is called the casting cell. This cell is fully closed off because the casting process requires a certain humidity at several temperatures. In these cells there are 3 racks in which modules can be coated. This adds up to a capacity of 60 modules. These 3 racks have one HB-Therm. This means that with the current racks only one temperature program per rack can be used.

Depending on the product type of the modules, the sawing cell is visited before the module returns to the beer cell again. The sawing cell is cell 6. There are 2 sawing places located in this cell. However, the products that I focus on during this research are being sawn on the bigger one in the back of the cell. The right part of this cell is used for the reparation of modules.

After side 1 of the products is finished it loops trough the beer cell and casting cell another time. once side 2 of the product is also finished the products visit cell 6 again to be sawn.

After sawing the products have to be flour tested, after processed and sanded. These three steps take place in the sanding cell. Just as the casting cell the sanding cell is a somewhat closed room with a proper extraction canal. When the module is flour tested and sanded the product either moves onto the gluing cells or the qc-testing cell. Product A is not glued and therefore goes to qc-testing after visiting the sanding cell.

The next step for product types B and C is gluing. Product type B is glued in cell 7, This cell is also used for R&D purposes besides the gluing of product B. Product type C is glued in cell 5. In this cell there are racks located to put the modules into. On the left side of the cell the modules that are waiting to get glue applied are placed. In the back of the cell the flange bushing is glued onto the module. At the left part of the cell the permeate port is glued on as a final gluing task.

Cell 12 is the qc-testing cell. In this cell the modules undergo a pressure test and a leaking test. To be able to execute these tests the module must be wet. Therefore, there is a humidifier machine and water basins. Product type B must be wet before flour testing as well and therefore already visits this cell earlier during the manufacturing process. Moreover, in this cell there is a robot that can lift the modules. This helps the operators with carrying the heavy modules, since these tests are performed wet the products still have to dry afterwards. Otherwise, they could be damaged while packaging the product. This is done in cell 13.

Engraving is performed while using the engraving machine in front of cell 11. For product type B and C engraving is performed after gluing. Product A is engraved after processing is done.

If you look at Table 9 and the cell description above, you may notice that 3 cells are not mentioned at all. This is because the beer filtration products do not visit cell 8, 9 and 10. Sometimes the prepotting/coating capacity of the wine cell is used for the beer filtration products however the sawing cell (Dynamic) and the compact cell are not of importance for the beer filtration products.

2.4.2. Transportation and allocation of inventory

The material parts that are needed for the beer manufacturing are stored in two inventory places. In Figure 16 beneath the manufacturing plant the inventory of the membranes is located. This inventory place is called “Taartpunt”. The inventory of the housing and spacer is located on the right of the manufacturing plant, this location also functions as the warehouse where the finished goods go to. These product parts are brought to the work cells with a tugger.

Between the work cells the unfinished goods are transported in batches by carts. The batch size per product is as follows:

Product A	10
Product B	5
Product C	10

Table 10: Batch size

Product type B has a batch size of 5 since this product is large and uses the same type of cart as the other products. This means that there is only place for 5 modules on the cart.

To roughly visualize how the beer filtration products flow through the factory I provided a spaghetti diagram of product type B. This product also visits the drying cell after being coated. Looking at the spaghetti diagram of product type B it can be seen that the product travels a long distance from raw materials to finished goods.

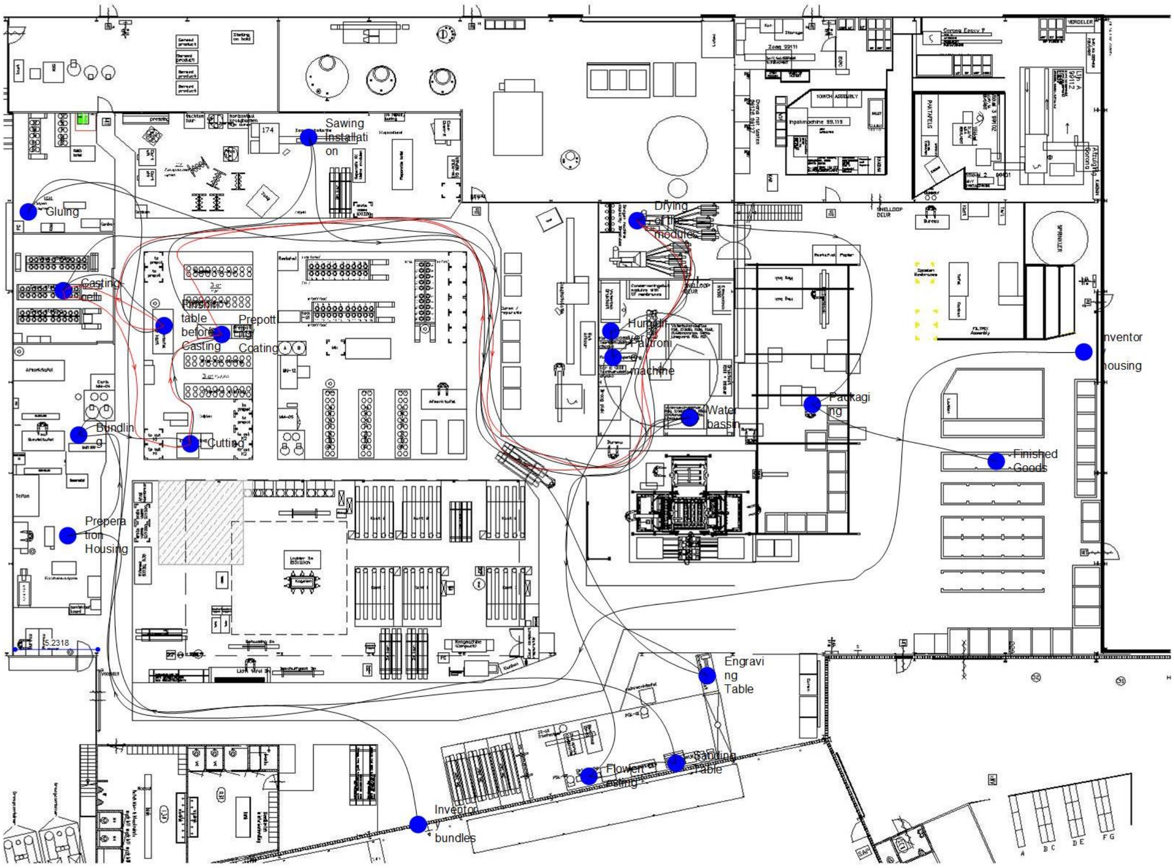

Figure 17: Spaghetti Diagram Product B

2.5. Conclusion

In this section I answered research question 1, I described the processing activities that transform the raw materials into the finished goods. I described the different beer filtration products that is focussed on during this research. Moreover, I explained the layout of the production plant in Enschede.

The production process of beer filtration membrane system consists out of 3 different product types which undergo mainly the same manufacturing steps. The whole manufacturing process consists out of thirteen steps from raw materials to finished goods as can be seen in Figure 3. All the beer filtration products undergo the steps from cutting until sawing twice, first side 1 and then side 2 of the modules. These thirteen steps are performed in the production plant in Enschede where a work cell layout is used for production. The work cells and their location can be found in Figure 16. Operators have fixed manufacturing steps assigned within their work cells. One exception on this would be the operators of the beer cell that perform multiple tasks that are also outside of the beer cell, for example: flour testing, casting and sawing.

Preparation cell	**Bundling cell**	**Beer cell**	**Casting cell**	**Gluing/ Sawing cell**	**“Schuurhok” cell**	**Testing cell**	**Packaging cell**
Preparation	Bundling	Cutting*	Casting*	Sawing*	Engraving	QC-Testing	Packaging
		Prepotting*		Gluing	Flour Testing	Drying	
		Coating*					

*Table 11: Work cells and corresponding manufacturing steps (every step indicated with * is performed twice)*

3. Theoretical Framework

Section 3.1 introduces the definition of lean manufacturing. Furthermore, I introduce the five principles of lean according to Womack & Jones (2003). Since lean focusses on waste reduction, you can find the main waste types within lean in Section 3.2. In Section 3.3 a description of the most used lean improvement tools is provided. Several of these lean tools are used further on in the report.

3.1. Definition of lean manufacturing

Lean is a broad concept and multiple sources have different definitions for lean. According to Slack & Jones (2016) you can see lean in three different ways: Firstly, lean can be used as a guideline of how to perform operations. The philosophy of lean aims for perfection by waste reduction and increase of flow. Secondly, lean can be seen as a management tool that helps to control and plan operations in an efficient way. Thirdly, lean offers a toolbox to enhance the performance of current operations. As you can see lean can be used in several ways, for example, while designing a process. However, if a company already has a functioning process, lean could also be used to control their process, in terms of planning and strategy. Lastly, when people notice that a process is not performing as required, they can use the improvement tools that are provided by the lean theory to enhance the process.

"A 'quick and dirty' definition of lean is 'doing more with less'" (Bicheno & Holweg, 2016, p. 1). With this definition Bicheno & Holweg (2016) mean using as few resources possible to reach the customers value. Lean is both very theoretical and practical. It offers the ideal situation you should try to reach. This ideal situation is different for every case, however it aims to reduce the waste and increase value and flow of products. Yet again lean also offers the tools that can be used to reach this ideal situation. As mentioned by Bicheno & Holweg (2016) using these tools to try and reach the ideal situation is a repetitive process. You cannot expect that by using a lean tool once on the current case the ideal situation will be reached. However, you can expect that by applying the lean tools to the current case the process will improve and get more efficient.

3.1.1. Five principles of lean

In order to make the definition and purpose of lean clearer I will introduce the five lean principles of Womack & Jones (2003). These five principles are not a step-by-step guide on how to reach the ideal situation, but they must be kept in mind while continuously trying to improve (Bicheno & Holweg, 2016).

1. Specify value

First of all, it is essential to clearly visualise the value that you want to offer as a company. When specifying this value, it is important that you take the value that the service or the product should offer to the customer (Womack & Jones, 2003). A second point of importance is to take into consideration what the customer is willing to pay for to reach this value.

2. Identify the value stream

The value stream is the path the product travels from raw material until arriving to the customer (Womack & Jones, 2003). It is important to visualise what this path looks like. A thing to keep in mind is that a bottleneck in this value stream will result in a decrease of value of the whole stream. By identifying the value stream you enable yourself to analyse performance and identify possible bottlenecks.

3. Flow

Once the value stream is identified you can look at the flow of value. The smaller the batch size is, the better the flow will be. When flow is not possible and a queue occurs, you should look at the causes and try to resolve the queue of unfinished products (Bicheno & Holweg, 2016). This can be established either by solving a bottleneck but also by producing on the cycle rate of the bottleneck.

4. Pull

Once the process is designed in such a way that the flow is present and there are no unfinished products standing around anymore, the company will be able to use a pull strategy. By ensuring flow the process gets faster and therefore more agile. This makes planning easier and enables to plan according to demand instead of capacity. The benefits of the pull strategy are that you only produce whenever it is needed. This makes it easier to spot quality issues and reduces the uncertainty that goes with forecasting (Bicheno & Holweg, 2016).

5. Perfection

Perfection is about reducing the waste and come as close to zero waste as possible (Bicheno & Holweg, 2016). Moreover, it includes delivering the value that the customer is paying for, in terms of product quality and delivering on time.

3.2. Types of waste according to lean manufacturing

Since the aim of lean is to reduce activities that do not add any value from the customers point of view to the product it is important to know the different types of waste. Moreover, you should also keep in mind the influence these kinds of waste have on the process. Before I introduce the different types of waste it is good to know that they can also be classified in another way. According to Womack & Jones (2003) there exists two types of Muda, which is the Japanese word for waste: Muda type 1 are non-value adding activities that are necessary to run the process. Muda type 2 are non-value adding activities that are unnecessary, and therefore pure waste that should be reduced or eliminated.

Beneath I list the different types of waste with a short description. During my research I will keep in mind the seven types of waste that were originally formulated within lean manufacturing and the later formulated waste of unused employee creativity (Bicheno & Holweg, 2016).

1. Waste of Overproduction

Overproduction can simply be described as producing more than needed or producing at the wrong time. Since you are producing products at the wrong time it immediately results in more costs (Bicheno & Holweg, 2016). The customer does not want these products yet and therefore they need to be stored (or maybe even destroyed). The storing of products also leads to risk of quality loss because there is a lot of transport involved.

2. Waste of Waiting

As it already insinuates, this waste occurs when either operators or products are waiting. Therefore, this waste can decrease flow drastically. Waste of waiting products is more problematic than an operator that is idle for a short period of time. If a product must wait, it will either turn out in WIP or inventory. Waiting of products can occur because of varying processing times per step but also because of batching throughout the manufacturing process. The aim for this category is to minimize the waiting time of the products. Moreover, it can occur that an operator must wait on a machine or information. Just as a product waiting around a waiting operator is inefficient. However, from the customer point of view it does not matter as much as products waiting, since this is not the value they pay for.

3. Waste of Transportation

This waste occurs when a product has to be transported more than necessary. That can happen because of a plant layout that lacks logic. While transportation cannot be minimized to zero, the aim should be to transport the (unfinished) products as little as possible (Bicheno & Holweg, 2016). When transporting there is always a slight risk involved of damaging the product (Bicheno & Holweg, 2016). Moreover, it means extra lead time that the customer is not paying for. Because of this increase of lead time the manufacturing costs increase. When there is waste of transportation working in batch sizes also becomes more likely, which results in a lower efficiency.

4. **Waste of Overprocessing**

This waste occurs when the product is more processed than the customer finds necessary. Again, looking from a customer perspective, they only pay for the necessary steps within the manufacturing process that actually add value. But as soon as that value is all added to the product a customer will be satisfied with the product. Therefore, if the manufacturing process contains steps that do not align with the perception of value from the customer this is pure waste. You could see this as producing more quality than the customer actually requests.

5. **Waste of Motion**

According to Martínez Sanahuja (2020) motion is the movement of persons that does not add value to the product. Mazlum & Pekeriçli (2016, p. 4) contradict with this by defining it as “any unnecessary movement performed by sources”. According to Bicheno & Holweg (2016, p. 19) “Unnecessary motions refer to both human and layout”. Therefore, I will see motion as obsolete movement by the operators, which can be caused because of the layout but also because of behaviour or habits.

6. **Waste of Inventory**

Waste of inventory means storing more supplies than required for the needs of the customer (Mazlum & Pekeriçli, 2016). There are a several losses caused by too much inventory, for example the holding costs. Having too much inventory also decreases your liquidity and stored products are also more prone to become damaged, since they must be controlled (Martínez Sanahuja, 2020). You could say that inventory is also a form of overprocessing because the products need to be stored and this does not add any value to the product.

7. **Waste of Defects**

This waste occurs when a product lacks quality or differs from the required specifications throughout the process. Whenever this occurs, a product has to be reworked or repaired. Whenever this is the case and a product needs to be reworked, it will result in extra costs and a higher lead time. If the quality issue is too severe and the product has to be scrapped that will also result in a lot of waste of materials and loss of value.

8. **Waste of unused employee creativity**

This waste is about not accepting and/or using the capabilities of people that are part of the process to improve the process. Moreover, it can also refer to people being assigned easy task while they are capable of doing way more (Martínez Sanahuja, 2020). Lean is all about using as little as possible to achieve as much as possible. Therefore, it is a good idea to use the full potential of operators and employees that know the process.

An aspect that can be noticed with the waste categories above is that these wastes are related to each other. Take waste of inventory for example. When producing too much or too early you have to stock the products somewhere in your warehouse. Therefore, the waste of overproduction and inventory are related. Moreover, inventory could also lead to overprocessing if you interpretate storing of finished good as an additional processing step. Therefore, these categories intersect and may cause each other to happen.

3.3. Lean improvement tools

There are multiple improvement tools within the lean-manufacturing theory that help reduce waste. During my research I will use several of these tools to come up with solutions that are aligned with waste reduction. Since the aim during this research is to increase efficiency, I need to know which lean improvement tools fit certain types of waste the best. Therefore, in this section I list the improvement tools that exist, a brief description of them and the effectiveness the tools have for what type of waste. A thing to keep in mind would be that lean is not just a simple set of tools that can be implemented to improve situations (Bicheno & Holweg, 2016). However, keeping them in mind throughout the research and adapting it in such a way it fits your case will enable you to improve the efficiency of the process.

3.3.1. Value Stream Mapping (VSM)

By making a value stream map you get a clearer view of the value of the product and how it flows. In a value stream map you list all the processing steps that it takes to make the product. After that you list those activities in three categories (Womack & Jones, 2003):

- Activities that create actual value
- Activities that do not create value themselves but are necessary to run the operations
- Activities that do not create value themselves and are also not necessary to run the operation

After categorising the activities, a clear picture of the waste along the value stream is established. This tool is useful for waste identification because it shows you what waste is present, and which wastes are relatively easy to eliminate. Moreover, value stream mapping enables us to design the future state (Bicheno & Holweg, 2016). Value stream mapping can also be used to identify WIP throughout the process since you can quickly see the difference between the different processing steps within the manufacturing process. The value stream mapping also enables you to calculate the Key Performance Indicators (KPIs) of the process. In this map you can easily spot the flow of product and information. Moreover, it shows the time it takes the product to gather all the value and flow from raw materials to the customer.

3.3.2. Sort, Simplify, Scan, Stabilize, Sustain (5S)

According to Theisens (2016) 5s focuses on establishing an organized work environment. The 5Ss respectively stand for (Theisens, 2016):

- Sort
- Straighten
- Shine
- Standardize
- Sustain

These 5s help to keep the work environment well organized. 'Sort' focuses on what is used often and therefore has to be located closely and what is not and therefore does not have to be located closely or can be thrown away. Once the workplace is sorted and all obsolete items are thrown away it is time to 'straighten' out the workplace. This S can be seen as assigning a location for materials (Theisens, 2016). The third S stands for 'shine'. The aim of this S is to keep the working environment clean by putting materials and items back to the location that they are assigned to (Theisens, 2016). The fourth S stands for 'standardize'. This means setting rules and guidelines, moreover, responsibilities will be determined (Theisens, 2016). The last S stands for 'sustain'. As the word already implies it means keeping up the first 4Ss and therefore make sure that the workspace does not fall back to the unorganized situation. This can be done by using audit checklists regularly (Theisens, 2016).

3.3.3. Just-In-Time (JIT)

This lean tool was invented at Toyota around the 1950s (Womack & Jones, 2003). It means delivering as late as possible but, as it says, Just-In-Time. This reduces the time you must stock either raw materials or finished goods. This lean tool is however a bit more difficult to implement. Just-In-Time (JIT) can be seen as a tool to establish the 'Pull' principle of lean. Before you can establish pull, you first have to establish flow by reducing waste. Moreover, in order to apply JIT successfully, changeover times have to be low (Womack & Jones, 2003). JIT is a tool that reduces the waste of waiting since raw materials are ordered when necessary and not just because of a safety stock. Just In Time is therefore a lean tool that helps with establishing pull.

3.3.4. Poka Yoke

Everyone makes mistakes without noticing it sometimes. Poka Yoke focuses on eliminating making these mistakes. Poka Yoke means preventing the occurrence of accidental/unnoticed mistakes (Bicheno & Holweg, 2016). These unintended mistakes are unnoticed by an operator himself when they make them. Therefore, Poka Yoke tries to come up with devices or procedures that prevent unintended mistakes to turn into quality issues along the production (Bicheno & Holweg, 2016). Poka Yoke can be implemented in many ways to prevent mistakes that would otherwise remain unnoticed which could turn into repair or quality issues. This lean improvement tool is rather effective for reducing waste of defects.

3.3.5. Kaizen

To describe kaizen as a lean tool might be an understatement, however the idea of kaizen provides some useful lean tools. First of all, Kaizen means improvement when you translate it literally from Japanese to English. Value starts at the customer and customer desires change over time, because of that Kaizen is all about continuous improvement (Bicheno & Holweg, 2016). Important is, that during this continuous improvement everyone is involved (Slack & Jones, 2016). The Kaizen method is founded on the following five principles according to the Lean Six Sigma Groep (2021):

- Teamwork
- Individual discipline
- Improved morale
- Quality Circles
- Suggestion for improvement

To implement Kaizen, you may organize a Kaizen event. This event is a short period of time in which a problem is defined and improved or solved (Lean Six Sigma Groep, 2021). During the Kaizen event a DMAIC-cycle is used (Lean Six Sigma Groep, 2021): Once the 'problem' is defined it is time to measure the problem. To be able to come up with solutions for the problem that is defined you should 'analyze' the problems with using the 'measurements' done before. After this you know what the problem is, how sever the problem exactly is and maybe, most importantly, why the problem is occurring. Knowing this, you can now come up with solutions and 'implement' these. The last phase of the Kaizen event is to 'control' whether the implementations solve the problem. Within the Kaizen theory the Kaizen events are used repetitive to achieve continuous improvement.

Kaizen is a broad lean tool which considers as many circumstances and measurements as possible. Therefore, the effectiveness that kaizen has for waste reduction is more or less the same for all of the waste types and can almost always be implemented.

3.3.6. Kanban

Kanban is a lean tool to establish pull (Bicheno & Holweg, 2016). It is a trigger for movement which can be in the form of a card or some other signalling (Slack & Jones, 2016). Multiple Kanban can also be given and the amount of Kanban presented indicate the number of materials that are requested to move up one stage within the value stream (Slack & Jones, 2016). According to Slack & Jones (2016) Kanban has three functions:

“ • It is an instruction for the preceding process to send more.
• It is a visual control tool to show up areas of overproduction and lack of synchronization.
• It is a tool for kaizen (continuous improvement).” (Slack & Jones, 2016, p. 514)

Kanban therefore helps to reduce the waste of waiting, the waste of overproduction, the waste of inventory, and the waste of motion.

3.3.7. Changeover reduction (SMED)

According to Bicheno & Holweg (2016) there exist three different views on changeover times, I favour the following definition: “[Changeover time] is the time that a machine is idle between batches” (Bicheno & Holweg, 2016, p. 148). Changeover time reduction can be established in multiple ways according to Slack & Jones (2016), for example:

“ • Measure and analyse changeover activities […]
• Separate external and internal activities […]
• Convert internal to external activities […]
• Practise changeover routines […]” (Slack & Jones, 2016, pp. 515-516).

If SMED is used correctly it will result in a decrease in the waste of waiting and therefore in a decrease of lead time.

3.3.8. Spaghetti diagram

A spaghetti diagram is used to visualise the waste of transportation and improving the layout (Bicheno & Holweg, 2016). It is called a spaghetti diagram because lines are drawn from points to the points to where the product has to travel to. Therefore, the less efficient the layout is, the more the diagram will look like a plate of spaghetti. At the end the total length that the product travels need to be calculated (Bicheno & Holweg, 2016). This tool is used for measuring the waste of transportation.

3.4. Conclusion

In this section the following questions were answered:
"What is lean manufacturing?"
"What kind of waste do there exist according to lean manufacturing?"
"Which lean improvement tools do exist?"

Lean manufacturing is a theory that aims to do as much as possible with as little resources as possible. According to Slack & Jones (2016) lean can be used in three ways: firstly, it can be used for how to run operations with as much flow and as less waste as possible. Secondly, lean is a method that can be used for planning and strategic purposes of operations. Lastly lean provides us with a set of tools which can be applied for process improvement. The lean philosophy is based on five principles (Womack & Jones, 2003) and focuses on making the process more efficient by eliminating waste. Within lean manufacturing there exists eight types of waste. Beneath in Table 12 the core of lean manufacturing is listed.

Lean Manufacturing		
The five principles	**The 8 Wastes**	**Most used improvement tools**
Specifying Value	Waste of Overproduction	Value Stream mapping
Identifying the value stream	Waste of Waiting	5S
Flow	Waste of Overprocessing	JIT
Pull	Waste of Motion	Poka Yoke
Perfection	Waste of Inventory	Kaizen
	Waste of Defect	Kanban
	Waste of Unused Employee Creativity	SMED
	Waste of Transportation	Spaghetti Diagram

Table 12: Principles, Wastes and tools

In Section 4 of the report, I use VSM and Spaghetti diagrams to identify and measure waste. These lean tools are provided by eVSM which is a plug-in program for Visio. The other lean tools mentioned in Section 3.2, are either already being applied within Pentair or are estimated to be less fitting to the case at Pentair. The VSM will be used to calculate a PCE% and identify waste in the process. The Spaghetti Diagrams will be used to analyse the layout of the Static department, since I expect this to be one of the most influential wastes to the efficiency of the manufacturing process of the beer filtration products.

4. Analysing the performance of the current situation

In Section 4.1, a description of the analysing methods and data validation is provided. In Section 4.2, I provide the VSM analysis of the process. In Section 4.3, the analysis of waste per work cell can be found. In Section 4.4, a more overall analysis of the waste present at the beer filtration product manufacturing process is provided.

4.1. Description of the analysis and data validation

Firstly, in order to be able to measure the performance of the current situation, a VSM analysis is done. Secondly, an analysis per work cell is done to identify which cells form the bottleneck(s) to the efficiency of the process. Lastly, an analysis is executed that focuses on how each waste is present. Because of this, solutions can be generated in Section 5 that target the proper waste types and bottlenecks. By analysing in three different ways, I hope to firstly, measure the performance of the current situation. Secondly, I hope to identify which cells are bottlenecks to the efficiency of the process. Thirdly, I hope to identify which kinds of waste are most influential on the efficiency of the process to come up with fitting solutions in Section 5.

4.1.1. Data validation

To identify and measure the different wastes I use value stream mapping, spaghetti diagrams (eVSM, VISIO plug-in) and data that is provided to me by the company. As input for the VSM I used operator times provided in the STW documents available within Pentair. This is the same data that is already mentioned in Section 2. The raw data for this STW-timings is sometimes hard to validate. Nevertheless, these timings only cover a small part of the whole PLT and are not the big focus of the research. Moreover, these STW-timings are performed using a standardized document within Pentair which increases the validity of the timings. The STW-timings data is also used within Pentair to plan production as well as in other calculations and cases. Non-operator timings, for example drying and curing times are fully valid. Therefore, the data used during this analysis is valid to use during the VSM analysis.

To ensure that the repair data is as valid as possible I use the repair data over the full year of 2021 and implement it in the VSM. I chose to take the data from last year because it provides a representative estimation since repair also differs over the months. Moreover, in comparison to last year, no manufacturing steps or circumstances were changed that could lead to changes in repair rates.

4.1.2. Validation of the model

In order to be able to analyse the current performance at the Static department of Pentair for the beer modules I first create a value stream map using eVSM. While mapping the beer value stream I keep certain restrictions and pitfalls of the VSM in mind.

- Currently there are three beer modules which all three follow different paths, so this must be included in the model. For every product one set is created to make the model fitting for the current mixed manufacturing process. This means that there is one model created that consists out of the manufacturing of the three different beer filtration products
- The model includes repair. It is modelled in such a way that there is repair after qc-testing with an average of 2 days additional lead time. In reality a module can be repaired at any time during the manufacturing process. The repair is modelled as an activity center. The cycle time of this activity is seen as NVA-time in the map. As a repair percentage I chose the data over the year 2021.
- The SCRAP in the module is included, the scrap percentage of the whole production is added to the packaging activity after repair. This percentage tells the model more production is needed in order to achieve the forecasted demand of 2022.

- The model is made with the aim to give a picture of the overall performance of the value stream. This map is made with the purpose to analyze the PCE% and the lead times of the different products.
- The activity times are taken from STW timings performed during the end of 2021. These STW times equal the operator cycle time per product. This means that within these activities there is VA-time and NVA-time, however in this value stream model I chose to not distinguish between these two since these operator times only equal a small fraction of the total lead time. Improvements of the VA-time per operator cycle would only be marginal.
- Since multiple value streams flow through the Static department at Pentair and are therefore processed by the same resources, I adjusted the resource efficiency according to pieces per day. By doing so I acquire a better picture of the actual resource utilization in the beer value stream only and the model is also more representative to the reality because of the resource efficiency. This means that the model takes into account that operators also spend a fraction of their available time on the manufacturing of other products.
- The times of the drying of the coating are partially seen as value adding. This manufacturing step is time consuming. While talking to R&D (personal communication, Resin specialist, 2022) I found out that the 40 hours of drying were just implemented without testing on it.
- The model assumes that operators work 7.5 hours a day for 5 days a week.
- The actual VSM of the current situation can be found in Appendix B. (This is one VSM that is cut in pieces with the aim to fit the page size and be readable)

To conclude the VSM is made to give a global picture of the performance of the beer value stream but not too detailed since this is not the aim of the research. Knowing that the model will never be fully representative to reality it is important to map it consistently to measure the improvements I make by implementing certain solutions further on during the research.

4.2. VSM analysis

Within the program I used charts to visualize the performance of the current value stream. The output that I acquired by modelling the VSM of the current situation can be found in Appendix B. The most important output figures are also shown in this section.

PCE% (in %)	13.37
PLT (in weeks)	4.64
Resource utilization (in %)	70.37

Table 13: KPIs current situation

As can be seen in Table 13, the PCE% calculated by eVSM equals 13.37%. This is fairly low, especially when considering that this value adding time also exists out of STW time that is actually not even value adding. This calculated PCE% takes into account the other products that also have to be produced by the same operators within the Static department. The 13.37% is representative since PCE% is nothing else than the percentage of the lead time which is value adding. Why this percentage is that low will be explained in the next section. The biggest part of value is being added in the beer cell and casting cell. This PCE% also shows that the PCE% of product type C provided in Section 1 was not a fully valid estimation, since it did not take into account any other products that influence the PCE% of each other. Moreover, the PCE% of product type C in Section 1 was calculated using an ER that is not even fully known, because of the push flow used for manufacturing the beer filtration products.

The average PLT of the products combined equals around 33 days. One activity that causes the high PLT is the external processing step of product type A. Since there is no data available of the fraction of time that is value adding at the external company, I assumed, while talking to Pentair, that 10% of this activity is value adding (Personal communication, Production technician lead, 2022).

Another thing I look at is the overall resource balance of the operators, which can be seen in Figure 18. The overall resource utilization of the operators at the static department that manufacture beer equals 70.37%. This is acceptable however not optimal. Because operators mostly only have one manufacturing step that they can perform, the resource utilization strongly differs per task as can be seen in Figure 18. At the moment Pentair schedules 2.5 FTE for the gluing tasks. Nevertheless, the total time for these tasks only equals around 40 hours, while the available operator time equals around 94 hours. This means that the gluing operators only have a utilization of 47%. Moreover, the operator of the preparation cell is barely able to handle the amount of STW they get assigned, as can be seen in Figure 18 below.

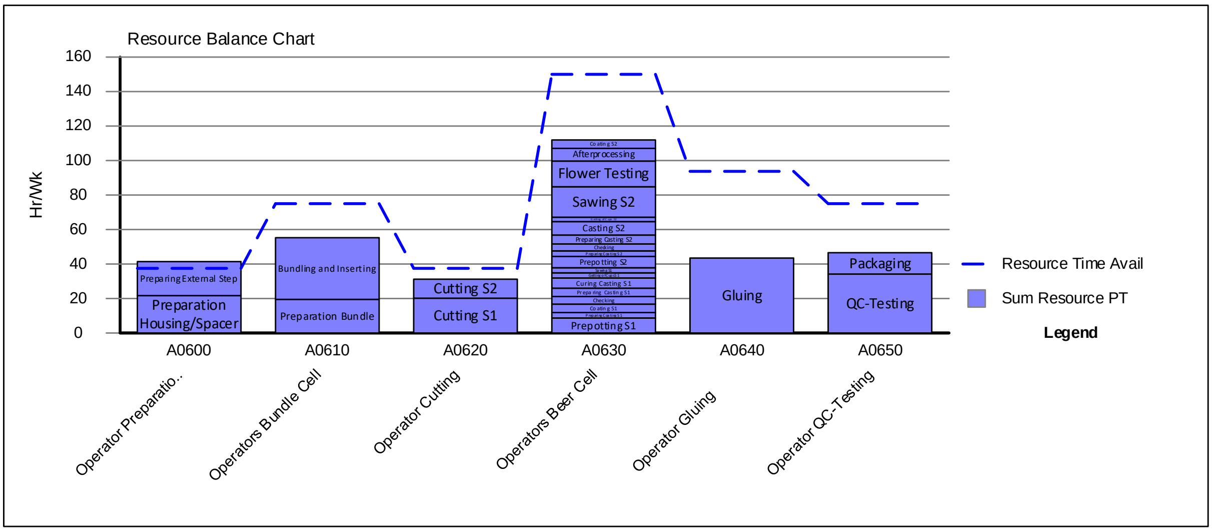

Figure 18: Resource Balance Chart (eVSM)

Looking at Figure 19 and Figure 20 you can see that the drying times are high in comparison with operator cycle times. The graphs show that the high spikes are restricting the manufacturing process concerning flow. These high spikes are the coating, casting, gluing and repair times. Although some of these steps are adding value their cycle times keep the process from flowing. The whole chart can be found in Appendix B.

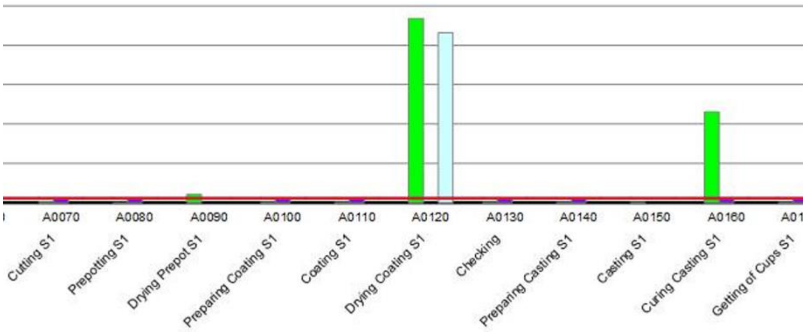

Figure 19: Cycle time bottlenecks (Drying coating + curing casting)

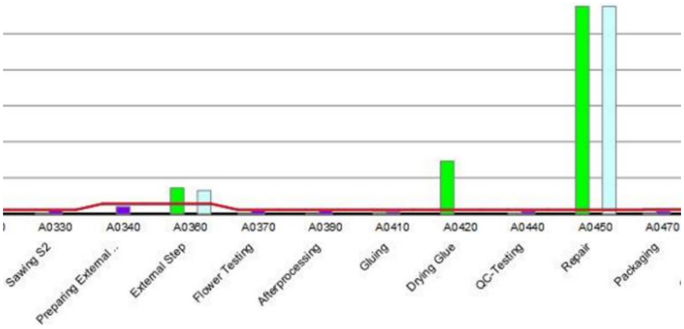

Figure 20: Cycle time bottlenecks (External step, gluing and repair)

4.3. Waste within the work cells itself

In this section I provide a description of the waste that is present per work cell. This description helps to identify the cells that have the most waste and therefore form the bottleneck of the manufacturing process of beer filtration products.

4.3.1. Preparation cell

In the preparation cell there is a lot of material and WIP standing around. Therefore, in this cell a lot of waste of waiting products occurs. This is partially due to the desynchronization between the cycle times of the preparation cell and bundling cell. In the cell there is a supermarket cart where the (unfinished) products that are ready to move on to the bundling cell are stored. The spacers that arrive at the preparation cell are often not prepared well by the supplier. Because of this bad quality of the material an operator of the preparation cell must walk to the sanding cell to sand it properly.

The location of the cell however is efficient since it is next to the bundling cell which performs the next manufacturing step. Location of the cells is therefore no bottleneck between these two steps. When I look at the size of the preparation cell, I find it too spacious. In my opinion a cell should only be the size that the operator needs to perform their task properly. At the moment the size of the cell only makes it easier to place WIP or materials, which has the consequence that the cells get messy and more inefficient. The crate for shipment to Company Y is also located in this cell. Since it takes a long time before they gather a batch of 20 ready for shipment, this is a big part of NVA-time. There is waste present in the preparation cell however this cell does not form one of the bottlenecks.

4.3.2. Bundling cell

The operator cycle time (OCT) of the bundling cell is higher than the OCTs for preparation and cutting. The varying cycle time between the preparation and bundling step creates WIP since the bundle cell is getting more modules than it can process. This is also due to the push strategy that is used now at Pentair. However, looking at the whole manufacturing process, this step is not a bottleneck to the efficiency. Looking at the task performed by the operator I conclude that the ergonomic circumstances during this step are not optimal. The working desk at which bundling is performed has a fixed height. Bundling operators fluctuate in height and therefore the table should be adjustable in height as well. Moreover, to make sure the bundle forms nicely and round, the operator has to hang the bundle in the ionization clamp. The combination of the high position of the clamp and the weight of the bundles makes it ergonomically inefficient. Although this does not contribute on the PCE% being low, I find it an important aspect that must be considered.

4.3.3. Beer cell

In the beer cell there are three manufacturing steps performed, respectively cutting, prepotting and coating. The first thing that creates waste is the fact that the product visits this cell twice. Looking at the cutting step in the beer cell there is not much waste creation. One of the bigger wastes is the waste of material that is being cut off. The respectively low cycle time of cutting (compared to prepotting and coating) is creating waste. The low cycle time of cutting creates WIP that stands around in the beer cell. This increases waste of waiting and waste of inventory, two of the crucial waste within the manufacturing process at Pentair.

Moreover, the beer cell creates the most waste of defects due to operator dependability in the prepotting and coating step. The defects that occur most frequently are air bubbles or holes in the potting as can be seen in Figure 21. Moreover, the drying times in the beer cell are high. This is due to bad quality of the heating system beneath. The heating installation can only go on or off, there is no regulator build in that ensures that the heat is applied steadily to the membranes. Since the tables in the beer cell cannot handle the current temperatures of the heat installation, the maximal temperature that the heat installation of the beer cell can generate is only 40 degrees of Celsius. The product can sustain higher temperatures and the process does not necessarily need to take this long. Product type B is dried on the drying machine behind the qc-testing cell. This drying machine dries modules on a temperature of 70 degrees, which results in a drying time of only 19 hours instead of 44. The high drying times after coating make the beer cell a bottleneck in the beer module manufacturing process.

Looking at the resource balance chart in Section 4.2. you can see that there are too many available operator hours for the operators of the beer cell. The total time they are operational equals 115 hours a week. The total availability equals 150 hours a week. This means that they are performing task besides their standard work, or they are idle for a significant time. In the beer cell there is a lot of WIP since the cycle times of prepotting and coating are the highest ones in the beer manufacturing process. This means that once other steps have processed the modules they move on and eventually will end up as WIP in the beer cell. This is mainly due to the push flow that is used at Pentair and the high processing times in the beer cell. This amount of WIP increases even more since the beer modules flow through this cell twice.

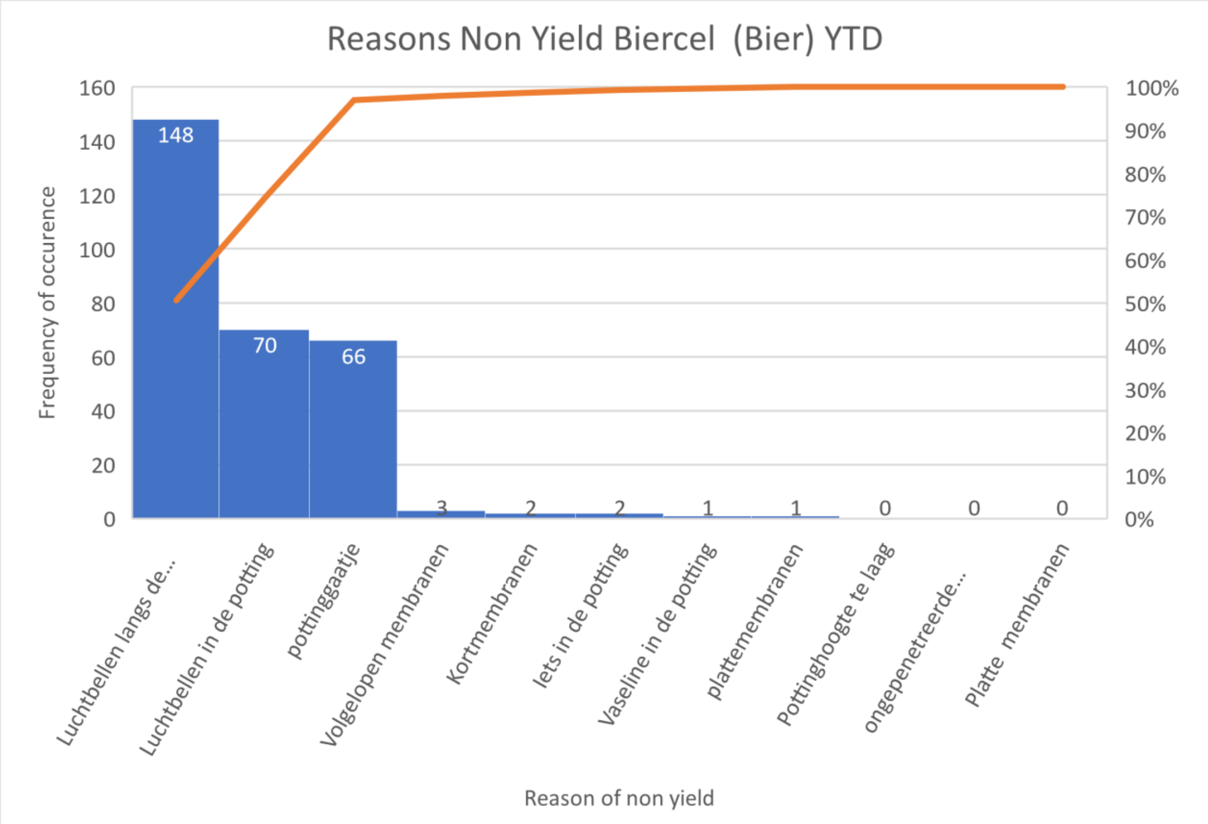

Figure 21: Pareto of the Type of defects in the beer cell (Pentair, 2022)

4.3.4. Casting cell

During the casting process it is important that the region that is casted has a certain temperature and humidity. To establish this at the moment Pentair makes use of a big casting cell where the temperature and humidity can be regulated. This casting cell however only has a capacity of 60 modules. Since this step takes long and has limited capacity it can also be considered as a potential bottleneck to the efficiency at Pentair in the future. The casting time equals around 19 hours per product side. These high cycle times are currently not a bottleneck since the cycle times of coating are higher. Nevertheless, it is a potential bottleneck once the beer cell is improved.

4.3.5. Sawing cell

In the sawing cell there is not that much waste since the cycle time is short and the manufacturing step is easy. The Conrad machine that is used to cut the beer modules on has a plate where you push the module onto. After that the machine cuts it on the desired length. Setting up the Conrad saw installation takes some time, however, does not form a huge amount of waste. Compared to the beer and casting cell the sawing cell is not a bottleneck to the efficiency of the current manufacturing process. A thing that can cause waste within the sawing cell is the unreliability of the Conrad saw installation. If the Conrad machine breaks down the WIP within the process increases since Pentair produces using a push flow.

4.3.6. Sanding cell

The sanding cell is relatively small compared to the tasks that have to be performed in it. Especially considering that the compact modules also have to be processed in this room. The flour testing installation and sanding tools are old. Moreover, there is only a capacity of one product per time for flour testing and the sanding is done manually. Since the sanding cell lacks capacity (because of surface restrictions) unfinished product pile up in front of the cell. This creates waste of waiting and waste of inventory. Moreover, it also makes the production hall look messy. The sanding step is also critical to the quality of the product.

4.3.7. Gluing cell

The gluing cell works in a U-flow, which is good for the flow in the cell itself. This U cell makes the products flow in on the left and leads them through the cell until they are glued and exit on the right. This U-layout makes it easy to visualize how far a product is in the gluing process and enables the operators to keep the cell clean and tidy. However, the gluing process is largely operator dependent and the cycle times of gluing are fairly long. After the beer cell this is the cell that causes the most defects. This occurs when the glue is not applied sufficiently. For example, operators will never be able to apply the same amount of glue for every module. Another example is the assembly of the glued flange bushing onto the module. Firstly, this assembly takes a lot of force since the flange bushing has to be pushed on there with high pressure. Secondly, while pressing the flange bushing onto the module the operator also has to make a turning movement with the flange bushing, to ensure that the flange bushing will be glued straight on the module. If these steps are performed poorly, air bubbles will form between the glue and the surface of the module. This can end up in leaking membranes or modules. In Figure 22 it can be seen that this is also one of the most reported defects.

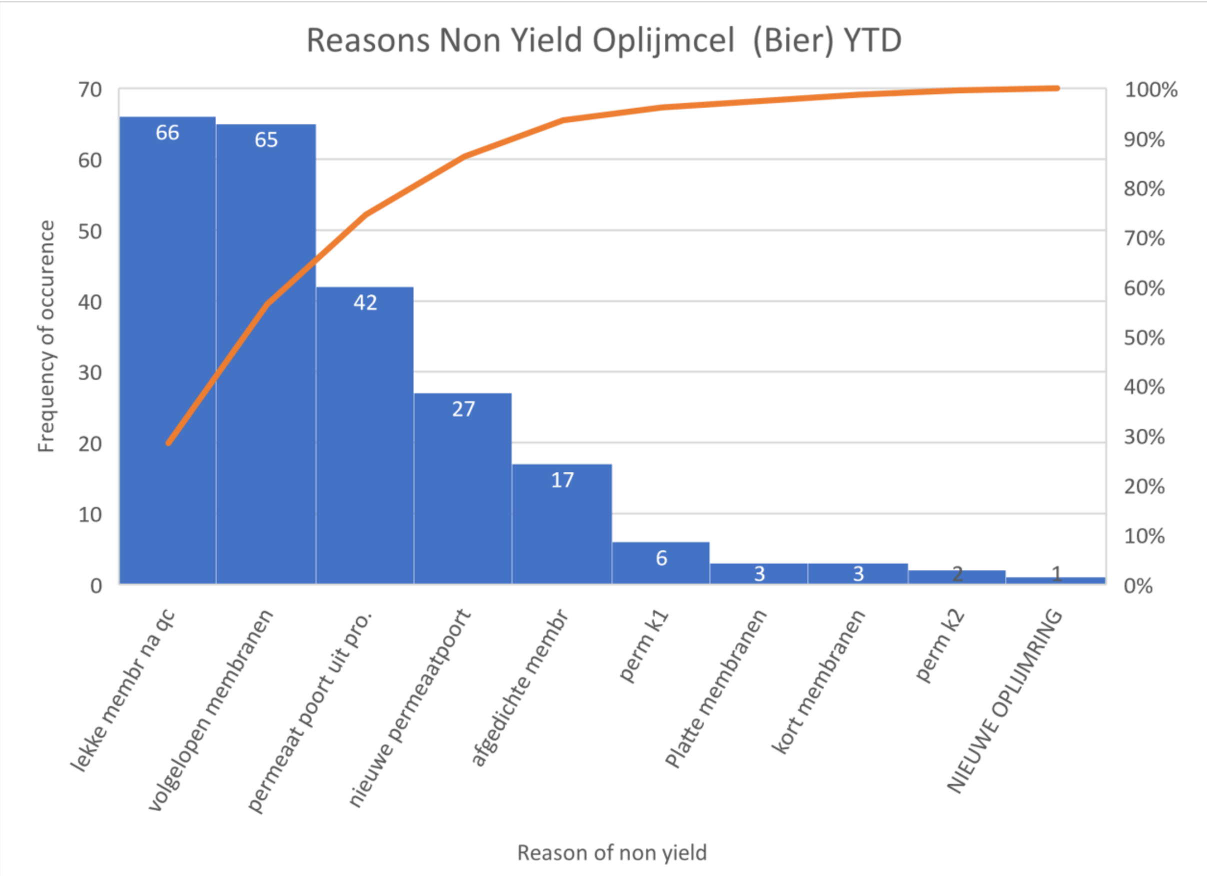

Figure 22: Pareto of the type of defects in the gluing cell (Pentair, 2022)

4.3.8. Testing cell

In the testing cell there is not much waste creation. Operators however do complain about the ergonomics in this cell. For the tests they need to screw on concentrate caps. These caps are screwed on manually which is really heavy on the wrists of the operators. Testing is done wet and therefore modules are heavy when they have to be lifted. This cell could be seen as a waste creator to the ergonomics of the operators. Nevertheless, this cell has a small influence on the PCE% and is therefore not considered as a bottleneck.

4.3.9. Conclusion waste within the work cell itself

The beer and casting cells currently are the bottlenecks to the efficiency of the manufacturing process. The high cycle times in these cells restrict the manufacturing process from flowing and therefore lower the PCE%. Moreover, the beer, casting, sanding and gluing cells create the most waste of defects, which results in additional repair days or scrap and therefore also lowers the PCE% and increases the PLT.

4.4. Waste in the manufacturing process at Pentair

In this section I assess the current manufacturing process according to the eight types of waste within lean. I elaborate on why and how the waste is occurring and what the consequences of the different types of waste are. I also explain how the different types of waste at Pentair influence the PCE%.

4.4.1. Waste of overproduction

Since the capacity of the beer filtration products manufacturing process is lower than the actual demand there is no waste of overproduction in the overall process. Between the different processing steps however there is waste of overproduction. An example is the production before the beer cell. There are more products cut than the beer cell can handle. Therefore, you could say that at the cutting cell there is waste of overproduction. The fact that the product is manufactured side by side only increases this waste. Concluding, there is waste of overproduction between processing steps. However, there is no waste of overproduction at the finished goods part since the demand is higher than the manufacturing capacity. This waste has an increase in WIP as consequence. Therefore, the influence of this waste is low on the PCE% at Pentair. It is a waste that is present at Pentair however it is not one of the most influential ones.

4.4.2. Waste of waiting

Several factors create waste of waiting in the process at the Static department at Pentair. The first factor is the varying cycle times as can be seen in Figure 23. Due to these cycle times, it is difficult to plan the process in such a way that there are no products or operators waiting around. In the eVSM graph you can see that the cycle times in the beer cell and casting cell are relatively high. Currently production is planned according to the cycle time of these bottlenecks. Within the process the product flows two times through these bottlenecks. These bottlenecks could be seen as the drum that sets the pace of the current push flow at Pentair.

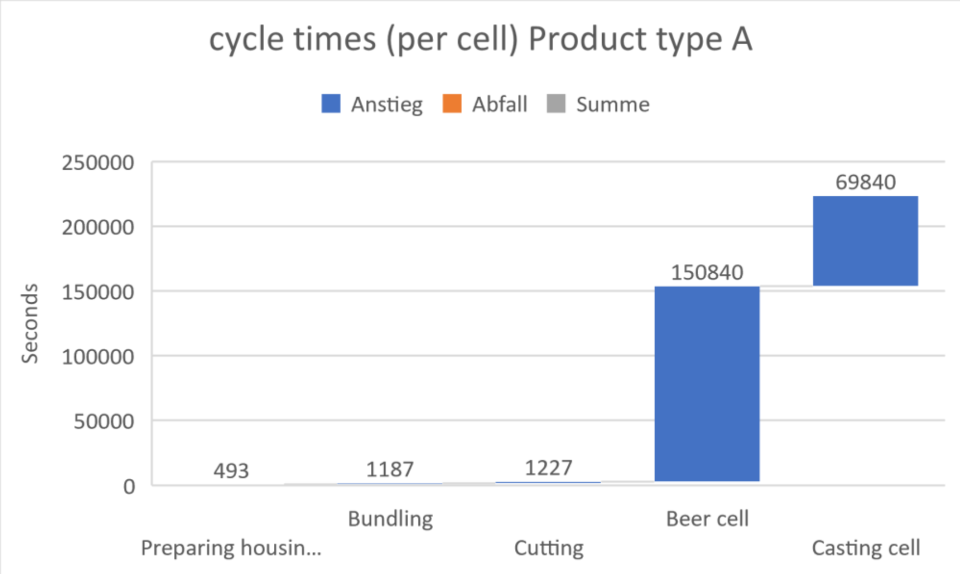

Figure 23: Difference in cycle times

A second factor is that currently unfinished products are transferred to the next work cell in batches (mostly in batches of 10). Until an operator has put the last piece on the cart the other 9 products are waiting. If the operator cycle time for this certain step in the process is high this means that the first piece that is lay on the cart must wait 9 times its own cycle time before it can transfer to the next work cell. See for example the bundling of product type A: this time would equal around 81 minutes of waiting, while the cycle time of product A for bundling is only 9 minutes (Pentair, 2022). The bundling of product type A is only an example, throughout the process products are batched for transportation between work cells and this creates a big amount of waste of waiting.

Besides the waste of waiting of products, waste of waiting employees also occurs several times at Pentair. This is due to the varying cycle times and the fact that operators get assigned fixed manufacturing steps. Since Pentair uses a batch flow this will result in certain work cells being idle. You could say that the waste of waiting at Pentair occurs because of bad synchronization of operator cycle times per processing step and inefficient work cell allocations. In Figure 24 the orange parts indicate waiting time and the blue parts indicate operator cycle time. There are 6 bars in the lead time chart, because the program returns a PLT with and without repair for every product. The bars that include red parts include repair. As you can see the waiting times are high. This waste therefore has a crucial influence on the low PCE%.

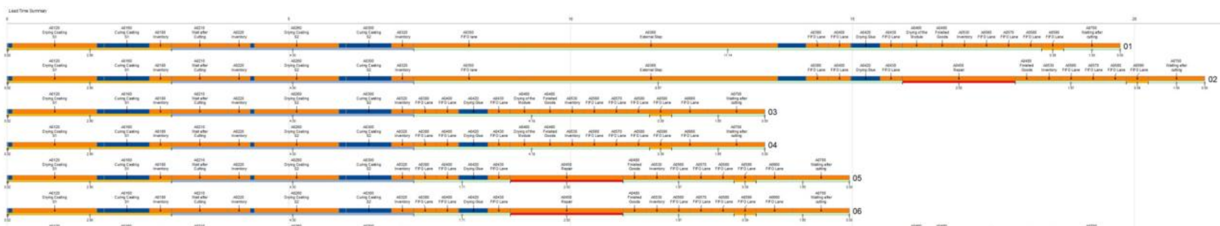

Figure 24: Lead times (eVSM)

4.4.3. Waste of transportation

Another waste that is present in a big amount at Pentair is the waste of transportation. This transportation is due to bad work cell allocation. To visualize and calculate the extent of this waste I use eVSM to make spaghetti diagrams. For visualization I provide the spaghetti diagram of the current situation for product type C in this section, as can be seen in Figure 25. The other spaghetti diagrams of the current situation can be found in Appendix B.

As you can see in the spaghetti diagram in Figure 25, product type C is being transported between work cells intensively. this is mostly due to the illogical work cell locations. Looking at the manufacturing process in Section 2.1. you can see that after sanding and flour-testing the product will be glued. The sanding cell and the gluing cell are in direct connection but are almost located as far away as possible from each other. This work cell allocation is partially inefficient because of the different products that all have to flow through the Static department. As you can see in the middle of the manufacturing hall there are two big cells that the beer filtration products do not visit within their manufacturing process. Even though they do not have to visit these cells to be manufactured, the products do have to be transported around them since the operators cannot transport the unfinished products through the work cells.

Secondly, in the beer cell and in the casting cell the products are being manufactured side by side. This causes the products to transport through these cells twice and therefore causes additional travelling meters. Beneath. In Figure 25 and Tables 14, 15 and 16 you can see the total travel distance per product type and explanation. The red part illustrates the distance that is travelled because of two side manufacturing. for product type A the green part in Table 14 illustrates the additional meters required for the external manufacturing step.

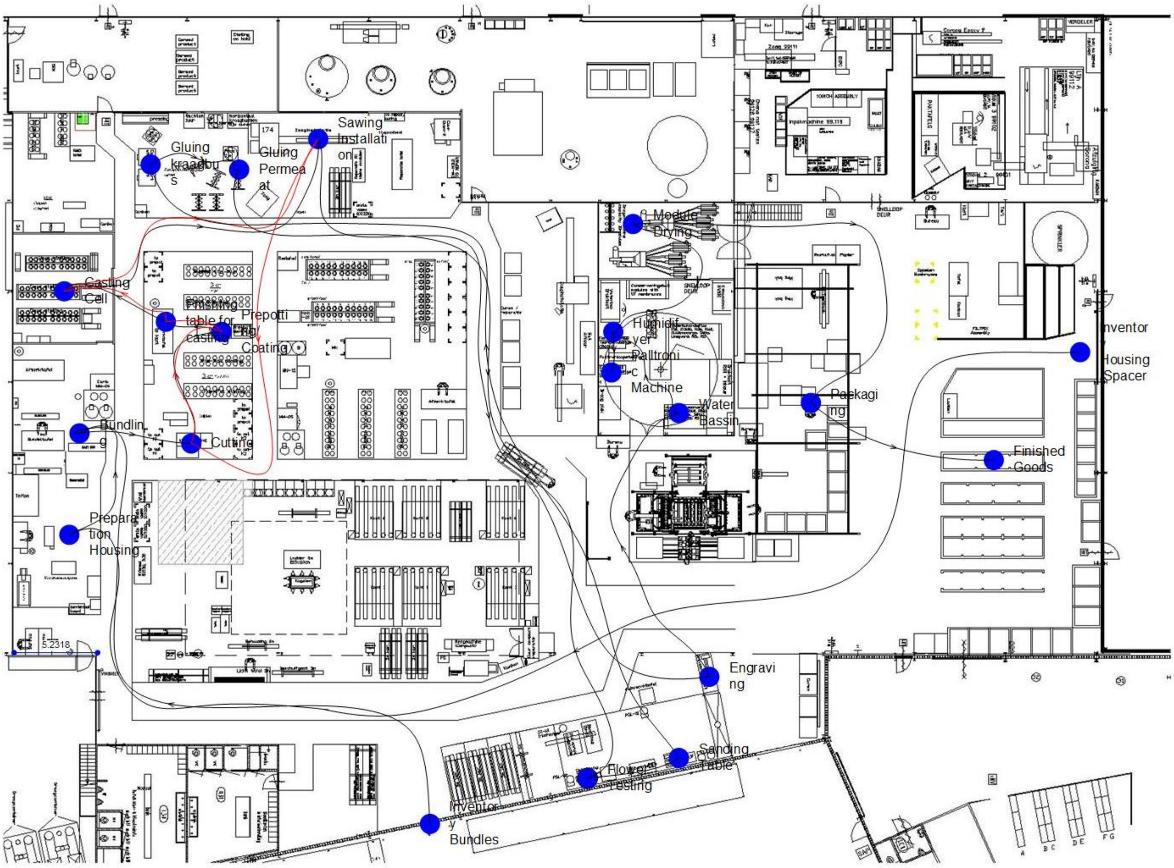

Figure 25: Spaghetti diagram product C

Waste of transportation product type A

Looking at Table 14, you can see that the total transportation distance equals 519.5 meters. In red you can see the distance that it takes the products to transport through the hall to manufacture side 2. Product type A has an external processing step that travels an additional 153.15 meters within the hall. To show how much additional transportation distance is caused by this external step you should also keep in mind that the unfinished products must be transported outside of the hall to the company Y. The additional travelling distance outside of the hall equals 115,6 kilometres. Moreover, this external step also creates an increase in lead time of 1 week. Compared to the other two beer filtration products, type A has the lowest inhouse transportation distance, this is partially because type A does not have to be glued.

FROM	TO	COLOR	DISTANCE	
Inventory bundle	Bundling		41.71	
Housing/Spacer Inventory	Preparation spacer		87.23	
Preparation spacer	Bundling		7.9	
Bundling	Cutting		8	
Cutting	Prepotting/Coating		9.76	
Prepotting/Coating	Checking before casting		3.77	
Checking before casting	Casting		8.75	
Casting	Cutting		18.29	
Cutting	Prepotting/Coating		9.67	
Prepotting/Coating	Checking before casting		3.72	
Checking before casting	Casting		9.23	40.91
Casting	Preparation for company Y		21.41	
Preparation for company Y	Warehouse		75.78	
Warehouse	Sawing installation		77.37	153.15
Sawing installation	Flour-testing		51.19	
Flour-testing	Water basin		25.83	
Water basin	Palltronic machine		7.13	
Palltronic machine	Module drying		13.5	
Module drying	Packaging		26.27	
Packaging	Finished goods		12.99	
Total travel distance			**519.5**	**in meters**

Table 14: Travelled Distance Type A

Waste of transportation product type B

Looking at Table 15, the first thing you notice is that the total travel distance of product type B is significantly longer than type A. This is mainly due to the side manufacturing loops that are longer. After product B has been coated it has to dry on the drying machine. This drying machine is located behind qc-testing and therefore it takes around 65 meters to get the unfinished products there. If the modules would not have to be dried on this drying machine but could be dried at the prepotting/coating racks this would decrease the total travel distance with circa 270 meters. The high travel distance is highly undesired since product B is the largest model, which makes it ergonomically speaking a bottleneck to move around. Therefore, it is remarkable that the biggest beer module has the biggest amount of inhouse travelling distance. Moreover, the distance from the sanding cell to the gluing cell also drastically increases the total distance.

FROM	TO	COLOR	DISTANCE	
Inventory spacer	Preparation spacer		87.25	
Preparation spacer	Bundling		10.64	
Inventory bundles	Bundling		42.76	
Bundling	Cutting		7.5	
Cutting	Prepotting/Coating		9.46	
Prepotting/Coating	Drying of the modules		67.77	
Drying of the modules	Finishing before casting		70.13	
Finishing before casting	Casting cell		7.99	
Casting cell	Cutting		15.42	
Cutting	Prepotting/Coating		9.6	
Prepotting/Coating	Drying of the modules		65.06	
Drying of the modules	Finishing before casting		68.58	
Finishing before casting	Casting cell		7.04	165.7
Casting cell	Sawing installation		21.61	
Sawing installation	Water basin		39.15	
Water basin	Flour-testing		28.87	
Flour-testing	Sanding Table		5.66	
Sanding Table	Gluing		78.23	
Gluing	Engraving		64.42	
Engraving	Humidifier		28.85	
Humidifier	Palltronic machine		1.67	
Palltronic machine	Drying of the modules		12.92	
Drying of the modules	Packaging		25.85	
Packaging	Finished goods		12.27	
Total travel distance			**788.7**	**in meters**

Table 15: Travelled distance Type B

Waste of transportation product type C

Looking at Table 16, you can see that the total travelled distance of product type C almost equals the one of type A. The distance it takes product A to prepare for the external step is almost equal to the gluing distance for product type C. Moreover, product type C can just like type A be dried in the beer cell itself which safes a lot of waste of transportation in comparison to product type B.

FROM	TO	COLOR	DISTANCE	
Inventory bundles	Bundling		43.32	
Inventory housing	Preparation housing		84.55	
Preparation housing	Bundling		11.05	
Bundling	Cutting		7.07	
Cutting	Prepotting/Coating		9.37	
Prepotting/Coating	Finishing table for casting		3.61	
Finishing table for casting	Casting cell		7.07	
Casting cell	Sawing installation		22.24	
Sawing installation	Cutting		27.03	
Cutting	Prepotting/Coating		9.64	
Prepotting/Coating	Finishing table for casting		3.71	
Finishing table for casting	Casting cell		7.28	
Casting cell	Sawing installation		21.56	69.22
Sawing installation	Flour-testing		51.65	
Flour-testing	Sanding table		5.92	
Sanding table	Gluing kraagbus		58.16	
Gluing kraagbus	Gluing permeate		6.29	
Gluing permeate	Engraving		52.02	
Engraving	Water Basin		20.22	
Water Basin	Humidifier		7.27	
Humidifier	Palltronic machine		2.57	
Palltronic machine	Module drying		14.77	
Module drying	Packaging		28.06	
Packaging	Finished goods		12.28	
Total travel distance			**516.71**	**In meters**

Table 16: Travelled distance type C

Conclusion waste of transportation

Looking at the travelled distance acquired as output of the spaghetti diagrams, you can conclude several things. There are three major bottlenecks that cause the distance to increase. The first bottleneck is the distance from the gluing cell to the sanding cell. Type B and C need to be glued and the inefficient location of these two cells adds circa 125 additional meters. The second bottleneck is the fact that the manufacturing steps in the beer and casting cell are performed side by side. Because of this, the products must be transported through these cells twice which on average adds circa 90 meters. The third bottleneck would be that product type B needs to be dried on the drying machine. If Pentair would implement a solution where these modules could dry at the same spot that they are being prepotted and coated this would already safe 270 travelling meters. With the current forecasts by the sales department of Pentair this travel distance adds up to a total travel distance of 1835 kilometres yearly* which almost equals the distance form Pentair X-Flow in Enschede to Madrid (1870 kilometres)

**I multiplied the number of products times travel distance*

This waste of transportation causes the process cycle efficiency to be low in several ways. Beneath the consequences of long travelling distance are listed:

- Stimulates working in batches over one-piece flow, since otherwise Pentair would have to transport 1835 kilometers within the production hall using a one-piece flow
- Operator intensive, ergonomically conditions get worse
- During transportation there is a higher chance of damaging the (unfinished) product
- High travel distance results in higher lead times
- Higher manufacturing costs

The main problem for the PCE% is that high transportation distance stimulates to work in batches. This means that not only travel times are non-value adding lead time, but also the time that a product spends waiting for other product to reach the batch size. Because of these high transportation distances, Pentair now works in batches of 10. This means that the first product of the batch that is finished spends at least 9 times its own cycle time to be transported to the next work cell.

4.4.4. Waste of overprocessing

Overprocessing means doing more than the customer desires or pays for. Looking at the beer manufacturing process of Pentair you can identify several wastes of overprocessing. To identify this waste, first you must understand what the customer value is. The customer desires a beer filtration product that has proper filtration capacities and good apparel concerning the housing. The steps performed in the manufacturing process that do not add value to these two values can be seen as waste of overprocessing. First, testing can be seen as overprocessing. If you have a proper manufacturing process you do not have to test all products as extensively as is done now at Pentair. Although testing assures quality it does not add any quality nor does the customer pay for it to be done. However, I found out that Pentair is actually obliged by the customer to test the quality and capability of the products. (Personal communication, Production technician Lead, 2022). Therefore, testing is in essence necessary nonvalue adding activity. Second, the product designs are old and not fitting for the models anymore. Product type C for example, was initially designed as a water product and still has features for water filtration. During the manufacturing process, these features have to be reworked to make it fitting for beer filtration. The waste of overprocessing however has a low influence on the PCE% and therefore will not be a focus point throughout the solution phase.

4.4.5. Waste of motion

Manufacturing at Pentair is done in work cells. This is done so they can keep the motion of the operators low. However, the work cells and their equipment sometimes fail in achieving this. Since Pentair uses a push flow for manufacturing, a lot of material and unfinished products stand around in the work cells. Sometimes work cells get too full and then WIP is placed randomly at a location where there is space. This WIP creates waste of motion since it is unnecessary movement of products, which then again has as a consequence that operators have to walk further distances to get materials to the desired places. The manufacturing hall is mostly designed in such a way that the operator does not need to move around too much. However, the current layout does not fully succeed in reducing this waste. The layout is messy and because of this WIP and raw materials are standing around in the work cells. Operators also create waste of motion since they must perform their daily tasks around the WIP and raw materials standing in the cells. Beneath I provide an example of waste of motion. In the example you can see the preparation cell. In this cell there is a crate located that is used for shipping product type A to the external processing step. Moreover, you can see a big machine standing in the middle of the cell. This machine is meant for testing which now barely happens. In the outer left of the cell the fixation sets are located. All these materials and machines standing around have the consequence that the operator has to go around it. As you can see on the picture below the operator has to go outside of the work cell to get to the spacers, which is not efficient. So, the biggest factor that is causing waste of motion in the current situation is materials and unfinished goods standing around in the work cells. Just as the preparation cells there are more cells where the material and product allocation is not logical. This creates waste of motion. Although this waste is present at Pentair, I do not consider this as one of the crucial wastes that cause the PCE% to be low.

Figure 26: Example of materials and WIP in a work cell

4.4.6. Waste of inventory

Currently at Pentair, there is waste of inventory occurring. Because of the varying cycle times per processing step and high transportation distances there is a lot of WIP. These inventory numbers cost a lot of money since it is frozen cash flow. The money that is standing around cannot be used or accessed. Therefore, one consequence of the waste of inventory is decrease of liquidity, which at Pentair on average for beer modules equals €330,000 (Personal communication, Production technician lead, 2022). Moreover, these inventories within the manufacturing process also cause the process to be inconsistent. Because the output becomes inconsistent it is harder to plan and estimate lead times. Moreover, this inventory causes the production floor to become messy and therefore less efficient. This waste has a significant influence on the PCE%.

4.4.7. Waste of defects

See Appendix I (confidential)

4.4.8. Waste of unused employee creativity

When I visited the production hall, I talked to several operators that had similar input to me. The operators at the Static department are the persons that have most knowledge about the process. Since they have to work in it every day, they are actually a part of the process itself. Employees complained to me that they sometimes do not really feel taken seriously. They feel like the suggestions for improvement they offer are not processed by the management teams. Moreover, Pentair now does not often include operators within project-groups for process improvement. This is waste, since multiple perspectives to a problem or opportunity enables a project-group to come up with the best fitting solution or improvement.

Moreover, the manufacturing process is designed in such a way that an operator sees what they need to do every day. And every work cell operates individually. Operators are capable of carrying way more responsibility, which also will make them feel valued more and increase the flow. At the moment it is too much of an 'island thinking' process. With 'island thinking' I mean that employees operate in their cell as they are supposed to at the moment. In the future Pentair should aim more for team feeling and shared responsibilities. This waste is present at Pentair in big amounts and influences the PCE% negatively. This waste however is difficult to measure but is considered while writing the implementation plan.

4.5. Conclusion

By analysing the current manufacturing process in three different approaches, I was able to measure the performance of the current situation. Moreover, I identified which cells form the bottlenecks to the efficiency of the current process and which wastes are most influential to the PCE% at the moment.

The process is analysed by looking at the performance of the process intercellular and to the performance within each cell. This performance I described according to the VSM that I created and already existing data provided by Pentair. The PCE% of the value stream of the beer filtration products at the Static department at Pentair equals 13.37%. The average PLT of the three beer filtration products equals around 33 days.

The biggest bottleneck to efficiency at the moment is the beer cell, which is due to high durations for drying of the coating. Besides the beer cell the casting and gluing cell also have high cycle times, which can be found in Figures 19 and 20 in Section 4.2. These high cycle times restrict the manufacturing process from flowing.

The three wastes that are most present in the beer filtration product manufacturing process and have the most influence on the low PCE% are waste of waiting, waste of defects and waste of transportation. Due to the long transportation distances between work cells, operators are used to working in batches between work cells. Due to batch assembly, waiting times get high. This is because products have to wait for batch completion. Another variable that is creating waste of waiting are the varying cycle times. These cycle times make it difficult to synchronize the process and use a pull flow.

The bottleneck cells at the moment create a lot of waste of waiting since the process cannot be synchronized, which stimulates batch-transfer and increases the amount of WIP in the process. Moreover, the plant layout of the static department also stimulates batch working and therefore decreases the PCE%.

In order to come up with solutions in Section 5 to increase the PCE% of the beer filtration manufacturing process I should aim to reduce:

- Waste of waiting
- Waste of transportation
- Waste of defects

I should aim to improve the process performed in the identified bottleneck cells:

- Beer cell
- Casting cell
- Gluing cell

5. Generating solutions to reduce waste

In section 5.1, solutions are provided that are generated with the aim to solve or improve the current bottlenecks that were found in Section 4.2. In Section 5.2, solutions are provided that are generated to reduce the most influential wastes found in Section 4.3.

5.1. Solutions that resolve the current bottleneck

Before starting the solution generation, I defined the most important criteria for the solutions together with the Lean Manager at Pentair. The criteria can be found in the list below:

- Payback period has to be within 3 years (therefore the calculated ROI should be higher than 1)
- Solution should not introduce additional risks of quality issues
- Surface reduction is important, since it creates space for new production lines
- Influence on the PLT or PCE% should be positive

Throughout Section 5.1, the solutions are rated according to these criteria. Moreover, profits are multiplied by an unknown number because of confidentiality.

In this section the solutions that aim to solve the bottlenecks are provided. The bottlenecks are respectively the coating, casting, gluing, and repair steps. The cycle times in these cells are high and exceed the takt times as can be seen in Figures 19 and 20 in Section 4.2. The manufacturing steps performed in the cells are critical to quality and therefore cause waste of defects. By resolving or improving these bottlenecks Pentair can establish more flow within the beer module manufacturing process and therefore increase the PCE% and decrease the PLT. Some of these solutions will not increase the PCE% while they are implemented individually. However, the solutions reduce the high cycle times or/and the threat to quality problems. While calculating the surface reduction costs, I assumed €120 per square meter per year, since other plant locations at the industrial area that Pentair is located cost €60 per square meter per year, without electrics, lights and heating. Where it is possible a ROI (3 years) is calculated for solutions by dividing the return at the end of year three by the investment made for the implementation of the solution.

5.1.1. Lowering coating height

Currently the coating is applied at a certain height that is prescribed in the work instructions for module type A and C. For module type C the bucket with coating is held against the fixation set that is around the spacer. According to the Resin specialist (personal communication, 2022) it might be a possibility to apply the coating lower than the current height. By implementing this Pentair will need less coating per module and the drying times for coating will be reduced. This solution can be implemented with a relatively low effort, the production process does not have to change to implement the solution. The two possible drawbacks of this solution are that it is unknown how the quality of the membranes will remain if they are coated with half of the current height and if the current buckets will not be changed it will also result in more waste of materials (coating substance). This will be something that has to be looked into by the R&D department if Pentair wants to implement this solution.

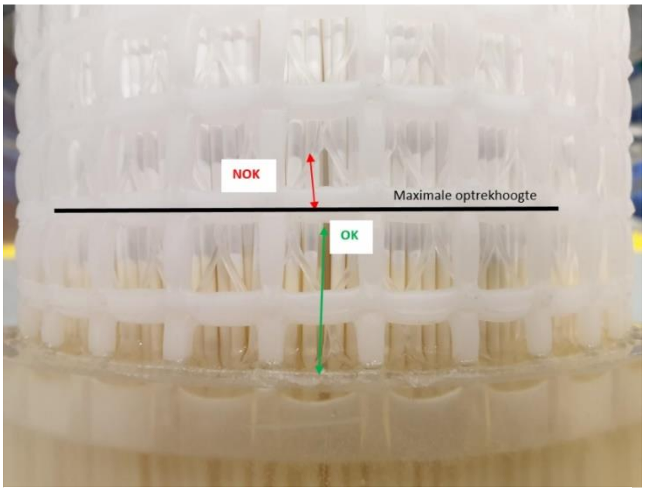

Figure 27: Acceptable coating heights

As can be seen in Figure 27 there is a maximum height which is allowed to be prepotted. As soon as the coating is higher the product is not sufficient anymore. A thing to look into is how low the membranes could be coated without loss of quality. This solution brings down the drying times of coating, which means that the bottleneck of the process is being reduced, as the cycle times of coating decreases and therefore the manufacturing process can flow better. If this solution will be implemented with decreasing the coating height with 50%, it will have the following impact:

- The PLT changes from 32.48 days to 30.45 days. Therefore, this solution will on average save Pentair 2 days. The PLT is decreased with 6.25% in comparison to the current situation.
- Since the drying times are decreased with 50%, Pentair only needs half of the capacity of the current beer cell. This means that the coating surface will be reduced by approximately 22m^2.
- Drying coating times are halved which means that coating, drying + cooling will take 24 hours instead of 44 hours.
- I assume €10,000 for machine and coating changes in order to be able to coat on half of the current coating height.

Investment costs will be low since the only requirement is a bucket redesign so that the waste of materials can be kept as low as possible. Moreover, this solution will increase the ergonomics of the operators in the beer cell. Since the buckets weigh around 7.5 kilograms and has to be lifted five to ten times this is heavy on the operator at the moment. By implementing coating on half of the height operators only have to carry and lift buckets with half the weight. Table 17 shows how the solution scores on the criteria:

KPIs for the solution	
PLT reduction	6.25%
Investment costs	€10,000
Costs saved	€105,890 + €2,628 (annual)
Surface reduction	21.9m^2
ROI (3 years)	11.37

Table 17: KPIs of the lowering coating height solution

5.1.2. Increasing capacity of the bottleneck

Most of the solutions in this section focus on reducing the biggest bottleneck (being the coating times in the beer cell). Nevertheless, once the cycle time of the coating bottleneck is reduced, Pentair should also focus on solving the new bottlenecks, which are the casting and gluing times. By increasing the capacity of this casting step Pentair could decrease the cycle time of the casting cell. Cycle times can be reduced by either improving the manufacturing process itself or expanding the physical capacity of the cell. This means that Pentair could also choose to place more casting racks and increase the capacity of the casting cell.

However, expanding the capacity of a cell would not be much aligned with the aim of the lean philosophy and since for the beer cell there are more effective solutions cell expansion is not favoured. The investment would be rather big, and Pentair would not win much agility for future improvements. Nevertheless, if for one of the bottlenecks an improvement of the manufacturing techniques is not feasible, increasing the physical cell capacity is the only solution to increase the cycle times for the manufacturing step. If Pentair decreases the cycle time of the bottlenecks, they will reduce the waste of waiting significantly and are able to synchronize and plan production in a more efficient way.

The expansion of the casting cell can be done in two ways. First, Pentair could choose to buy additional racks and increase the physical capacity of the casting cell. This solution will be high in costs since these racks use a HB-Therm to regulate temperature. If Pentair would implement another rack in the casting cell, the weekly capacity of the casting cell would be improved from 150 to 200. The casting cell has to be expanded if Pentair wants to implement this. Together with the Production Technician Lead I looked into quotes of the years before. Based on the costs of these quotes the investment costs of the expansion of the casting cell are estimated to be around €25,000. A new HB-Therm has to be bought and the whole rack has to be installed. Moreover, the current casting cell would have to be expanded.

Increase weekly capacity	33.3%
Costs of extra HB-Therm and rack and cell expansion	€25,000

Table 18: Impact/costs, extra casting rack

Increase weekly capacity	20%
Increase annual operator costs	€7,593.75< X <€15,885.75

Table 19: Impact/costs, casting on Saturday

A second alternative is to look into the planning of the casting cell. Due to the long casting times, it is difficult to plan it in such a way that the casting cups are used 120 hours in the 5 working days. Therefore, the current capacity of the casting cell equals 300 sides of modules, which means that it can process 150 modules per week. During the weekend capacity is lost since the longest casting time only equals 20 hours. This means that one potential day that could be used for casting is missed. The idea therefore is to employ an (additional) operator on Saturdays, which means that over weekends Pentair can put another 60 modules on the casting cups. The weekly capacity of the casting cell will therefore increase to 180 modules. The operator load on that day can vary between 3.75 and 7.83 hours according to STW timings and the modules that will be casted that day. This will result in an additional cost between €7,593.75 and €15,885.75 annually.

If an operator would not have a full working day by performing STW tasks for casting they can fill the rest of the day with gluing, checking raw materials or cleaning the hall. Depending on the actual demand Pentair can increase the profits with the numbers displayed in Table 20. This solution has the aim to match the processing rate of the coating process while accelerated coating is implemented. If accelerated coating is not implemented this will not be beneficial to implement. Since the extra profit shown in Table 20 will only be acquired if the beer cell capacity is increased to 40 modules per day, the saved costs are calculated by keeping in mind the sales percentages for the beer modules. An extra operator on Saturdays will equal 30 modules extra per week, an extra rack will equal 50 modules extra per week. The extra modules are multiplied by the sales prices minus the manufacturing costs. These prices and costs were estimated together with the Production technician lead at Pentair (personal communication, Production technician lead, 2022). Table 21 shows how the solution shows on the criteria.

Increase of pieces per week	**Extra profit**
+30 pieces a week	€6,689,239
+50 pieces a week	€11,148,732

Table 20: Growth of profit

KPIs for the solution	
PLT reduction	Stays the same
Investment costs	€15,885.75 annually (Saturday worker) or €25,000 once (cell expansion)
Costs saved	€6,689,239 till €11,148,732 (extra profit) *restricted by demand getting higher
Surface reduction	80m^2
ROI (3 years)	Unknown, due to restrictions of increase of demand.

Table 21: KPIs increasing capacity of the bottleneck

5.1.3. Merging the casting and gluing manufacturing steps

Another idea is to produce using the flange bushing as a casting cup and the casting substance as glue. This enables Pentair to perform the gluing and casting step simultaneously. To realise this the design of the flange bushing has to be reworked in a way that it can function as a casting cup. This solution would save a lot of time since the gluing and casting times are currently bottlenecks within the manufacturing process at Pentair. This idea was introduced to me by the Lean manager of Pentair (personal communication, Lean Manager, 2022)

Product Type	Casting duration (In hours)	Gluing duration (In hours)
A	19*	N.A.
B	18*	19
C	20*	21

*Table 22: Casting/Gluing duration (*means that a product has to wait this time twice within the manufacturing process)*

If Pentair would implement this solution, they would have to make sure that all three beer filtration products can undergo the new method for the casting/gluing step. Moreover, research has to be done whether this change would create an additional risk of quality issues. Currently at Pentair gluing and casting are two steps that already create a certain amount of waste of defects as they are critical manufacturing steps. Merging them together could end up in more quality issues since the manufacturing step gets even more critical.

If this new manufacturing step can be implemented successfully, Pentair can reduce the waste of defects that is created because of the operator dependability during the sanding and gluing steps of the beer modules. Moreover, the merging of these two steps reduces the bottleneck times and therefore makes the process more plannable. by getting rid of the gluing step in the manufacturing process the lead time will be reduced. Moreover, Pentair will have one less critical manufacturing step to quality, and therefore the implementation of the solution provided in Section 5.1.4 would become obsolete.

When this solution is implemented successfully operators do not have to glue the flange bushing on the modules anymore. However, the permeate for product type C still must be glued on manually. This gluing of the permeate will be done in a one-piece flow. This solution saves time and eliminates a step that is critical to quality, respectively, the gluing of the flange bushing. Therefore, Pentair will safe operator and drying times and increase the quality of the product. When this solution is implemented product type B does not have to be glued anymore and product type C only still needs partial gluing. Since product A does not need to be glued this solution will not change the manufacturing process of this type.

When Pentair succeeds to implement merging of the casting and gluing step, they will get the following results:

- The average PLT of the three beer filtration products will be reduced by 1.5% in comparison to the current situation. Currently the average PLT is 32.48. When implementing the merging, casting and gluing step it will be reduced to 31.99.
- The surface required for gluing in the current situation will at least be reduced with $80m^2$ since Pentair does not need a place for gluing the flange bushing of product types B and C. Moreover, the R&D part of the gluing cell will also be scrapped.
- Gluing operator time will be reduced significantly. Annually 1470 operator hours less would be required.

	OCT Gluing current situation (in seconds)	**OCT Gluing new situation (in seconds)**
Type A	0	0
Type B	1022	0
Type C	2547	705

Table 23: Operator time difference

- Annually, gluing times are reduced significantly. Product type C needs 12350 hours of drying less and product type B needs 24300 hours of drying less.
- 36% of the total beer modules repair can be eliminated because of this change if the solution is implemented successfully. Because of this 0.36FTE will be saved.

KPIs for the solution	
PLT reduction	1.5%
Investment Costs	Unknown, due to the research that is still required
Costs saved	€176,282 (annually/surface and operator)
Surface reduction	$80m^2$
ROI (3 years)	Unknown, due to the research that is still required

Table 24: KPIs merging gluing and casting step

Estimating the investment costs of this solution is not possible since additional research has to be done to the feasibility and the changes required to actually make the solution work.

5.1.4. Automating the gluing/sanding step

The current gluing and sanding steps are critical steps in the production of Pentair. Sanding at Pentair is done by hand at the moment. An operator uses an angle grinder and starts sanding the surface that will be glued in the next manufacturing step. Leaking membranes that are retraced to the gluing cell can therefore also be caused by bad sanding quality. Therefore, the sanding step is a critical step in terms of quality loss.

The waste of defects that is caused in these steps could be reduced by using a pressing machine that pushes the flange bushing on the module with the same force and the same turning movement. Moreover, a cobot could be used for applying the glue. This ensures that it is always the same amount of glue that is applied as equally as possible on the module and the flange bushings. Since the cobot is programmable Pentair ensures that once in a certain time frame the gluing is refreshed by getting rid of the beginning of the glue that could react with the air. By applying this Pentair eliminates the variety in pressure force and turning speed that operators have.

The automation of these steps could make the critical manufacturing steps more consistent and reduce the waste of defects and the number of products that have to be repaired or scrapped. One of the other Pentair locations already uses a workstation that could be implemented at the location in Enschede as well. If Pentair could combine this working table with a cobot that applies the glue, Pentair eliminates all variables and inconsistencies in the gluing cell.

Furthermore, before the gluing station a sanding cobot can be applied that sands the module with the same precision every time. Moreover, this sanding cobot will have a build in extraction which keeps the air around the cobot clean and safe for the operators. Current tests in the sanding cell showed that the air quality was near the threshold of being unhealthy for operators (personal communication, Production technician lead, 2022). The investment of the sanding cell cobot will cost around €200,000 (personal communication, Production technician lead, 2022). The costs of the modules returned in 2021 because of quality issues due to bad sanding/gluing equalled around €139,440 (personal communication, Production technician lead, 2022). By automating the sanding and gluing process Pentair can reduce these scrap costs. These sanding and gluing cobots will enable Pentair to produce on a higher quality while ensuring more safety. If Pentair implements this solution it will result in the following numbers as shown in Table 25:

- Current FTE required for gluing is 2.5. In the new situation 1 operator should be able to operate with the gluing and sanding cobot.
- Due to the automation quality will increase, annually Pentair will safe €139,440 on modules that will be returned.
- Surface reduction will equal 30m^2.

KPIs for the solution	
PLT reduction	Unknown
Investment costs	Circa €500,000
Costs saved	€408.811 (annually)
Surface reduction	30m^2
ROI (3 years)	2.45

Table 25: KPIs solution automating sanding/gluing

5.1.5. Accelerated coating

See Appendix J (confidential).

5.1.6. Conclusion solutions for solving the bottleneck

The solutions provided in Section 5.1 all focus on reducing the high cycle times in the manufacturing process and/or reducing the repair percentage. In Table 26 I listed the solution with their impacts. One thing that should be kept in mind is that increasing the capacity of the casting cell will only be beneficial if accelerated coating is implemented and demand increases. Moreover, the two solutions that focus on an improvement of the gluing step cannot be implemented both.

Solution	PLT decrease%	Cost saved	Surface reduction	Repair	ROI
Lowering coating height	6.25	€105,890 + €2,628 (annual)	21.9m^2	Likely higher	11.37
Expanding casting cell	unknown	€11,148,732(annually) *demand has to be 200 per week	-20m^2	unchanged	*
Casting on Saturdays	unchanged	€6,689,239(annually) *demand has to be 180 per week	unchanged	unchanged	*
Merging the casting and gluing step	1.5	€176,282 (annually)	80m^2	36% decrease of beer repair	*
Sanding/Gluing cobot	Unknown (likely to decrease)	€408.811 (annually)	30m^2	44% decrease of beer repair	2.45
Accelerated coating	12.72	€211,781 (one time) + €4,104 annually	34.2m^2	unchanged	0.71 < X < 0.84

*Table 26: Summary of solutions *(the two solutions that improve the gluing step cannot be implemented both)*

As you can see in Table 26, accelerated coating has the biggest influence on the PLT and on the PCE% and therefore has to be included in the concept if the investment budget allows it, which might seem illogical since the ROI is estimated to be lower than 1. Lowering coating height could bring additional quality issues and therefore will not be a part of the concept. If demand increases in the future Pentair should choose to firstly aim to increase casting capacity by planning a shift on Saturdays to raise the casting capacity to 180 modules per week. When this capacity is not sufficient anymore Pentair can expand the casting cell so that another rack fits in it to match the capacity for the coating step. The feasibility of the solution that merges the casting and gluing step is still questionable. Additional R&D research will be required to prove the feasibility and therefore the automation of the sanding and gluing step is favoured over the other solution for the improvement of gluing. Moreover, the repair decrease of sanding/gluing cobot is also estimated to be higher than when merging the casting and gluing step.

5.2. Solutions for increasing efficiency in general

Now that I provided solutions on equalling out the high cycle times and reducing the waste of defects and therefore increase the possibilities to establish flow in Section 5.1, it is time to look at how Pentair can establish flow in general. The solutions provided in this section therefore are more general than the solutions in Section 5.1 and focus on establishing flow by reducing the waste that was identified in Section 4.3. Therefore, the impact of these solutions is harder to measure but should still be considered when the concept is formulated. The solutions focus on decreasing or eliminating the eight wastes as much as possible while the bottleneck is solved.

5.2.1. More team feeling instead of island thinking

Pentair manufactures products by using work cells. Therefore, every task has a specific operator assigned which stimulates the operators to focus on their own task instead of the whole manufacturing process. Due to varying operator cycle times per manufacturing step the process gets desynchronized. Currently, the long coating and casting times also create desynchronization in the process. And these times form the bottleneck to the synchronization of the process.

To acquire better communication and flow between processing steps I will introduce beer teams that will be dedicated to the manufacturing of the beer filtration products. These teams will help to balance the workload of operators more equally, since then multiple operators can share the workload of multiple manufacturing steps. Moreover, it will enable Pentair to problem solve in a more efficient way. Low-level problems should be solved on an operator team level. If the problem is more complicated it will be levelled up progressively until it ends up at the management of Pentair X-Flow as can be seen in Figure 28. These teams have a shared responsibility that the manufacturing steps performed by them are executed properly and in a one-piece flow wherever possible. Because of a clear protocol for problem solving at the department and the teams, the risk of quality issues will be decreased since the problems will end up at the right persons.

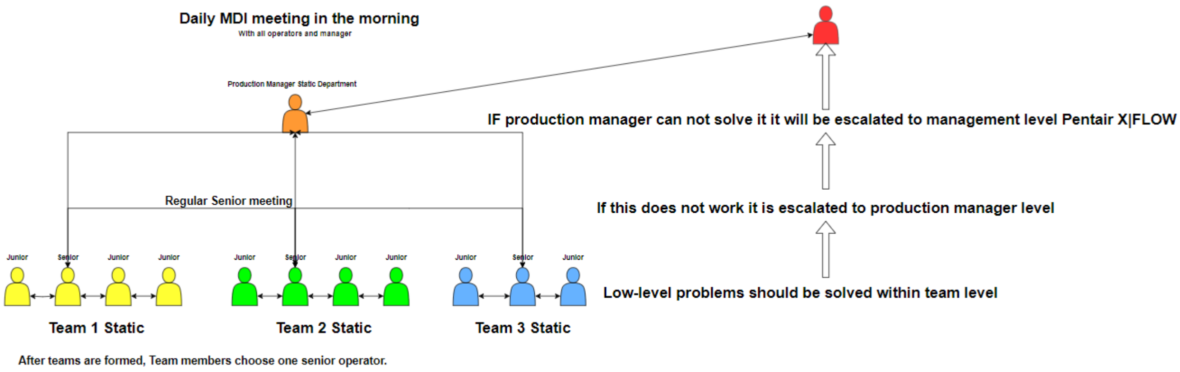

Figure 28: Team formulation

By implementing the solution provided in this section, Pentair will establish a better flow within the teams and the process. Because of this improved flow the WIP can be kept lower. Pentair will form three beer value stream teams. If there is desynchronization between these teams WIP will still occur, but this WIP will then be put between the teams and therefore Pentair can better monitor the manufacturing process of the beer modules. Using the STW timings I can calculate how much operators are needed per team for which production number of beer modules. These calculations can be found in Tables 27, 28 and 29. Introducing beer teams enables Pentair to reduce the WIP between the manufacturing steps of the teams. Therefore, a lot of waste of waiting will be reduced. Moreover, the teams are responsible for the quality that is transferred to the other operator teams. This will be established through an incoming good inspection at the next team. With a relatively low effort Pentair could increase the PCE% significantly.

Team 1

Team 1 will perform the manufacturing steps in the beginning of the value stream of the beer modules. These tasks are respectively:

- Preparation of the housings/spacer
- Preparation bundles
- Bundling and inserting
- Cutting

To establish these teams Pentair has to train the operators in such a way that they can perform multiple of these tasks. The trained skills have to be updated on the skills-matrix board that is currently already implemented at the Static department. Training the operators all the tasks in this 'beer value stream team' will take around 2 months. Once the operators know how to perform all the different tasks, the team is operational. The team has a shared responsibility for producing what is needed at a certain time with proper quality according to STND10206, which is a quality standard document within Pentair. Since operators can perform all the task, Pentair can more efficiently arrange the required FTEs. Moreover, the team is also responsible to check whether the raw materials that are used are of good quality. If this is not the case operators are empowered to stop production and PROC-10010 (procedure) will be started. Keeping in mind the production amount currently, respectively (10, 5, 10) for product type A, B and C, Pentair needs 2.61 FTE. The calculations for the required FTE are based on the STW timings performed within Pentair. With the current production rate three operators will be scheduled for team 1 (beer). The future maximal demand will most likely equal around 40 modules a day. In Table 27 you can see how many FTEs are required for team 1 for different production amounts.

Number of products (per day)	Required FTE	Allocated FTE
25 (Current)	2.61	3
30 (12, 6, 12)	3.13	4
30 (10, 10, 10)	3.33	4
35 (15, 5, 15)	3.55	4
35 (12, 11, 12)	3.85	4
40 (15, 10, 15)	4.27	5
40 (14, 12, 14)	4.37	5

Table 27: required FTE team 1

Team 2

Team 2 will perform the following manufacturing activities within the beer value stream at the Static department:

- Prepotting or kitting
- Coating
- Casting
- Sawing
- Flour testing

Team 2 more or less already exists within the Static department. At the moment this team is called the beer team since it is operational in the beer cell mostly. Therefore, this team does not need as much training to learn the different manufacturing steps as the other two teams. This team will now also get a shared responsibility that they are producing on time and with proper quality. In Table 28 you can see how many FTEs team 2 requires for different production amounts.

Number of products (per day)	Required FTE	Allocated FTE
25 (Current)	2.98	3
30 (12, 6, 12)	3.57	4
30 (10, 10, 10)	3.64	4
35 (15, 5, 15)	4.14	5
35 (12, 11, 12)	4.23	5
40 (15, 10, 15)	4.80	5
40 (14, 12, 14)	4.83	5

Table 28: Required FTE team 2

Team 3

Team 3 will perform the following manufacturing steps within the beer value stream of the Static department at Pentair:

- Gluing
- Engraving
- QC-testing
- Packaging

Operators that are currently working at the qc-testing cell mentioned to me that they would like to get modules in a one-piece flow. Just like team 1 and 2, team 3 will have a shared responsibility. The operators of team 3 also need time to learn all the different tasks however this does not have to take long. In Table 29 you can see how many FTEs team 3 requires for different production amounts.

Number of products (per day)	Required FTE	Allocated FTE
25 (Current)	2.01	2
30 (12, 6, 12)	2.41	3
30 (10, 10, 10)	2.40	3
35 (15, 5, 15)	2.82	3
35 (12, 11, 12)	2.80	3
40 (15, 10, 15)	3.21	4
40 (14, 12, 14)	3.20	4

Table 29: Required FTE team 3

The operator time that is not used as STW-time can be used for ensuring the materials which are used for the manufacturing steps of team 1 are matching quality standards and clean up the place or for doing continuous improvement actions. Per day this would result in 3 hours for checking of materials and keeping the workspace of team 1 clean. Moreover, the teams have a visualization board that is used to show the progress to management but also to the other beer teams operative at the Static department. When team 2 or team 3 is suffering from a serious problem team 1 and/or 2 should adjust their production to keep the WIP as small as possible. This visualization board will be implemented with an Andon-light. If the Andon-light of a team turns red the teams down-stream have to stop producing to keep WIP low. These teams will then get other tasks assigned by the production manager.

Between the teams there can be a (standard) WIP, nevertheless, WIP should be tried to be kept to a minimum and the teams should try to produce one-piece flow wherever the manufacturing process allows it. For the wine value stream that flows through the Static department an additional 3 FTEs are required. With the new teams there exist the following FTE scenarios:

Number of products (per day)	Team 1	Team 2	Team 3	Total
25 (Current)	3	3	2	8
30 (12, 6, 12)	4	4	3	11
30 (10, 10, 10)	4	4	3	11
35 (15, 5, 15)	4	5	3	12
35 (12, 11, 12)	4	5	3	12
40 (15, 10, 15)	5	5	4	14
40 (14, 12, 14)	5	5	4	14

Table 30: Required FTE per team

Not all FTE capacity is used for STW works, however, within the Static department, there are a lot of chores that still need to be done. This leftover operator capacity should be spent on checking quality of raw materials, keeping the workspace clean and updating visualization regularly. Although this solution is not that innovative, if it is implemented successfully, it will have a great impact.

5.2.2. Ensuring more quality of the raw materials entering the process

Looking at the defects within the Static department at Pentair I noticed that most of the problems occur during the coating/casting/gluing phase of the manufacturing process. In the current situation these steps are rather operator dependent and therefore the quality gets inconsistent. Another critical manufacturing step to the quality of the product is the sanding before gluing. One way to reduce the waste of defects would be by improving these critical steps in the process, for example by implementing one of the solutions mentioned in Section 5.1.5 or 5.1.4.

However, repair at the moment is not only caused by the process itself. The quality of the materials entering the process often does not meet the defined quality standards. Therefore, the aim of Pentair should be to intensify the quality control before materials actually enter the manufacturing process. This can be the checking of spacers/housing and bundles but besides that also the materials being used like clamps and permeate stops, production tooling, etc. Once all the external materials are of proper quality, Pentair can conclude that the actual repair and scrap that is happening is due to the manufacturing process itself. This will result in a process where you can identify more easily where the waste is coming from, since the input variability is minimized. Moreover, it already takes away a part of the current waste of defects. Better quality of products will be established by multiple solutions:

- Intensive quality control at the membrane production hall (inhouse) before membranes are stored as inventory.
- Talking to suppliers and ensuring that spacers and housings are delivered with the desired specifications. Defining clear CTQ-values. Talking and determining necessary critical specifications on materials and drawings.
- Regular maintenance to machinery located in the Static department. Switch from maintenance after breakdown to preventive maintenance.

By checking the input materials of the manufacturing process intensively the lead time will be reduced, and the process therefore will become more agile. This is a different way of phrasing an increase of PCE% due to the reduction of waste of defects.

Implementing the solution above will be a relatively low investment. Clear CTQs (Critical to Quality) are already defined within Pentair and just have to be demanded from the suppliers of material. The costs that the supplier charges for it will only be marginal. Quality is a key value when it comes to the products that Pentair delivers and is of big value for the customer.

More extensive quality control will be done by the operators within the Static department concerning materials that are used in the process, for example clamps, stops etc. At the inhouse membrane production the operators also have to spend more STW time on observing the materials and check the quality of materials used in the process. Let’s say that per week material checking takes up to 1 hour at the end of Friday. All operators in this hour get the time to check the quality of materials. If something is not as it should be it is reported, and the (raw) material is marked and put on hold. The beginning of the following week the QA-department goes through all the materials that are put on hold by the operators.

The profit that comes with this investment are difficult to grasp in terms of money, since defects occur partially because of bad quality of raw materials but are not registered liked that. This solution however enables pentair to eliminate this variable and focus on the other dangers to waste creation in the long term. For the implementation of this solution Pentairs needs to use change-management.

Therefore this solution is fairly difficult to implement with a high success. It is more about changing the habits within the Static department at Pentair than about investing a certain amount of money.

5.2.3. Kitting instead of prepotting

One solution could be to kit the membranes instead of prepotting it. The current prepotting step in the manufacturing process requires the casting and coating steps to be performed first for side 1 and second for side 2. This is because they cannot hang the module vertically while both sides are prepotted because of the risk that the prepot of the upper side might run down into the module itself. This risk is due to the prepotting viscosity number staying too low for too long, and because of gravity and the capular function of the membranes that will cause the prepotting to run down into the membranes. This is undesired and leads to quality issues.

The fact that these steps have to be performed side by side increases the number of manufacturing steps. since manufacturing steps with high cycle times have to be performed twice and Pentair uses a push flow strategy this increase the amount of WIP. Another inefficiency that the current prepotting manufacturing step is causing is a shared capacity on the racks in the beer and wine cell. This shared capacity is undesired since it makes planning the capacity of the racks difficult, which leads to an inefficient usage. Moreover, the prepotting process is outdated and inefficient because there is a lot of waste of materials. Every time a module gets prepotted, a plate with rest material is thrown away.

A solution to resolve this might be to kit the beer modules instead of prepotting them. If the modules are being kitted, Pentair does not have the risk of substances running to the middle of the membrane while coating it horizontally. Kitting is currently already used at the Dynamic department of Pentair. The difference with this manufacturing process is that coating is done horizontally and the membranes itself are different. Therefore, this idea has to be tested before it can be implemented. While talking to an R&D Engineer at Pentair (personal communication, Resin specialist, 2022), I got the confirmation that this could be a possibility. However, there is a risk of membranes that still remain open without it being detected by an operator since it is difficult to identify open membranes after kitting. The open membranes become visible after coating/casting and then it is basically already too late to still fix the issue and ensure the quality of the product. Nevertheless, this is the same for the products that are already being kitted successfully at the dynamic department of Pentair. I tested whether this solution is feasible and can be implemented in the long term, this test can be found in appendix D.

If kitting is implemented, Pentair does not have a shared allocation for prepotting and coating. This means that there is no shared capacity limit anymore, which makes planning the process easier. Another benefit is that the waste of material will go down. During kitting waste of material is almost zero, therefore operators will not have to throw away prepotting plates anymore. Moreover, if kitting is implemented and Pentair manages to hang the bundle and the spacer/housing separately while coating, products can be coated and casted for both side after one another. This eliminates the loop through the Static department that is the case in the current situation.

5.2.4. Coating piece by piece instead of in batches

Currently operators apply coating in batches of 10 for product types A and C. Product type B is coated in batches of 5. This is done because of the restrictions of the coating buckets. 7.5 kilos of the coating components are put together into a bucket. The components in this coating substance react with each other and are therefore fitted for coating only for a limited amount of time. Once this time is exceeded the substance cannot be used anymore. While talking to the Resin specialist (personal communication, 2022) I found out that the maximum time the substance can be used for coating after the components react equals 1 hour. Within this hour Pentair could chose to apply coating one by one. In this way a one-piece flow will still be established. The coating that is not used after that hour is thrown away.

This solution will most likely have a slightly positive influence on the PCE%. Nevertheless, it will increase the waste of materials. The benefits of the solution would be minimal for the current manufacturing process.

5.2.5. Producing in line/ improving plant layout

First of all, Pentair should get rid of the work cells within the Static department that are used by the products manufactured at the Dynamic department. The current allocation of these cells increases waste of transportation for both the modules produced at the Dynamic and the Static department. This means that the listed cells will be relocated from the Static department to either the current location of the Technical Service or the Dynamic department.

- Sawing cell (Dynamic)
- QC-testing (Dynamic)
- Packaging (Dynamic)

By terminating work cell manufacturing and operating as a team, Pentair can manufacture more flexibly. Producing in line makes it easier to ensure quality and visualize the status of the products. If somewhere on the line a problem occurs, the whole production line will be stopped. Operators will be empowered to make this decision as it will help to keep flow synchronized. The lights will turn red, and the production line will be put on hold until the manufacturing step that is experiencing trouble solves the issue by help of a multidisciplinary team. In this way the WIP in the process will be kept minimal and quality issues will be noticed more often. This solution will reduce waste of waiting and the waste of defects drastically. The only difficult manufacturing step that still must be batched will be the casting step of the process.

By reducing waste of transportation, production will be more agile because of a one-piece flow where possible and a push flow. Simply said, the less space there is between workstations the less WIP can be placed, and the more likely operators will be willing to manufacture using a one-piece flow. While producing in line Pentair has to keep in mind that the layout has to be logic for the product flow, material flow, operator flow but also information flow. Since operators are working on a line together, they will be working more dependent on another. To implement this solution within the Static department at Pentair there was a plant layout event held from the 18th to the 19th of May. The outcome of this event was significant. in Table 31 you can find the reduction in the waste of transportation for the three beer products. The implementation of this reduction is feasible within 3-5 years. The reduction in travel distance per product will make it easier to work in a one-piece flow wherever the manufacturing process does not restrict it.

Product Type	Travel distance – Current layout (in meters)	Travel distance – New layout (in meters)
A	519.5	373.86
B	788.7	334.12
C	516.71	285.04

Table 31: Waste of transportation reduction

In order to find out how improving the lay-out of the static department can impact the PLT I modelled a VSM model. In this model I implemented one-piece flow transfer wherever the current processing steps does not restrict it. The results retrieved from the eVSM are significant:

- The average PLT of the three beer filtration products will be reduced by 28.66%. Currently the average PLT is 32.48. When implementing the merging casting and gluing step it will be reduced to 23.17.
- Pentair saves 10 days of PLT.

- Since the PLT decrease equals 10 days Pentair saves 10 days per one time production (daily) multiplied by the manufacturing costs of the modules, which results in €529,452 saved one time.
- Investment costs are estimated to be between €50,000 to €200,000 based on investment during the last three years (personal communication, Production Technician Lead, 2022).

KPIs for the solution	
PLT reduction	28.66%
Investment costs	€50,000 to €200,000
Costs saved	€529,452 (one time)
Surface reduction	Unknown
ROI	2.65< X <10.59

Table 32: KPIs of the solution

5.3. Conclusion

During the solution generation ten solutions were formulated. Five solutions have the aim to solve or improve a bottleneck and with that improve the PCE%. The other five solution aim to reduce the waste that are most influential as stated in Section 4. These 5 solutions are more general solutions.

With the help of the formulated criteria, the impact/effort meeting (which can be found in Appendix G), and the conversations with the Lean manager it was decided that the following solutions were chosen to form a concept in Section 6:

- Automating sanding/gluing step
- Accelerated coating
- Team formation
- Kitting instead of prepotting
- Ensuring more quality of raw materials
- Improving plant layout

The solutions that are estimated to have the biggest impact on the PCE% and PLT of the beer filtration product manufacturing process are: automating the sanding/gluing step, accelerated coating and improving the plant layout.

Since only 6 solutions were chosen to be implemented in the concept, 4 solutions are chosen not to be included together with the lean manager. In Table 33 you can find which solutions are not chosen and the reasons why.

Solutions that were not chosen:	**Reason why:**
Lowering coating height	This solution introduces additional quality issues
Expansion of the casting capacity	This solution will later on be used as a recommendation since for the current situation it does not solve a problem and therefore it does not increase the efficiency.
Merging the casting and gluing step	This solution needs additional research to show the feasibility.
Coating piece by piece instead of batches	This solution does not improve the efficiency at the moment. Moreover, it will result in an increase of waste of materials

Table 33: Solutions that are not chosen

6. Concept & Implementation

In this section a concept for the future state is introduced. The concept contains six of the solutions that were introduced and rated in Section 5. As you can see in the conclusion in Section 5.1.6 the solutions all have different impacts on the bottlenecks identified in Section 4.2. In Section 6.1, I will elaborate on which solutions will be a part of the concept and why. In Section 6.2 I will provide a sketch of a future state with all the solutions that are chosen to form the concept. In Section 6.3 I will provide the impact the solution will have according to eVSM and calculations performed by hand. In Section 6.4, I will provide an implementation plan for the concept.

6.1. Chosen solutions that form the concept

While formulating the final concept I consider the impact/effort matrix provided in Appendix G. In this matrix three solution have a relatively low effort and a high impact. Moreover, I also pay attention to the impact that the solutions have on the PLT, the required investment and on the expected returns which can be found in Section 5. The solutions that will be implemented are the following:

- Accelerated coating
- Automating sanding/gluing step
- Kitting instead of prepotting
- Improving plant layout
- Ensuring more quality of raw materials
- Team formation (and visualization)

6.2. Sketch of the Concept

While making a sketch of a production line that included all the solution mentioned in Section 6.1, I first started drawing a more general concept. This concept can be seen in Figure 29 and focuses on keeping the distance between steps low and therefore improve the allocation of the manufacturing

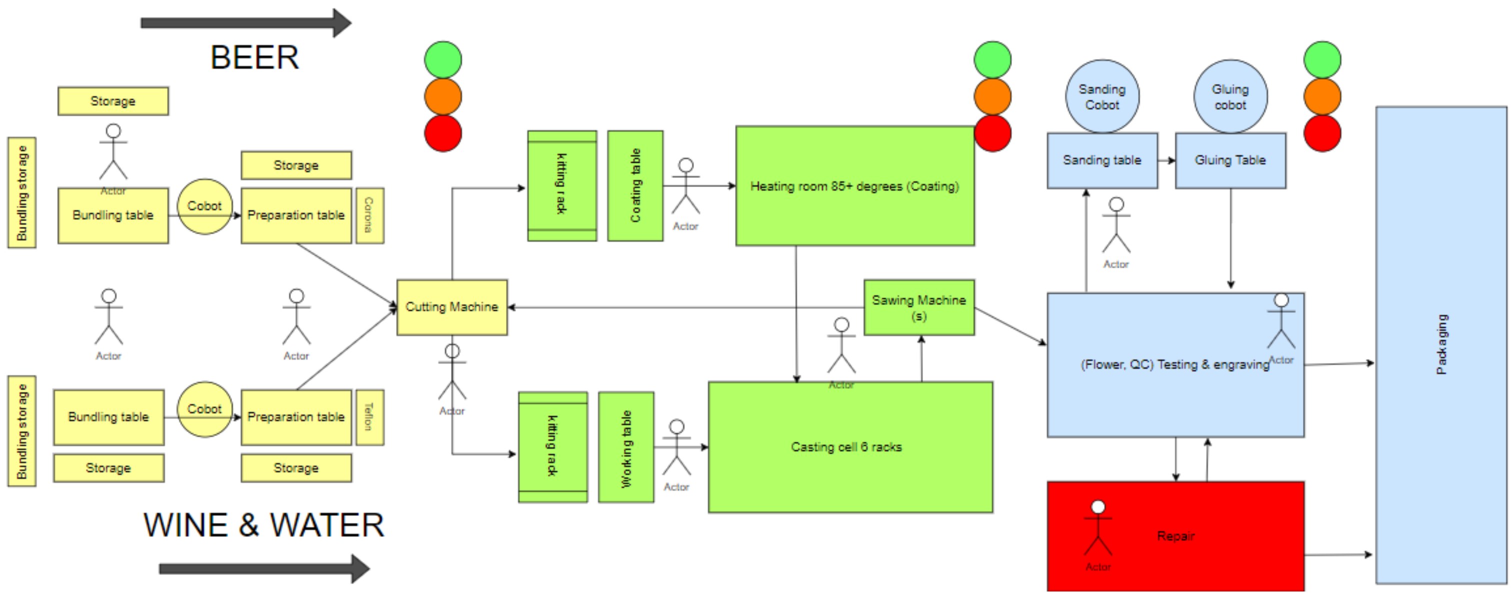

Figure 29: Sketch of the concept

steps by placing the sawing machine close to the cutting machine. This will help to decrease waste of transportation and waste of waiting. Since the manufacturing steps are closer to another, less WIP can be stored in between two manufacturing steps and batch-flow will be eliminated or reduced because of a decrease in transportation. This also means that products do not spend as much time anymore for batch completion.

In the concept I place racks that function as a supermarket for the modules that are kitted. In these racks the kit applied to the module can dry. Once a module is ready to be coated the operator of team 1 pushes it further to the side of the coating tables or preparation table before casting. An operator of team 2 now can pick it up and prepare it for coating or casting. These racks will increase the visualization of the production. Introducing kitting instead of prepotting would enable Pentair to use the room dedicated for the coating of beer modules. If Pentair continues to use the prepotting manufacturing step this would mean that a part of the room capacity would also have to be used for the drying of prepot

For the concept I assume that Pentair fails to coat for both sides at once and therefore still must loop through the manufacturing steps: cutting, kitting, coating, casting and sawing. To make this loop as efficient as possible, the sawing and cutting machines are placed central in the production line (personal communication, Production Technician Lead, 2022).

In the beginning I divide the production of beer filtration products and wine & water products into dedicated production lines. The value streams first cross at the cutting machine. After modules are cut, they are kitted. These partial beer and wine production lines work in a one-piece flow in a rate according to the takt time of the cutting operator. Therefore, the cutting machine will be the pacemaker of the new manufacturing process.

The heating cell is put in line with the beer line in the beginning since only beer filtration and a few wine & water products are being coated. In this way Pentair can keep transportation meters low since most of the wine & water products get casted after kitting. This casting cell will be used for all the modules produced on the Static department. This will make it easier to increase capacity for casting. Moreover, the casting racks in the wine cell already use the same HB-Therms that are also used in the current beer casting cell. Therefore, it makes the most sense to put all the casting racks into one casting cell and to then regulate the temperature and humidity in this casting cell just like it is done in the current casting cell.

As you can see the sanding and gluing is done by two cobots in the concept. Pentair will need one operator to work with the gluing/sanding cobot. Since all products have to be tested, I decided to put the testing location as central as possible. therefore, the total travel distance is minimalized. Repair is put close to testing, since this will reduce the travel distance between testing and repair which now is significant and stimulates operators to use batch transfer. Due to a better communication of the CTQs to the suppliers, including good and clear drawings with measuring reports, Pentair can keep materials that are stored at the line to a minimum. Therefore, waste of motion will be reduced since the line will be tidier than the current work cells.

By implementing this concept several improvements can be achieved. Firstly, the concept eliminates the most significant bottleneck that is defined in Section 4.2, respectively the high drying time for coating. Secondly, the concept will improve the layout which will keep the transportation meters as small as possible. In combination with the formulated teams, this will stimulate one-piece flow wherever the production process allows it. Keeping this in mind, one-piece transfer can be used for all manufacturing steps besides the casting in the new concept. Moreover, automating the gluing/sanding step results in a lower repair percentage. This one piece-flow will reduce the wastes identified in Section 4.3, and therefore increase the PCE%.

6.3. Impact of the Concept

In order to get a good estimation of how big the impact will be I modelled a VSM that includes all the solutions that form the concept. In this model I assume that everywhere where the manufacturing steps do not restrict batch work, a one-piece flow will be used. This one-piece flow will be possible because of the team formation and the improved plant layout of the Static department. Therefore, almost every FIFO-lane, included in the VSM of the current situation will disappear. Moreover, the 'drying casting' activity is reduced from 44 to 6 hours for product types A and C and from 19 to 6 for product type B. These 6 hours consist out of 4 hours drying time and 2 hours to cool the membranes down after the heat appliance. Another thing that is changed in the model is that kitting is implemented instead of prepotting. The kitting appliance takes 180 seconds, and the kit needs 1 hour to dry.

The last thing that was altered which has an impact on the PCE% and PLT of the module is the repair percentage. Because of the automation of the sanding and gluing steps I assume that gluing related problems will not occur anymore and therefore the new repair percentage of beer modules will equal 12.04%. The gluing and sanding STW timings were not altered in the model since I cannot make an estimation of these. Therefore, the impact that the concept could have on the PCE% is most likely bigger than the model estimates. All these changes will cause the PCE% and PLT to differ. Nevertheless, the outcomes of this model will be a rough estimation of the impact the new situation will have on the PCE% and the PLT. The output however can be used to motivate the implementation of the concept.

Looking at the output of the VSM model of the concept, provided in Figure 30, I can conclude that the PCE% increases from 13.37% to 24.52%. Moreover, the average PLT of the three beer modules decrease from 32.48 days to 18.83 days. These differences in PLT and PCE% make the beer module production more agile and easier to plan. Moreover, this enables Pentair to increase production whenever needed. Because of producing one-piece flow, WIP will be reduced. In Appendix F you can find a figure in which red dots visualize the current carts with WIP (beer filtration products) at Pentair. When the concept is implemented, these carts will not be used anymore. Since the PLT is decreased by 13.65 days I can calculate the WIP-costs that will be saved by multiplying the manufacturing costs by the daily production times the PLT reduction days. This WIP-reduction results in €722,700 additional liquidity, which at the current production is trapped in the manufacturing process. Moreover, in the new model the operator costs can be kept lower since gluing at the moment is a time-consuming step and results in more repair. If I combine the savings calculated in Section 5.1, I can calculate a total annual saving which equals €415,706. Depending on the total square meters saved during the plant layout changes, these savings can become higher.

Z0010		#0
Time Summary		
LTVANVA	2,69	Wk
Total Value Added	4744,06	Min
Value Added Percent	24,52	%

Z0020		all
Cost Summary		
Total Added Costs	2,47	K€ / Day
Total Annual Inv Carry Cost	0,00	K€

A0690		all
Resources Summary		
Total Resource Time Avail	337,50	Hr / Wk
Total Resource Time Used	274,45	Hr / Wk
Total Resource Utilization	81,32	%

Figure 30: KPIs whilst implementing the concept successfully (retrieved from the eVSM model)

In order to see how the teams that were suggested work out, I modelled the teams as a resource instead of individual operators and assigned the teams the tasks they need to perform. You can see in

Figure 31 that in the new situation by introducing dedicated beer teams, Pentair can divide workload more evenly and make sure that all operators can manage to perform their daily tasks. The operator utilization increases from 70.37% to 81.32%. Since I am calculating with 7.5 available operator hours a day this is seen as an improvement. Besides these standard works, operators have buffer times for checking quality, keeping their work areas clean or/and filling in forms. A thing that should be kept in mind is that in both VSM models the repair operator time was not included since these STW times are not available. In both models I keep the average repair time equal to keep the models comparable.

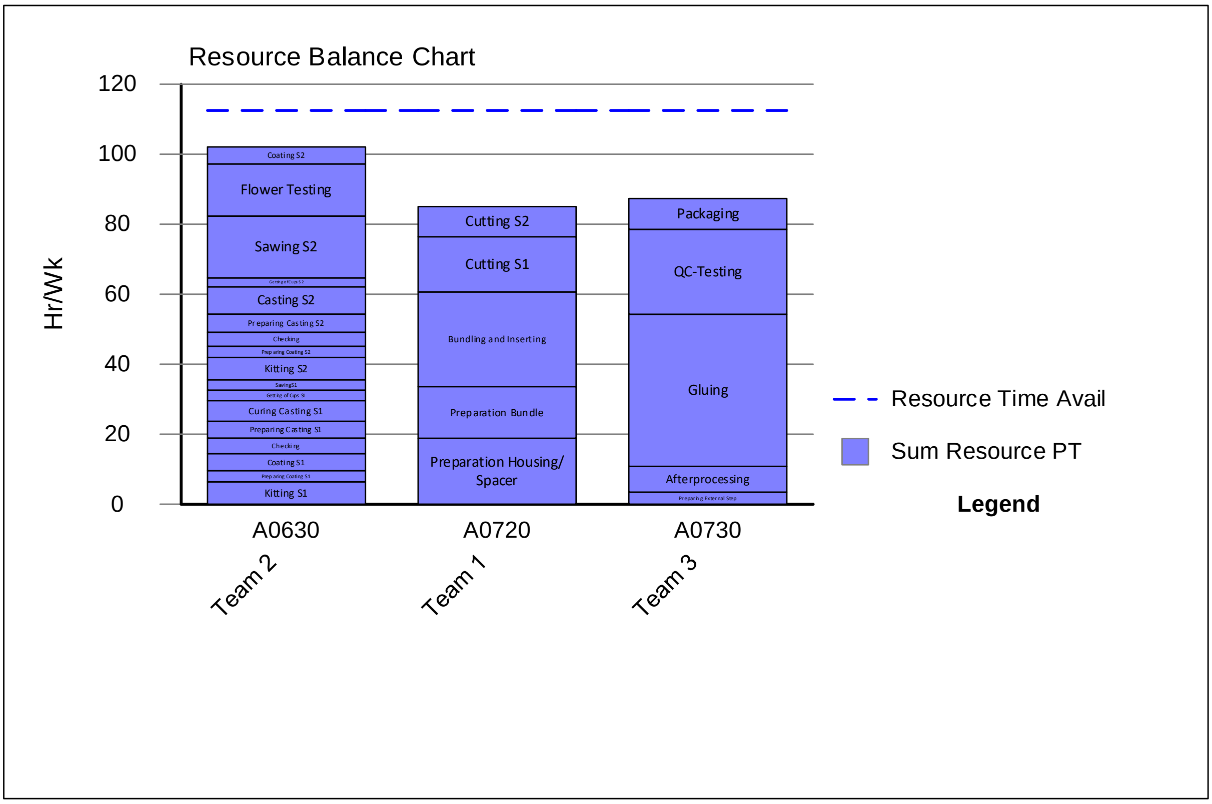

Figure 31: Resource balance whilst implementing the concept

The VSM model of the situation with the concept implemented can be found in Appendix E. To calculate a ROI of the concept I first of all estimated the costs of the new coating cell to be around €100,000 based on prices of quotes from last years (personal communication, Product Technician Lead, 2022). The costs of automation of the sanding and gluing steps will approximately cost around €500,000 (personal communication, Product Technician Lead, 2022). The team formation does not require investments to be established. Two other big investments are implementation of accelerated coating and the layout change. The investment for the implementation of accelerated coating is estimated on €250,000 to €300,000 and the plant layout change was estimated between €50,000 to €200,000 (based on investment in the last three year). Together this results in an investment in the range of €900,000 to €1,100,000. The return of this investment after three years will equal around €2,087,655.21 (or more based on the surface reduction due to the improved layout). The ROI over 3 years of the concept is therefore estimated to be around 1.89 to 2.3. In this calculation the costs of the cobots in between the bundling and cutting tables are not included since this is an additional automation that will not necessarily increase the PCE% or reduce the PLT. Nevertheless, the cobots will increase the ergonomics of the operators. The investment of the two ionization cobots between bundling and preparation of the housing/spacer equals around €100,000. The KPIs of the concept can be found in Tables 34 and 35.

Estimated investment costs	€900,000 to €1,100,000
Costs saved	€ 840,537.45 (one time) + €415,705.92 (annually)
Surface reduction	80m²
ROI (3 years)	1.89 to 2.3

Table 34: Return and investment of the concept

KPIs for the concept	Current Situation	Concept situation
PCE% (in %)	13.37%	24.52%
PLT (in weeks)	4.46	2.69

Table 35: KPIs of the concept

6.4. Implementation plan

In this section the implementation plan of the concept is provided. In Section 6.4.1, I will elaborate on who should be included while the concept is implemented. In Section 6.4.2, I will elaborate on how to implement the different solutions that the concepts exist out of. In Section 6.4.3, I provide additional things that should be kept in mind while the concept is implemented.

6.4.1. Who has to be included while implementing the concept?

In order to visualize to the management of Pentair who should be consulted during the implementation of certain solutions I made a RACI-matrix. This matrix is used to visualize which employees and departments have which role in a certain process (Lean Six Sigma Groep, 2021). The process for this case at Pentair would be the solution implementation. To reach the full potential of the concept it is key that employees within Pentair know their strengths and weaknesses and perform according to their role. The RACI-matrix uses 4 roles respectively (Lean Six Sigma Groep, 2021):

- **Responsible**: This is the person that is performing the task. In the case of Pentair this would mean the employee that is in charge of implementing a certain solution
- **Accountable**: This is the person that ultimately is responsible for the quality of the implementation of the solution.
- **Consulted**: This is the person that is consulted for advice before the implementation of a solution.
- **Informed**: These are employees that need to know of the implementation of solutions but don't have responsibility and are also not consulted.

legend
R=Responsible
A=Accountable
C=Consulted
I=Informed

Table 36: Legend for RACI-matrix

In Table 37 you can see the RACI-matrix formulated for solution implementation at the Static department at Pentair. This matrix can be used by the Lean manager to involve the required stakeholders per implemented solution.

		Operators Static	Operators warehouse	Production Team lead	Lean Manager	QA department	Inkoop department	R&D Department	PI I Department	Production technician lead	Logistics planner	Value stream manager
1	More team feeling	R	R	R + A	A	C	R					I
2	Ensuring more quality of raw materials entering the systems	R	R	I	A	R	R				C	I
3	Kitting instead of prepotting	R	I	I	A	C + I	R	R	R	R	C	I
4	Accelerated coating	I	I	I	A	C	R		R			I
5	Increasing casting cell capacity	R	I	R	R + A	C	R		R			I
6	Merging the casting and gluing step	I	I	I	A	C+I	R	R+A	R			I
7	Improving plant lay-out	R	R	R	A	R		R	R	R	R	C
8	Automating gluing & Sanding step	I	I	R	R+A	R	R		R	C	C	I

Table 37: RACI-matrix for solution implementation

6.4.2. How to implement the concept

The concept consists out of solutions that are easy to implement and out of solutions that need a longer time frame to be implemented. The solutions with the most impact for the flow at Pentair are the accelerated coating and the layout change. For the concept implementation I describe what to focus on short time, respectively within half a year. After that, I describe how to implement the solutions that require more action and are therefore long-term focus.

Short-term focus

First, the focus should be on working in teams. This is not difficult and therefore can already be applied within a short time frame. The start will be the formulation of teams. After that, operators can teach each other how they perform their task and will grow into a team in which one operator can perform multiple tasks. Once these teams are fully operative the next step can be taken. This is something the production team lead should work on together with the operators from the Static department. Within half a year these teams should be operational. Here the focus should also be to shift responsibility to the teams rather than management from above.

Second, the operators of the Static department, the Production Team Lead and the QA-department should come up with a way to ensure the quality of the raw materials that enter the process. My suggestion would be to plan a fixed hour every week at which all the operators of the Static department and the Production Team Lead check the materials that are used and mark the ones that differ from the CTQ. At the beginning of the following week QA can then walk through the materials that are marked by the operators. Moreover, the 'inkoop' department should focus on communicating the CTQ to suppliers more precisely. Short term this will increase the FYP% and show what Repair & Scrap is really caused by the manufacturing process itself.

Third, kitting should be applied instead of prepotting within half a year. For this a different plug has to be designed by the R&D department so that the kit can be applied more easily. Moreover, operators from the Dynamic department have to teach the operators of the Static department how to kit on high quality. Kitting was tested and proved to be a feasible alternative for prepotting.

Last, a layout event was held around the end of May 2022. In this event all the different employees of Pentair that are stakeholders concerning the Static department layout were included. As can be seen in the RACI-matrix concerning this solution a lot of different employees are responsible. At the end of this event a concept for the layout of the Static department was formulated together by all the responsible employees within Pentair. The impact of the new layout on the travel distance is significant as can be seen in Table 38.

Product Type	Travel distance – Current layout (in meters)	Travel distance – New layout (in meters)
A	519.5	373.86
B	788.7	334.12
C	516.71	285.04

Table 38: Reduction of the travel distance

This layout can make a big difference since it will enable the operators at the Static department to work in a one-piece flow wherever the process does not restrict it. Moreover, it will free space for alternative production possibilities. The outcome of this event will be implemented later since this will be a bigger investment and production most likely has to stop during the layout change. I recommend to implement the actual layout change at the beginning or during holidays.

Long-term focus

The long-term focus should be on implementing accelerated coating of beer modules. The PII department would have to focus on this together with R&D department. Once a model is designed it should be implemented together with the layout change. Since production for both changes have to be stopped, implementing both solutions at the same time will make the most sense. Moreover, the long-term focus should be on purchasing the cobot for sanding and gluing. This is also a task for the PII department.

If demand increases in the future and accelerated coating would be implemented successfully an operator will be employed on Saturdays to perform an additional casting round or the casting room has to expanded with more racks. When the accelerated coating is implemented and demand would increase, the casting cell will become the new bottleneck. For the casting room one additional rack would be enough to equal the production capacity of the coating room.

6.4.3. Things to keep in mind while implementing solutions to increase the PCE%

Operators support for solutions is crucial, especially for all the solutions for which operators are responsible in the RACI-matrix. If operators of the Static department do not feel that they are also experiencing benefits of the changes made at the department, the impact of the solution will also be suboptimal or close to zero. Therefore, it is important to align the goal of all employees and work together on a shared goal. An example would be that after improving the plant layout a one-piece flow will not necessary be established yet. Operators will have to see that if they produce in a one-piece flow, they also benefit of it themselves. Therefore, implementation should be done by using a bottom-up approach rather than a top-down approach, which currently is the case at Pentair.

The other way around it is also applicable. If operators have any suggestions on how to improve their daily work or the production at the Static department, they should be taken seriously by management. Even more importantly they should be updated about the status of those suggestions regularly. Change-management is difficult and requires dedication of all the employees that are involved. Moreover, at the same time there should always be room for discussion.

Depending on whether the responsibility of solutions end up at the right department and who is all dedicated and supporting the solutions, the impact of the concept differs.

6.5. Conclusion

The concept as can be seen in Figure 29 includes the following solutions from Section 5:

- Accelerated coating
- Automating sanding/gluing step
- Kitting instead of prepotting
- Improving plant layout
- Ensuring more quality of raw materials
- Team formation (and visualization)

The impact of the concept to the PCE% and the PLT is significant. When the concept is implemented successfully the PCE% will increase from 13.37% to 24.52% and the PLT will be reduced from 4.46 weeks to 2.69 weeks. Depending on how successful the concept is implemented the impact on the PCE% and PLT will differ. Therefore, it is important that the right task end up at the right departments. Table 37 displays a RACI-matrix which can be used during the implementation of solutions.
The implementation of the individual solutions is sorted into two categories, respectively short term and long-term focus. Depending on how high the investment costs per solution are and whether

production has to be stopped they are assigned to one of the two categories. In Table 39 you can see which solution is assigned either into the short term or the long-term category during the implementation phase.

Short term focus	**Long term focus**
Team formation (and visualization)	Accelerated coating
Ensuring more quality of raw materials	Automating Sanding/gluing step
Kitting instead of prepotting	Plant layout improvement
Plant layout event	

Table 39: Focus during implementation

During the implementation of the solutions the emphasis should be on implementing using a bottom-up approach instead of top-down approach. The impact of the solutions is strongly dependent on the operators and therefore they should be included during the implementation process in order to reach the desired impact.

7. Conclusion & recommendations

In this chapter I will provide the conclusion and recommendations of this thesis. Section 7.1 provides the overall conclusion to the main research question. In section 7.2 I provide the recommendations I have for Pentair. In Section 7.3 I will elaborate on the validity of the conclusion of this research.

7.1. Conclusion

The main question of the bachelor thesis is: **'How to increase the Process Cycle Efficiency (PCE%) of the beer manufacturing process at Pentair by looking at the different kinds of waste according to lean?'**. To be able to formulate a proper conclusion I use the individual answers for each of the chapters throughout this report.

Current beer manufacturing process

The beer manufacturing process consist out of 3 product types, respectively product types A, B, and C, which mainly undergo same manufacturing steps. Product type A is the only beer filtration product that is not glued but requires an external manufacturing step instead. Since product type A is not glued it also requires less operator time to be manufactured as can be seen in Table 40.

Operator time	*(In Minutes)*			
	Product type	A	B	C
	Preparing spacers	5:25	19:03	N/A
	Preparing housing	N/A	N/A	7:11
	Preparing bundles	6:10	10:00	6:10
	Inserting bundles	11:35	9:02	15:41
SIDE 1	Cutting	6:55	13:54	4:40
	Prepotting	3:05	3:05	3:05
	Literate	1:00	1:00	1:00
	Preparing coating	1:30	1:30	1:30
	Coating	2:05	3:05	2:05
	Checking	1:53	2:54	1:53
	Preparing casting	2:21	1:44	2:26
	Casting	2:18	1:56	3:40
	Getting of the cups	1:27	0:36	1:46
	Sawing	N/A	N/A	3:29
SIDE 2	Cutting	4:39	7:21	1:48
	Prepotting	3:05	3:05	3:05
	Literate	1:00	1:00	1:00
	preparing coating	1:30	1:30	1:30
	Coating	2:05	3:05	2:05
	Checking	1:53	1:53	1:53
	Preparing casting	2:26	2:26	2:26
	Casting	3:40	3:40	3:40
	Getting of the cups	1:12	1:12	1:12
	Sawing	11:12	12:07	3:29
	Flourtesting	6:50	13:32	3:50
	After-processing	5:40	N/A	3:00
	Glueing	N/A	17:12	42:54
	QC test & drying	8:11	12:45	13:57
	Packaging	5:48	5:23	1:51
Total OP Time	*(In Minutes)*	**01:44:55**	**02:34:00**	**02:22:16**

Table 40: Operator times per product

The current manufacturing process of the beer filtration products in the static department at Pentair consists out of 13 manufacturing steps which are performed in 8 different cells, which you can see in Table 41.

Preparation cell	Bundling cell	Beer cell	Casting cell	Gluing/ Sawing cell	“Schuurhok” cell	Testing cell	Packaging cell
Preparation	Bundling	Cutting*	Casting*	Sawing*	Engraving	QC-Testing	Packaging
		Prepotting*		Gluing	Flour Testing	Drying	
		Coating*					

*Table 41: Work cells and corresponding manufacturing steps (every step indicated with * is performed twice)*

Analysing the performance of the current situation

The VSM model that I designed in eVSM on Visio calculated the combined PCE% of the beer filtration products, which equals 13.37%. The average PLT of the three beer filtration products equals 33 days.

The three wastes that are most present at Pentair and cause the PCE% to be low are:

- Waste of transportation
- Waste of defects
- Waste of waiting

To identify the waste of transportation at Pentair I made spaghetti diagrams. The travel distance per products respectively is: 519.5, 788.7 and 516.71 meters. These long transportation distances stimulate batch transfer between manufacturing steps in the current process. This means that products have to wait until the batch is complete and therefore spend more time in the process itself. The waste of defects in the year 2021 was significant. A repair on one of the product sides takes around 2 days. These 2 repair days are not value adding and therefore decrease the PCE% of the current process. Moreover, products needed to be scrapped because they did not meet the quality standards.

The waste of waiting has the biggest influence on the low PCE% of the beer filtration products. This waste is partially caused by the transportation waste. In the current situation Pentair tries to keep the waste of transportation low by transferring using batch sizes of respectively 10, 5 and 10 pieces for product types A, B and C. Batching, nevertheless, result in longer waiting times of product since they have to wait for batch completion until they can be transferred on to other manufacturing steps.

During the analysis of the current situation, it was noticed that the variation of cycle times per process step strongly differs as can be seen in Figure 32. These long cycle times for the coating, casting, gluing and repair steps troubles the flow of the beer manufacturing process and increase the amount of WIP and waste of waiting. These high processing times therefore are seen as bottlenecks to the flow of the process.

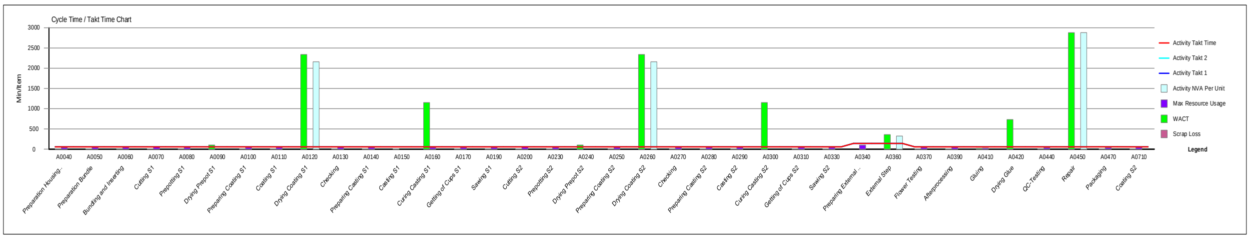

Figure 32: Variation in processing times

Solutions for waste reduction

To reduce the waste in the beer manufacturing process and to therefore higher the PCE% I thought of ideas myself and consulted stakeholders. Firstly, solutions were generated with the aim to solve the bottlenecks. Secondly, more general solution for waste reduction were generated. The generated solutions with the aim to solve the current bottlenecks can be found in Table 42. In the table I provide an estimated decrease of the PLT and the influence It has on the surface required as well as the repair percentage of the beer modules. Moreover, where possible, an ROI(3 years) was calculated by dividing the return over 3 years by the investment for the implementation of the solution.

Solution	PLT decrease%	Cost saved	Surface reduction	Repair	ROI
Accelerated coating	12.72	€211,781 (one time) + €4,104 annually	$34.2m^2$	unchanged	0.71 < X < 0.84
Lowering coating height	6.25	€105,890 + €2,628 (annual)	$21.9m^2$	Likely higher	11.37
Expanding casting cell	unknown	€11,148,732(annually) *demand has to be 200 per week	$-20m^2$	unchanged	*
Casting on Saturdays	Stays the same	€6,689,239(annually) *demand has to be 180 per week	NA	unchanged	*
Merging the casting and gluing step	1.5	€176,282 (annually)	$80m^2$	36% decrease of beer repair	*
Sanding/Gluing cobot	Unknown (likely to decrease)	€408.811 (annually)	$30m^2$	44% decrease of beer repair	2.45

*Table 42: Solutions for bottleneck reduction *(the two solutions that improve the gluing step cannot be implemented both)*

The solutions that were generated that do not aim to solve a specific bottleneck but will help to increase the PCE% of the beer manufacturing process are listed below:

- More team feeling instead of island thinking
- Ensuring more quality of raw materials entering the process
- Kitting instead of prepotting
- Coating piece by piece instead of in batches
- Producing in line instead of in work cells

In order to identify which solutions would make it into the final concept I kept in mind the outcome of the impact/effort meeting with the stakeholders (which can be found in appendix G), how the different solution score on the criteria, and the conversations with the Lean manager.

Concept generation

In the final concept that is recommended to pentair several of the solutions were be included:

- Accelerated coating
- Automating sanding/gluing step
- Kitting instead of prepotting
- Ensuring more quality of raw materials
- Team formation (Visualization)

I made a concept of how the new Beer manufacturing process could look like whilst the concept is implemented as can be seen in Figure 33.

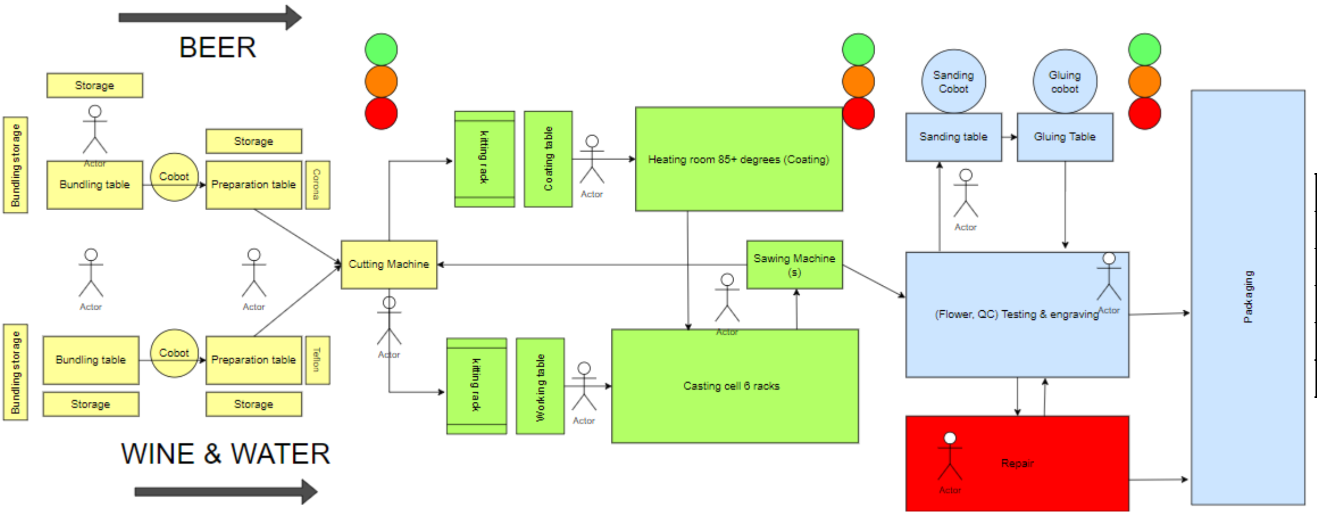

Figure 33: Sketch of the concept

Moreover, an estimation was made of the impact the concept will have. A VSM was made in a similar way it was done for the current situation. This was done because I want to measure the difference as valid as possible. The PCE% increase when the concept is implemented is estimated to be from 13.37% to 24.52% . Below, in Tables 43 and 44 you can see the KPIs and the investments/returns when the concept is implemented succesfully.

Estimated investment costs	€900,000 to €1,100,000
Costs saved	€ 840,537.45 (one time) + €415,705.92 (annually)
Surface reduction	80m^2
ROI (3 years)	1.89 to 2.3

Table 43: Investment/return of the concept

KPIs for the concept	Current Situation	Concept situation
PCE% (in %)	13.37%	24.52%
PLT (in weeks)	4.46	2.69

Table 44: KPIs of the concept

Implementation of the concept

During the implementation of the concept, I advise Pentair to make sure that the different solutions that form the concept end up at the right department and employees. To help Pentair with this a RACI matrix was designed that shows which solution involves which department/employees. The RACI-matrix can be seen in Table 45. Moreover, it is really important to make sure that the operators of the static department feel involved during the implementation of new solutions. This could be done by trying to implement solutions bottom-up instead of top-down.

#		Operators Static	Operators warehouse	Production Team lead	Lean Manager	QA department	Inkoop department	R&D Department	PII Department	Production technician lead	Logistics planner	Value stream manager
1	More team feeling	R	R	R + A	A	C	R					I
2	Ensuring more quality of raw materials entering the systems	R	R	I	A	R	R				C	I
3	Kitting instead of prepotting	R	I	I	A	C + I	R	R	R	R	C	I
4	Accelerated coating	I	I	I	A	C	R		R			I
5	Increasing casting cell capacity	R	I	R	R + A	C	R		R			I
6	Merging the casting and gluing step	I	I	I	A	C+I	R	R+A	R			I
7	Improving plant lay-out	R	R	R	A	R		R	R	R	R	C
8	Automating gluing & Sanding step	I	I	R	R+A	R	R		R	C	C	I

Table 45: RACI-matrix

7.2. Recommendations

I advise Pentair to include several of the solutions that were found throughout this research in their beer manufacturing process at the static department. Beneath I listed the ones that have the most potential and feasibility:

More team feeling

The operators of the static department should be divided into several teams. This enables the operators to share workloads more efficiently and makes it easier to synchronize the production as much as possible. Moreover, visualization becomes easier because of these teams as I would advise Pentair to let the teams work in a one-piece flow as much as possible. I would therefore advise Pentair to learn operators several tasks in order to be able to create multidisciplinary beer teams.

Ensuring more quality of raw materials entering the system

Ensuring more quality of raw materials can be done by communicating the clear CTQs including clear drawings with measuring report. Demanding from the suppliers to deliver raw materials according to specifications to keep repair & scrap as low as possible. This is more of a short-term recommendation.

Kitting instead of prepotting

By implementing kitting instead of prepotting for the beer filtration products Pentair does no longer need to dry the prepot on the same racks where the coating also has to dry. Moreover, this can be done horizontally which enables more flexibility within the process. In order to implement this solution, I would advise Pentair to let the operators of the dynamic department teach the operators of the static department how to apply kit on the membrane bundles. This is a short-term recommendation since it is easy to implement and has low investment costs.

Accelerated coating

Accelerated coating reduces the drying times of coating from 40 hours to 4 hours. The PII department should look into the implementation of this solution into the process. This is a long term advise since the investment cost will be relatively high.

Improving the plant layout

I advise Pentair to improve the plant layout of the Static department. For this layout improvement an event was held where all the important stakeholders were included. Once a new layout is designed it is important that the operators also support it. The implementation of the new layout should be done somewhere before the holidays since the production process will have to be stopped for it.

Automation of the gluing/sanding step

I would advise Pentair to look into the automation of the gluing and sanding step since a big amount of repair and scrap is retraceable to these two manufacturing steps. The investment costs are high, nevertheless, the return will also be significant because of the decrease in the repair and scrap percentages. Furthermore, one operator less is required.

Increasing the capacity of the casting cell

When accelerated coating is applied the casting cell will become the manufacturing step with the highest cycle time. In order to be able to match the new capacity of the coating step Pentair should look into increasing the casting cell or casting on Saturdays to match the production rate of the coating step.

Executing additional research

Throughout my research I discovered several additional subjects that should be researched. My advice would be to look into how a membrane bundle and a housing/spacer can be coated without the bundle being taped to the module. When a solution for this problem is found, Pentair does no longer have to produce side after side anymore for any manufacturing steps. Moreover, I advise Pentair to execute more research into the solution that merges the casting and gluing steps. If this solution is proven to be feasible it could simplify the process and therefore enable manufacturing the products with more efficiency.

7.3. Discussion

Concerning the validity and reliability of the research there are several points open for discussion. First, operator timings are not always noted in a structured way and therefore difficult to check. Nevertheless, the operator timings only form a small part of the total processing times and were kept the same through the two VSM models used in the research.

Moreover, throughout the research it was difficult to build a VSM model that perfectly illustrated the current process at Pentair. Nevertheless, the aim of the two models, being as detailed as needed to measure the performance of the current situation and the concept situation, was kept in mind while designing them. This means that the models are mapped as much as possible in the same way (except implemented solutions). I therefore think that the impact of the concept and solutions will be relatively representative.

The investment costs of the solutions and the concept are estimated with help of the production technician lead and based on quotations of last years. This means that the investment cost will most likely not be exactly as mentioned. Nevertheless, it provides a good indication of the actual investment costs. Another factor is that I did not get to validate the effect that the team-formation will have. Since this solution relies on change management and on how willing people are to implementation changes, the outcome can differ. Therefore, I cannot fully validate the effect that the team-formation solution has. The extent to which this solution works will influence the actual PCE% after the concept implementation.

Additional research to higher the PCE% should be executed to the feasibility of merging the casting and the gluing step. When this is proven to be feasible the PCE% could increase, as long cycle times are combined. Moreover, Pentair will then merge two steps that are prone to quality issues. This makes it easier to control the waste of defects. Additional research could also be executed into the design of the products. By redesigning the product, the manufacturing process could be simplified which makes it easier to keep efficiency high.

As mentioned in Section 3, lean is all about improving continuously. Therefore, as a follow-up to this thesis, Pentair should keep their focus on improving the manufacturing process of the beer filtration products and should look for opportunities to increase the efficiency of said process whenever possible.

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Appendix A: Standard work timings

STW Observations						
in seconds	Product A		Product B		Product C	
	Lowest	Highest	Lowest	Highest	Lowest	Highest
Preparing Spacers	259	368	524	2060	NA	NA
Preparing Housings	NA	NA	NA	NA	371	448
Preparing Bundles	202	524	265	704	238	562
Inserting Bundles	654	787	498	672	690	1006
Cutting S1	300	452	810	903	229	317
Prepotting	178	274	199	255	160	253
Preparing Coating	54	91	54	91	54	91
Coating	98.3	138.6	159.6	195.6	93	132
Checking	88	129	166.2	186.8	93	134
Preparing Casting	115	153	103	106	135	178
Casting	114	149	104	119	219.2	228
Getting of Cups	59	93	31	91	102	114
Cutting S2	182	301	400	543	106	119
Sawing	617	743	366	735	196	227
Flour-testing	382	436	627	998	168	243
After processing	317	356	NA	NA	164	181.3
Gluing	NA	NA	1010	1200	2477	3484
Testing qc-mod	440	519	723	785	825	865
Packaging	289	367	218	335	101	197

Table 46: Minimum and maximum STW Observations

Appendix B: eVSM model for the current situation

In this section of the appendix, you can find the VSM model of the current situation. This is one model that is cut in several parts to make it as readable as possible

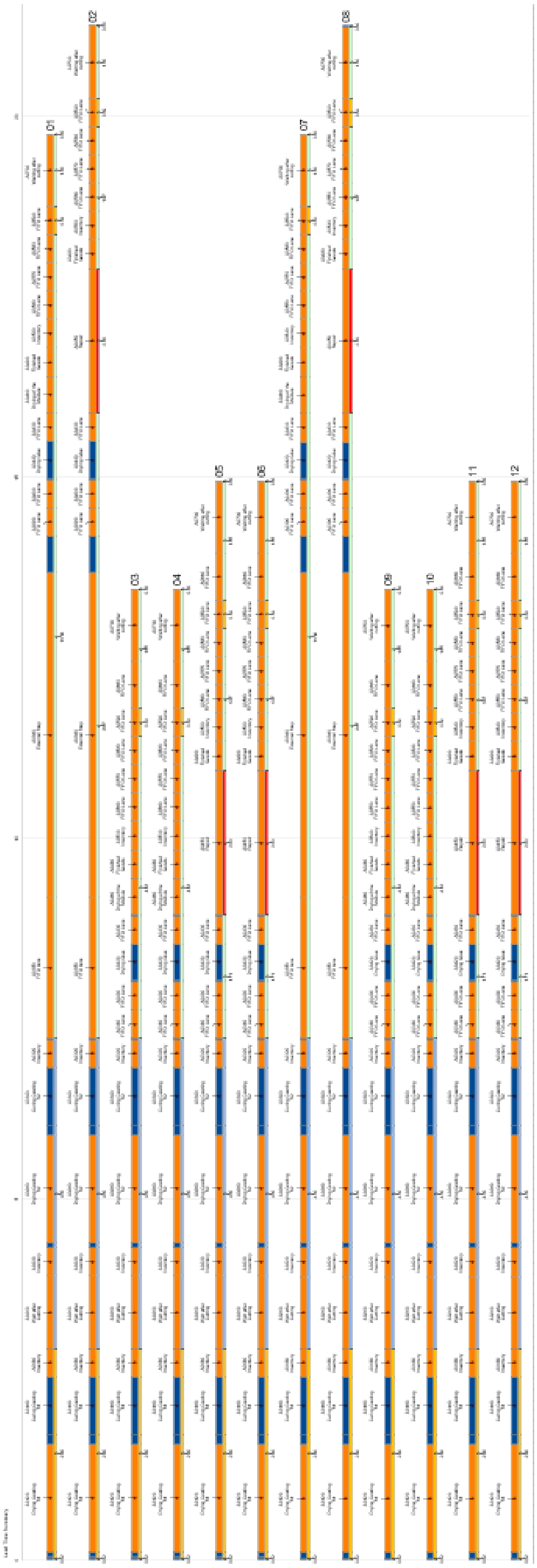

Figure 34: PLT output eVSM

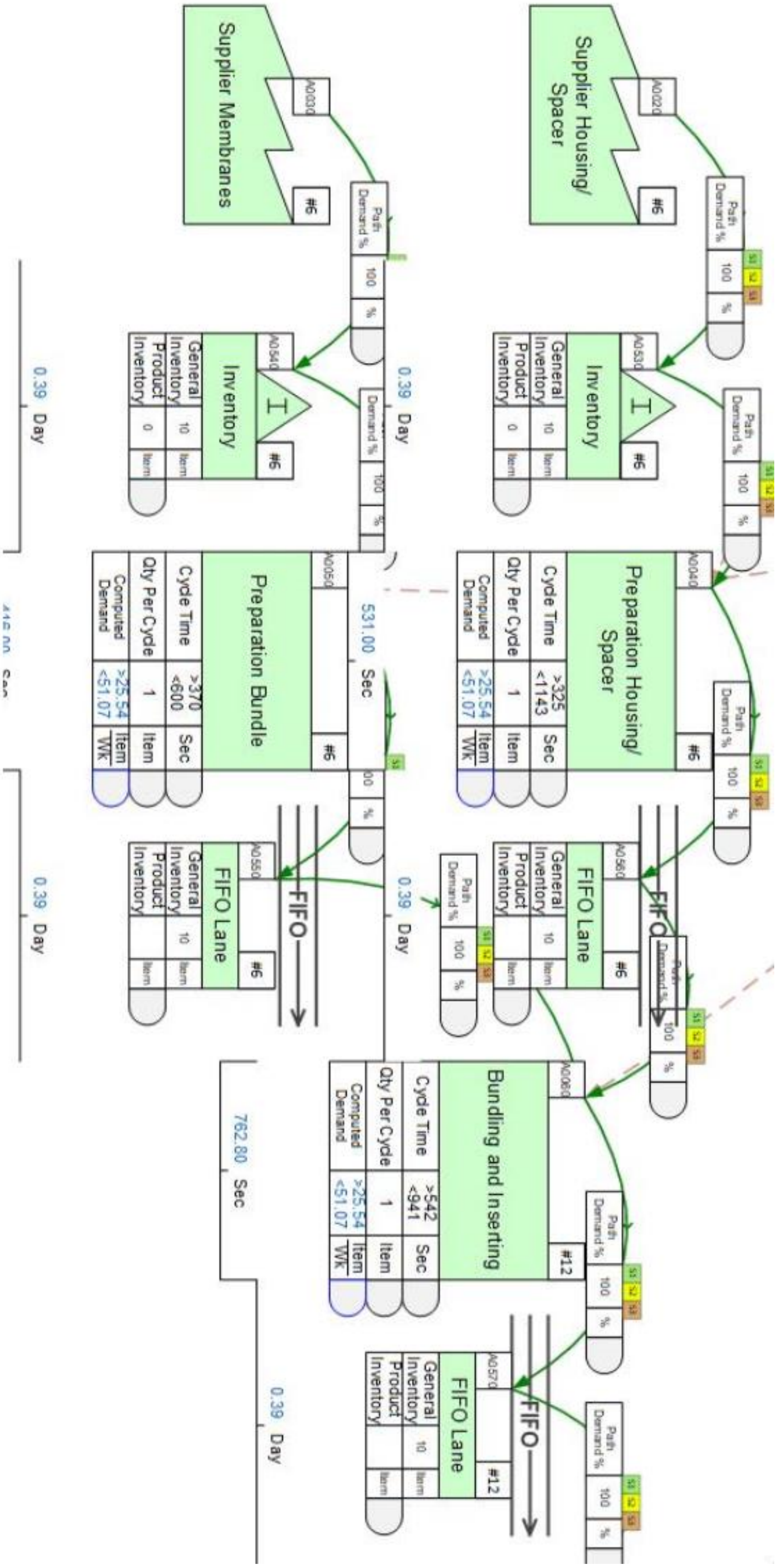

Figure 35: Current situation VSM 1

Figure 36: Current situation VSM 2

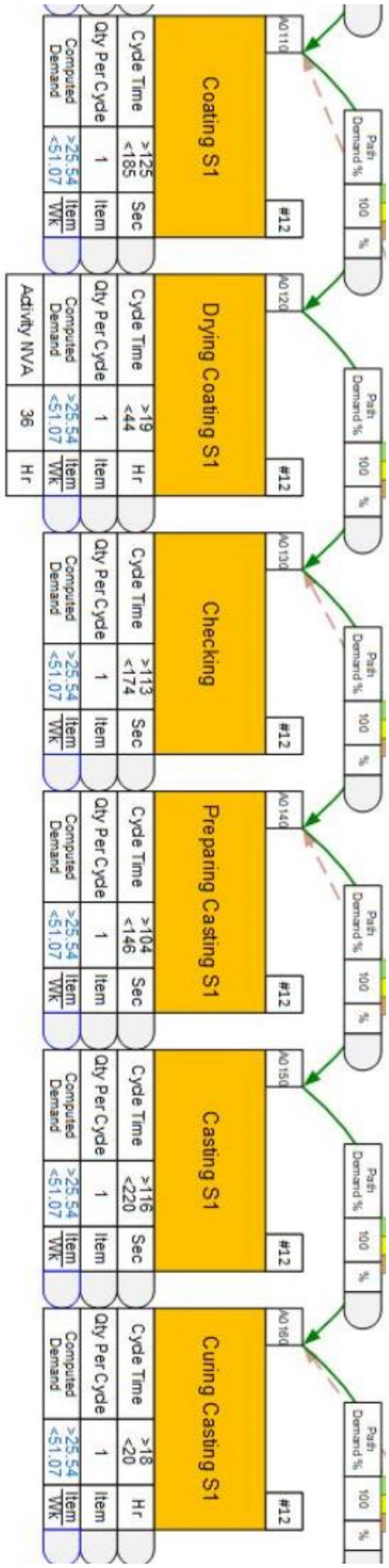

Figure 37: Current Situation VSM 3

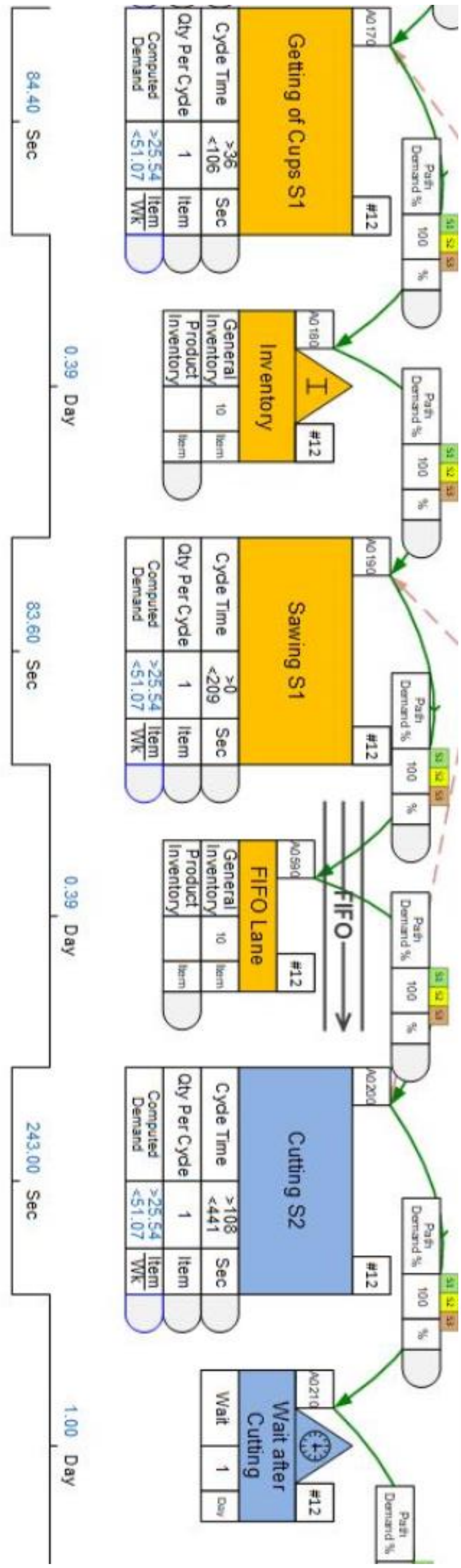

Figure 38: Current situation VSM 4

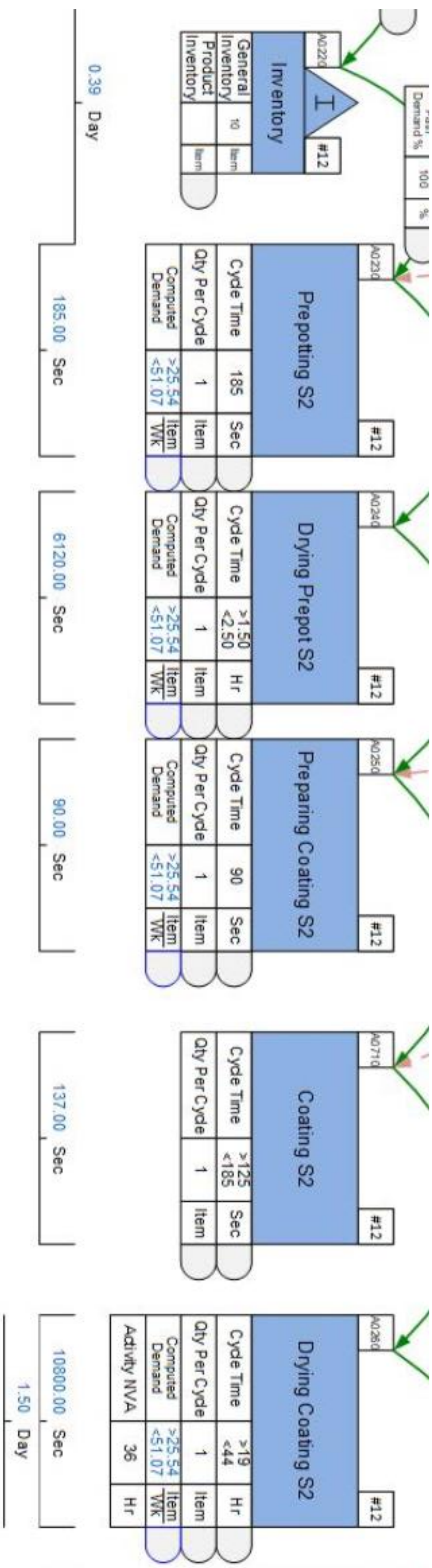

Figure 39: Current Situation VSM 5

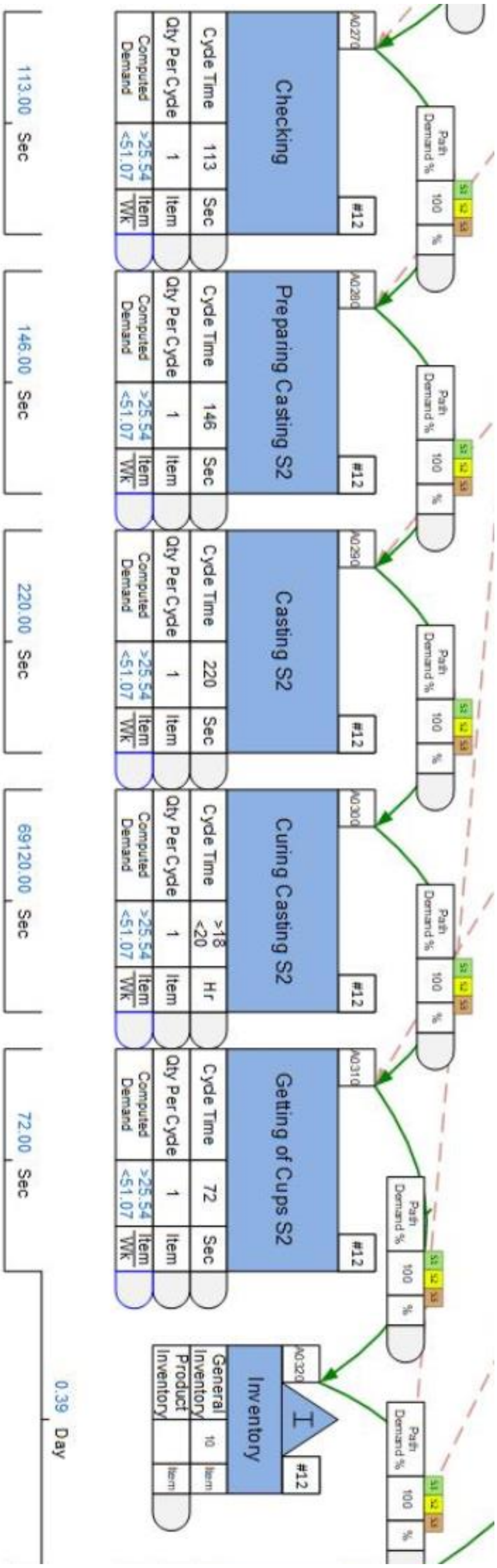

Figure 40: Current Situation VSM 6

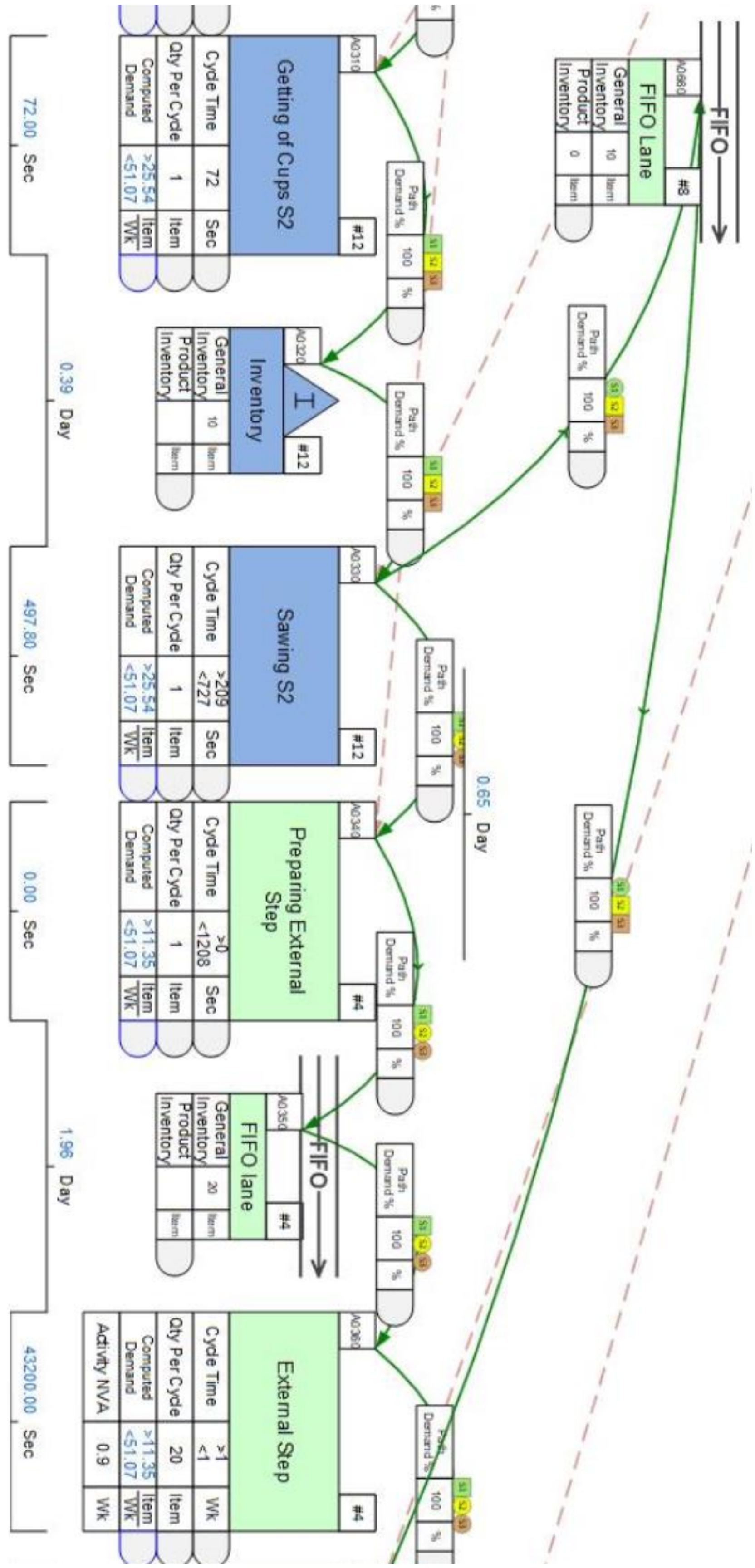

Figure 41: Current Situation VSM 7

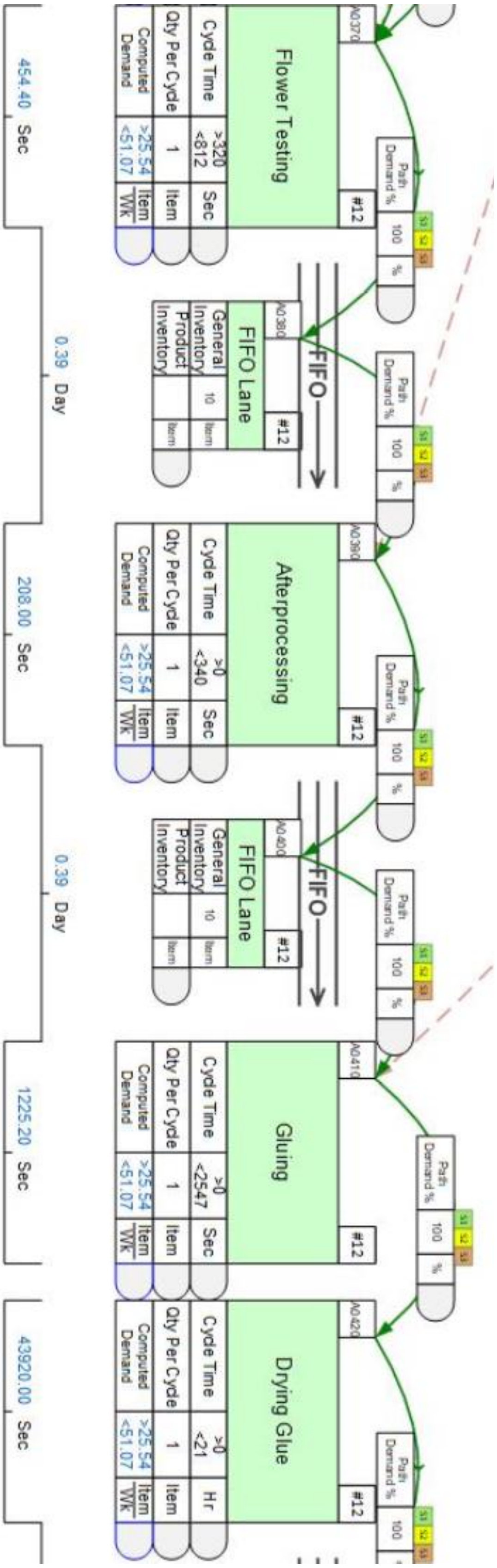

Figure 42: Current Situation VSM 8

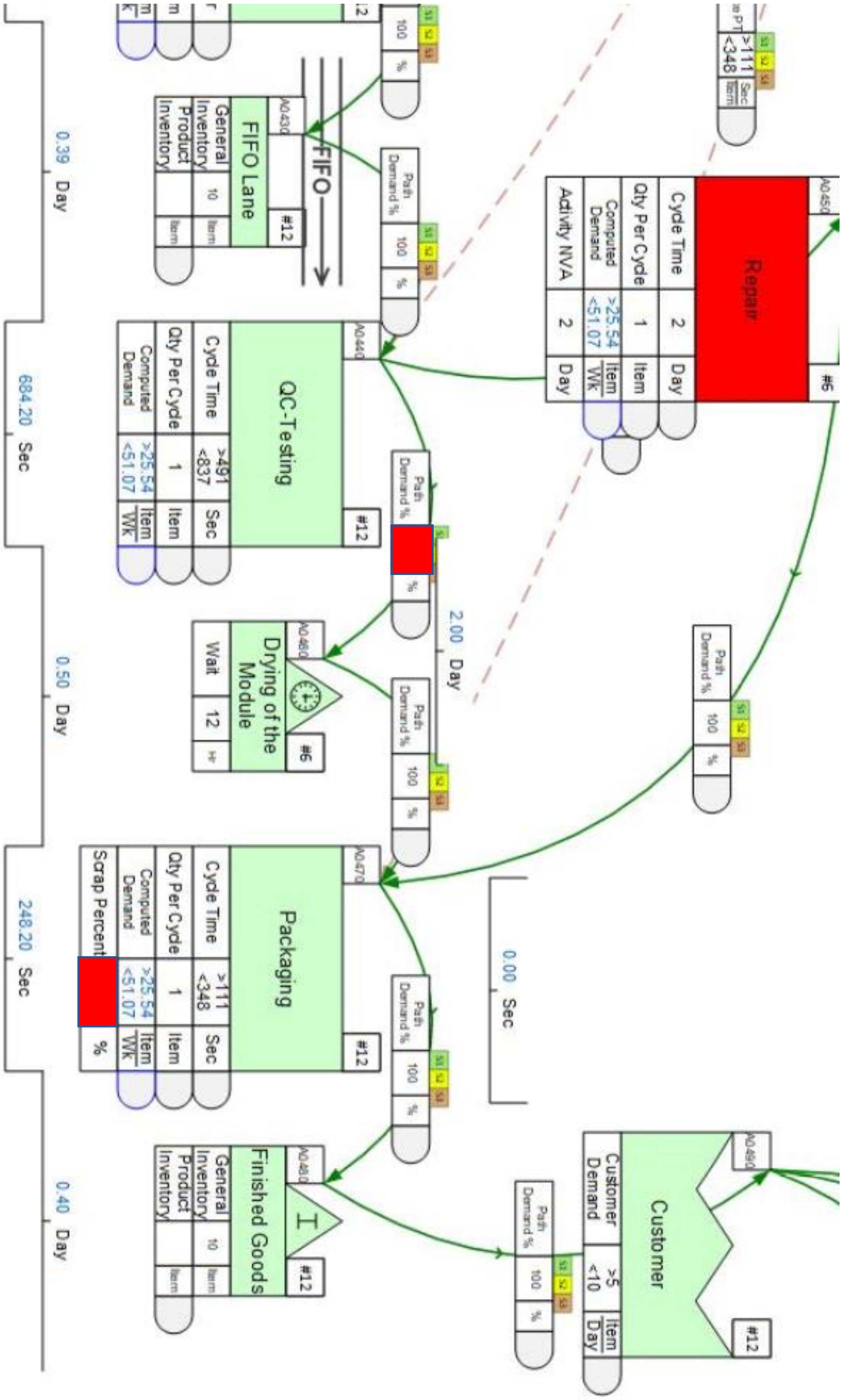

Figure 43: Current Situation VSM 9

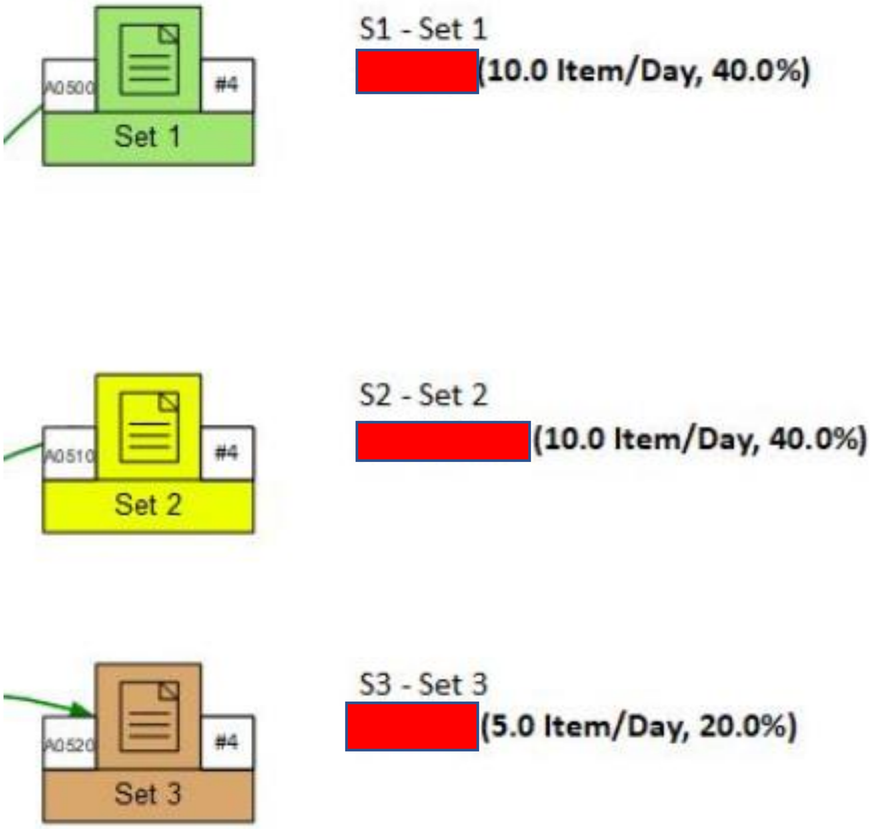

Figure 44: Customer demand VSM

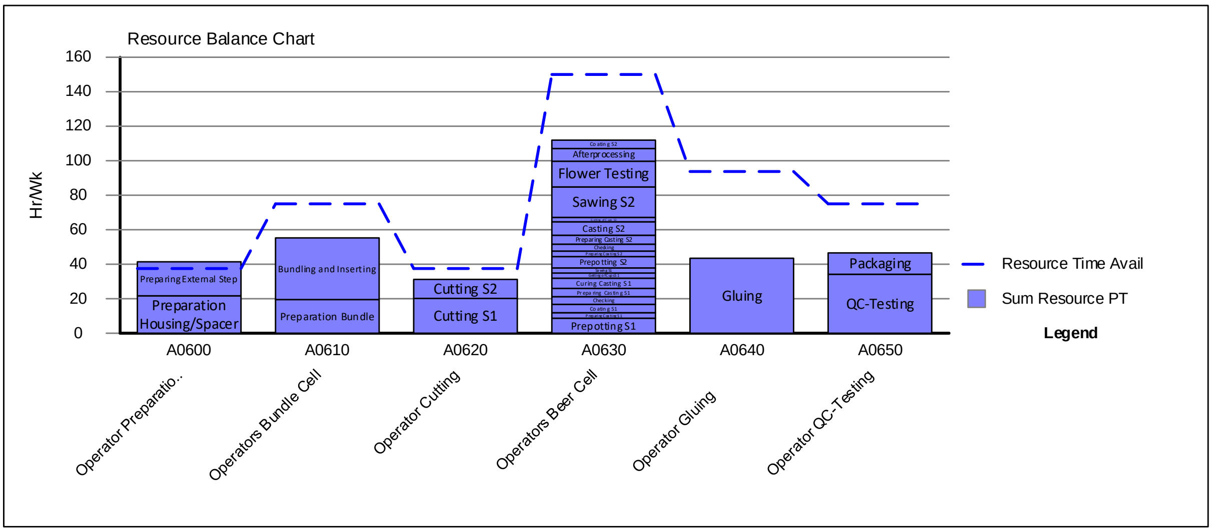

Figure 45: Resource balance Current Situation

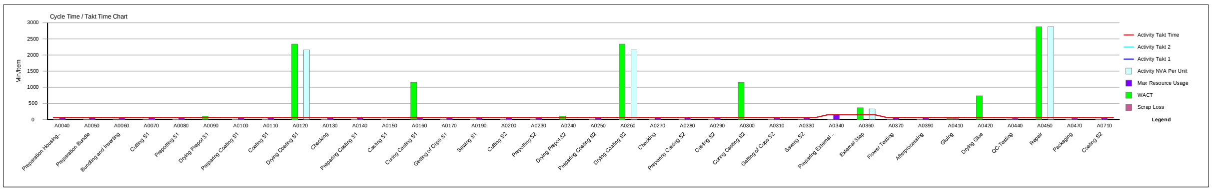

Figure 46: Cycle versus Takt Time

Z0010		#0
Time Summary		
LTVANVA	4.64	Wk
Total Value Added	4469.23	Min
Value Added Percent	13.37	%

Z0020		all
Cost Summary		
Total Added Costs	2.97	K€ / Day
Total Annual Inv Carry Cost	0.00	K€

A0690		all
Resources Summary		
Total Resource Time Avail	468.75	Hr / Wk
Total Resource Time Used	329.84	Hr / Wk
Total Resource Utilization	70.37	%

Figure 47: Summary eVSM Current situation

Appendix C: Spaghetti diagrams of the current situation

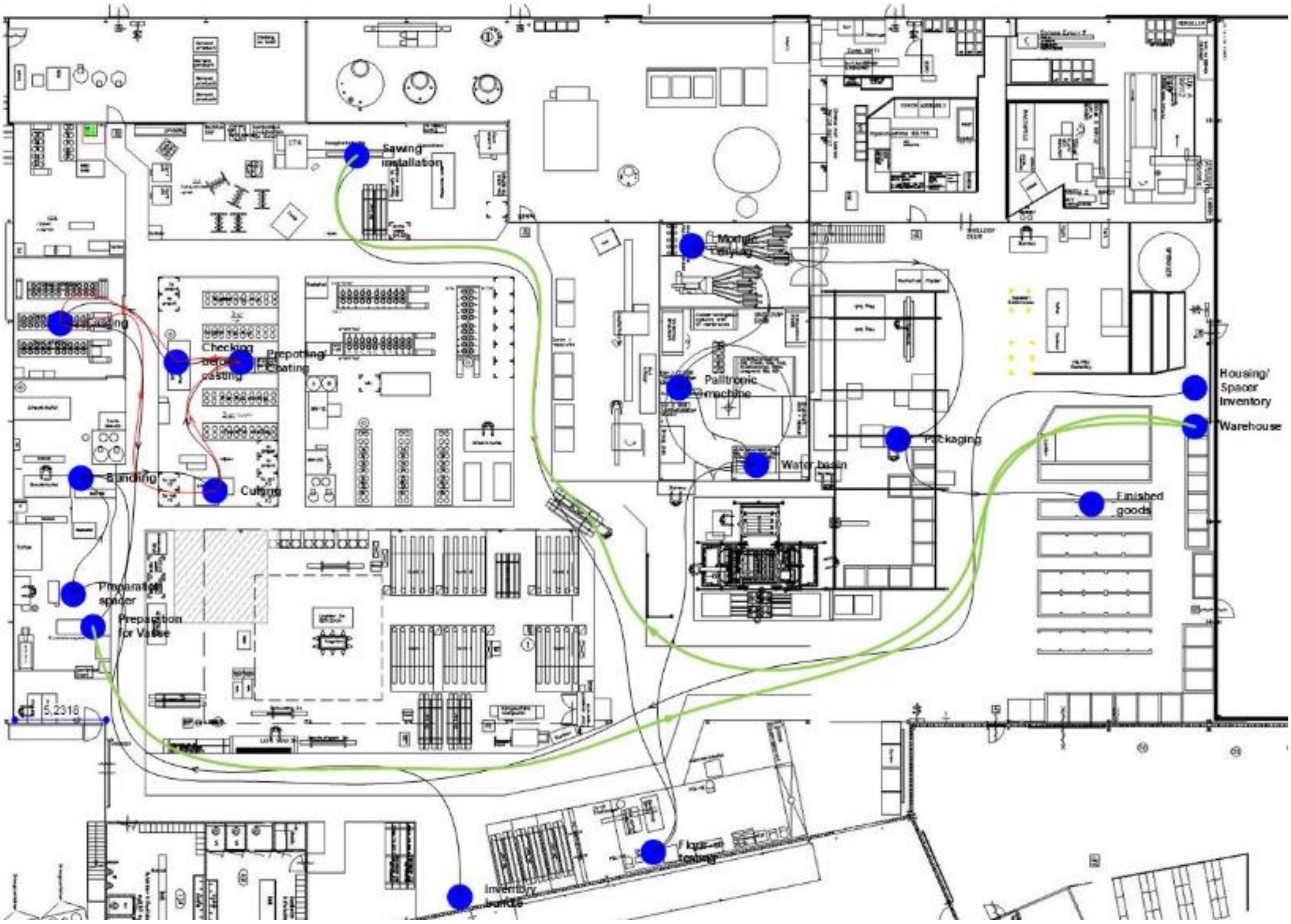

Figure 48: Spaghetti diagram, current situation, product type A

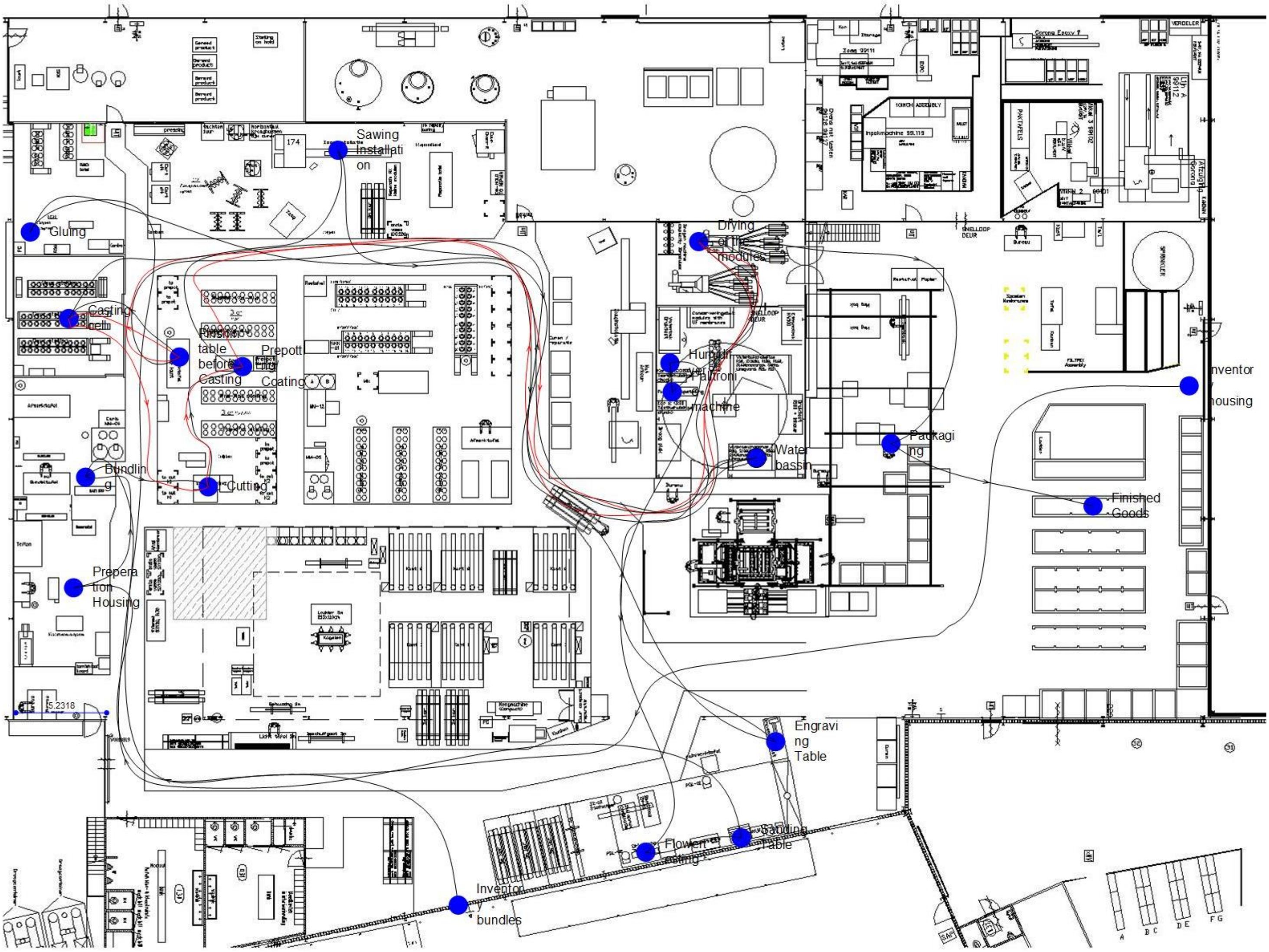

Figure 49: Spaghetti Diagram, current situation, product type B

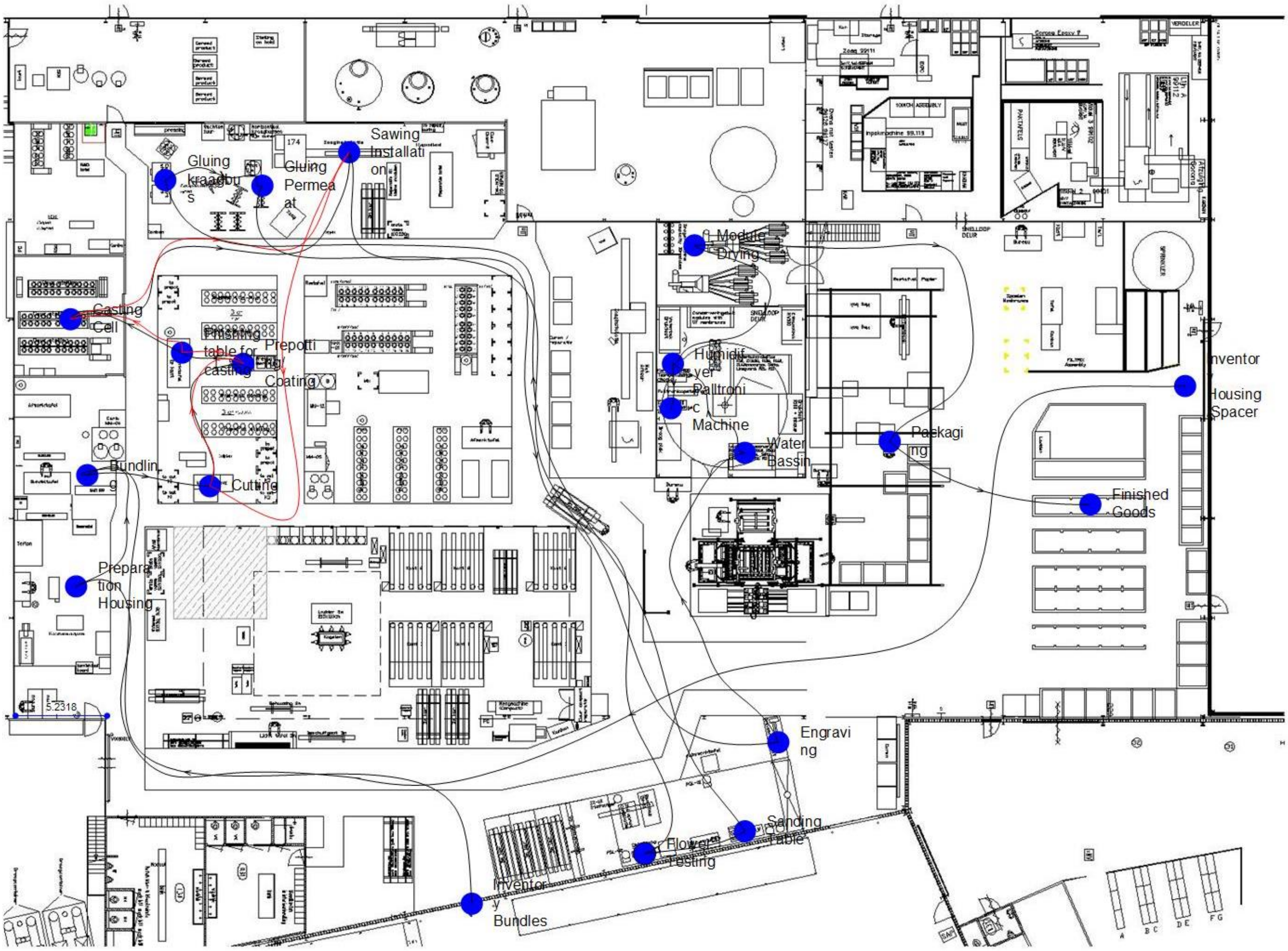

Figure 50: Spaghetti Diagram, Current situation, product type C

Appendix D: Test for kitting instead of prepotting

The 21st of April 2022 a test was run on kitting instead of prepotting a Product type C module. The test was run with this module type C since this type is the most difficult to kit because of the internal frame the product uses. The module was kitted without a kitting plug, which at the moment is used at the Dynamic department. This plug could make it easier to kit. Since the plug was not in the module whilst it was kitted, it was more difficult to put pressure on the membranes that are closest to the conus because the tape is the only force that is working on the membranes.

Although the plug was not used during the testing, the test was executed successfully for side 1 of the module. The casting was almost I figured out that the quality issue was not caused by the kit. All membranes were open after sawing, which means that the kitting was applied well.

On the 28th of April the second side of the module was kitted. For the validity of the test this was done by another operator in the Dynamic department. For the kitting of side 2 there was also no plug used. Since the test on product type C was successful, I know that Pentair can implement kitting instead of prepotting for all the beer modules. The result for side 2 was also promising. The quality of the casting was good. There were no leaking membranes or membranes that were still closed. In theory this module could have been sold to the customer if it would be communicated.

Appendix E: eVSM output while implementing the concept

In this section of the appendix, you can find the VSM model of the while implementing the concept. This is one model that is cut in several parts to make it as readable as possible

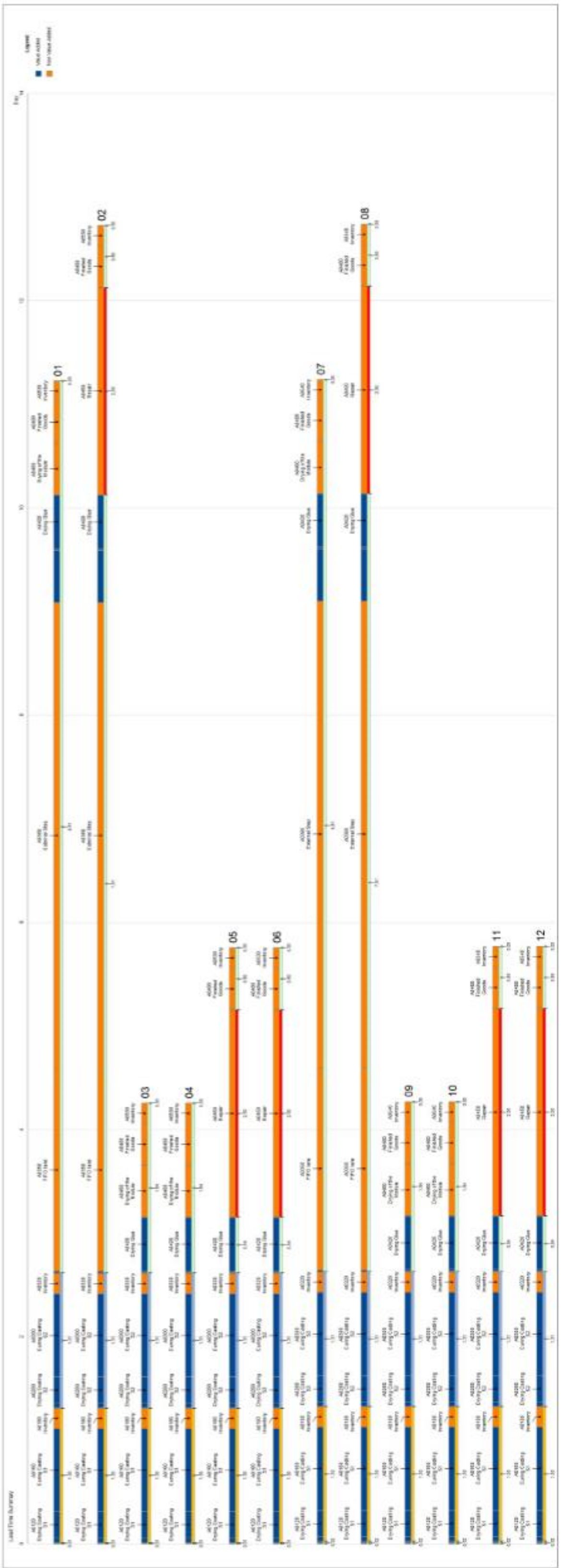

Figure 51: PLT output VSM

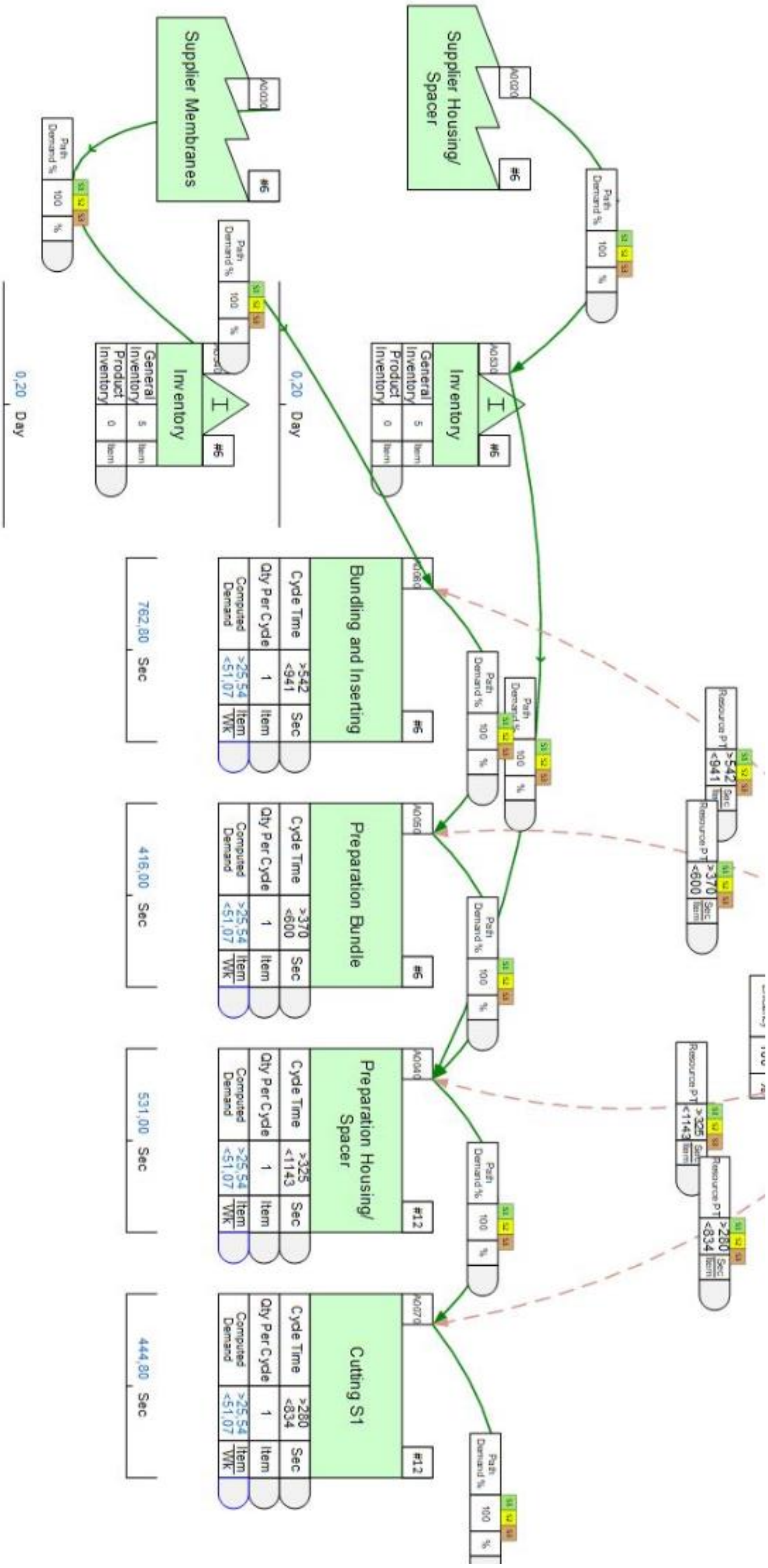

Figure 52: Concept VSM 1

Figure 53: Concept VSM 2

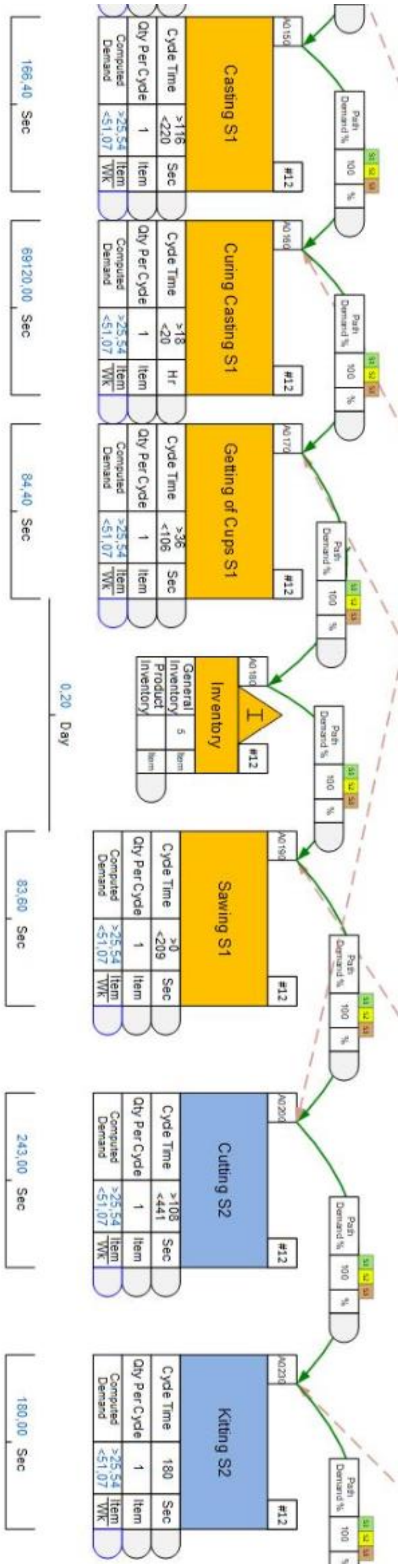

Figure 54: Concept VSM 3

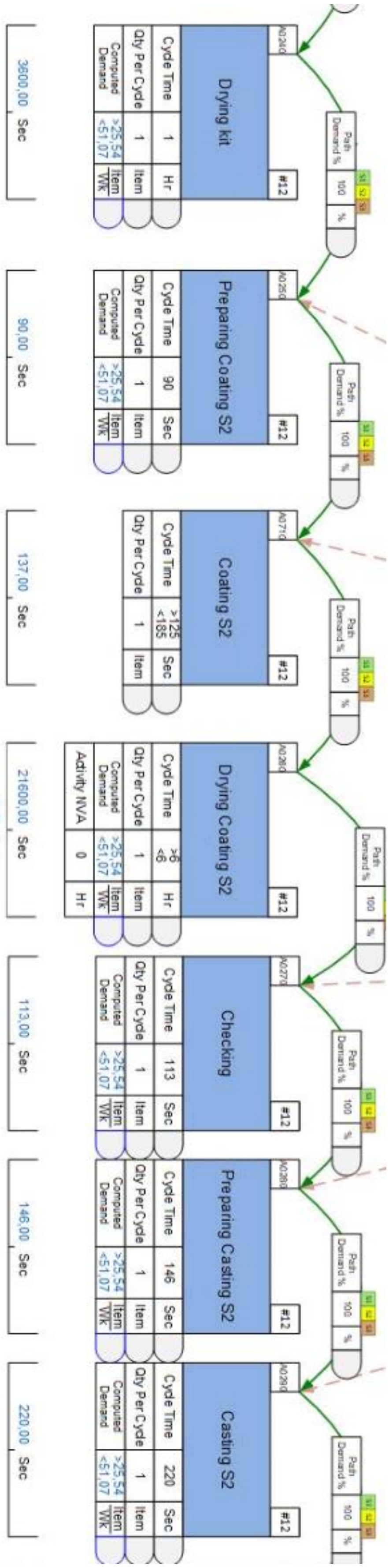

Figure 55: Concept VSM 4

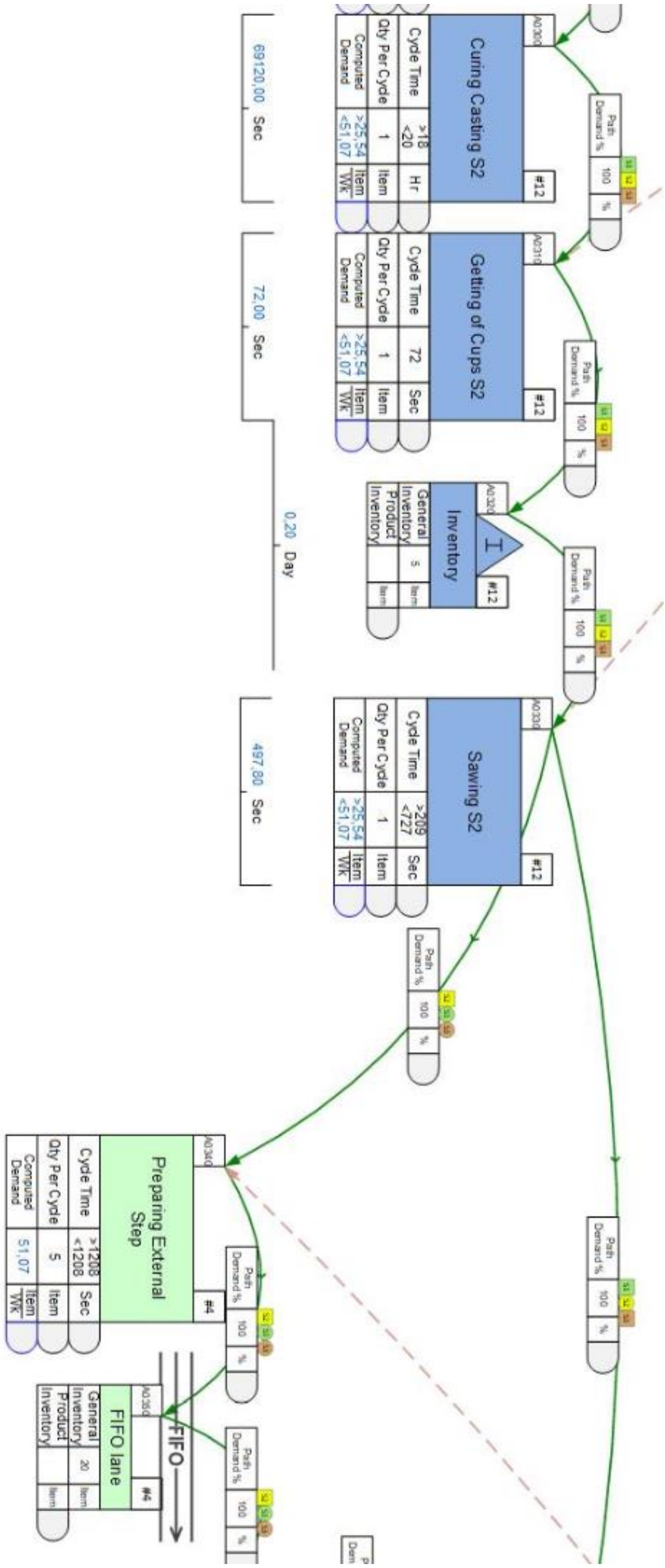

Figure 56: Concept VSM 5

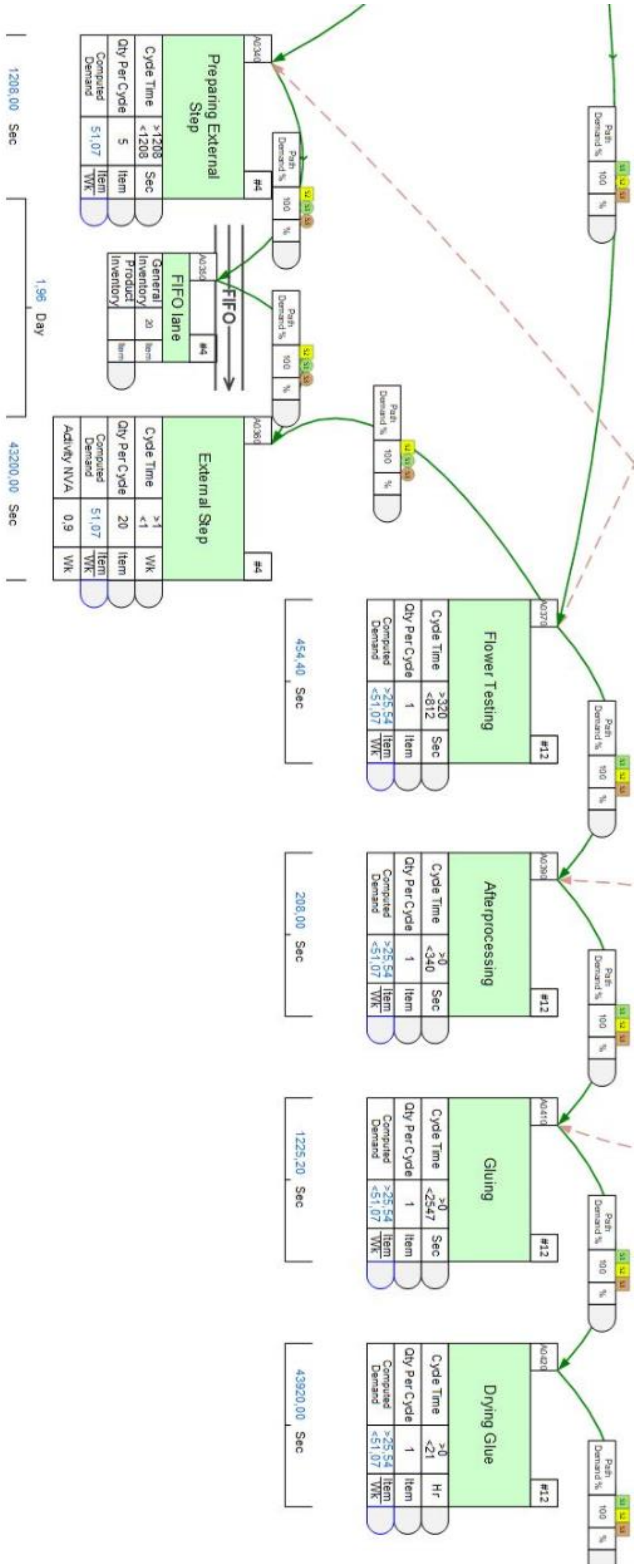

Figure 57: Concept VSM 6

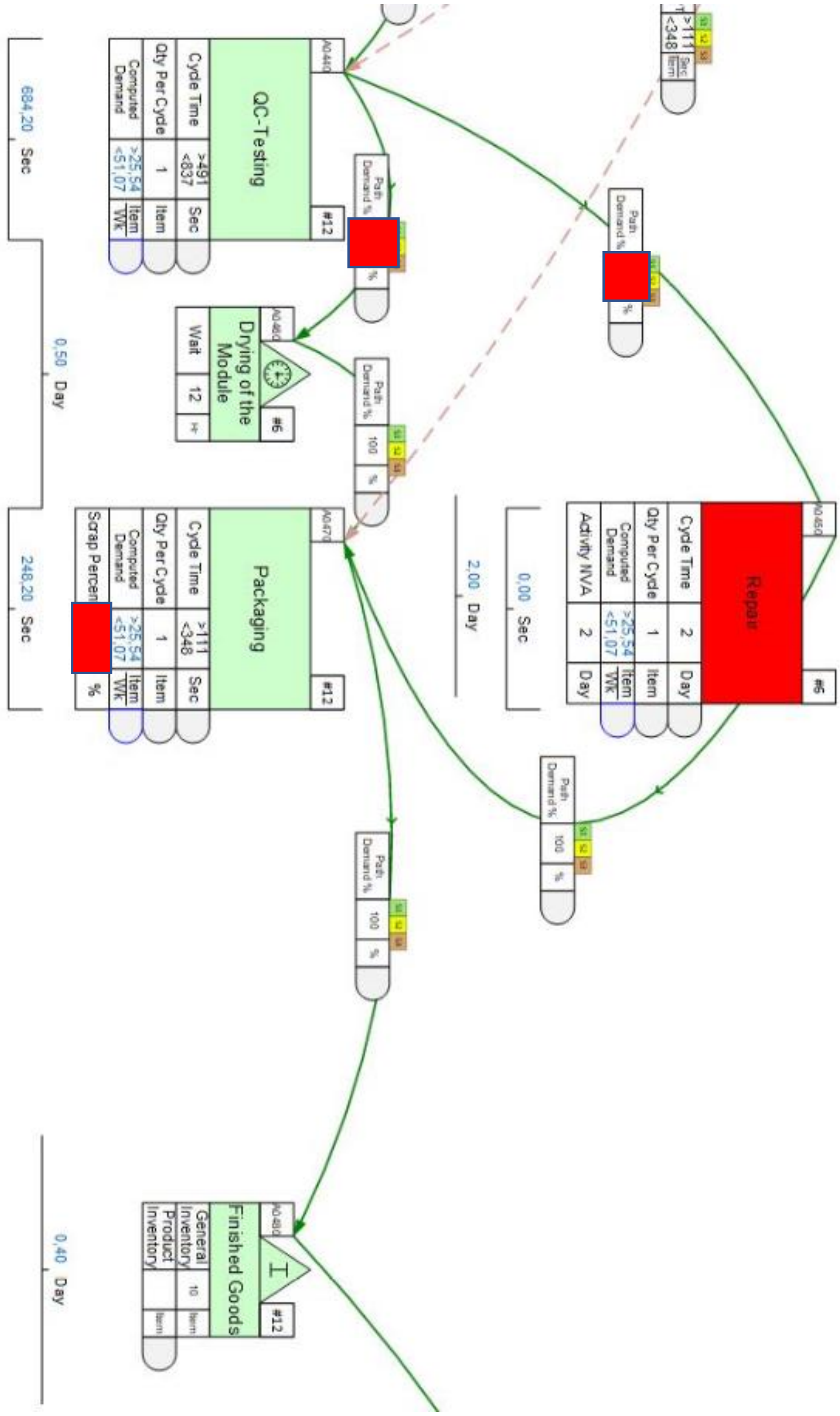

Figure 58: Concept VSM 7

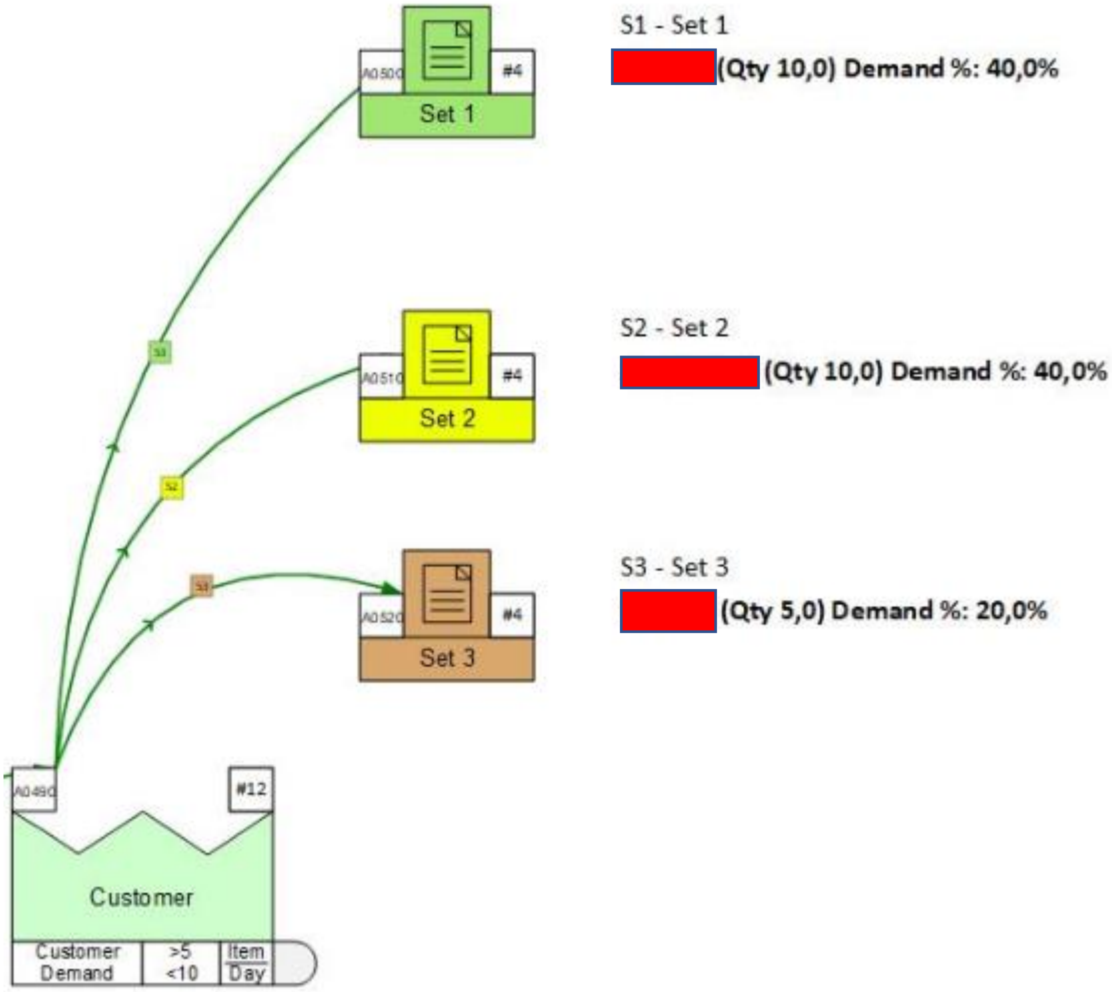

Figure 59: Concept VSM 8

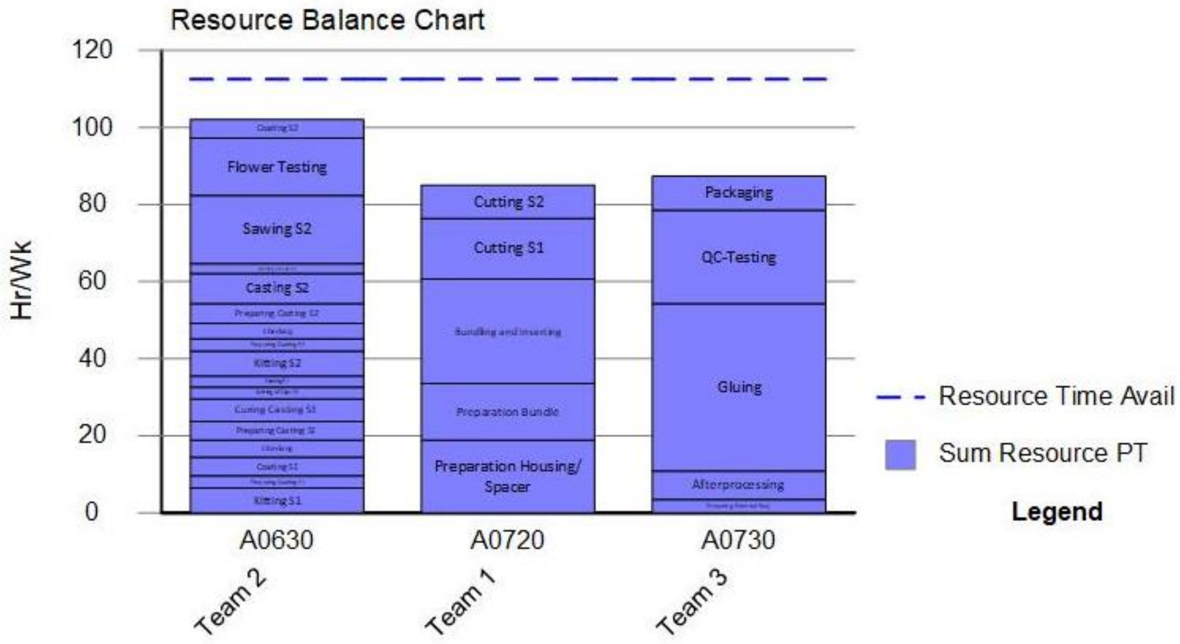

Figure 60: Resource balance concept situation

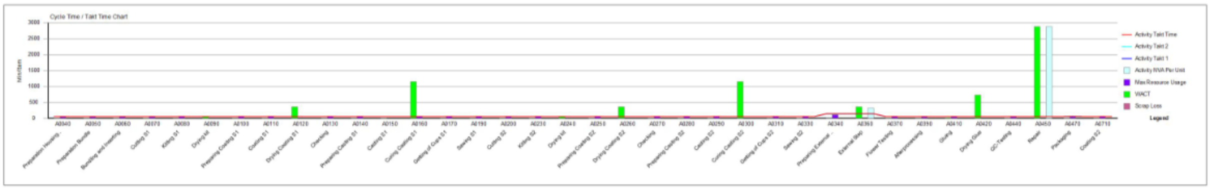

Figure 61: Cycle versus takt time concept situation

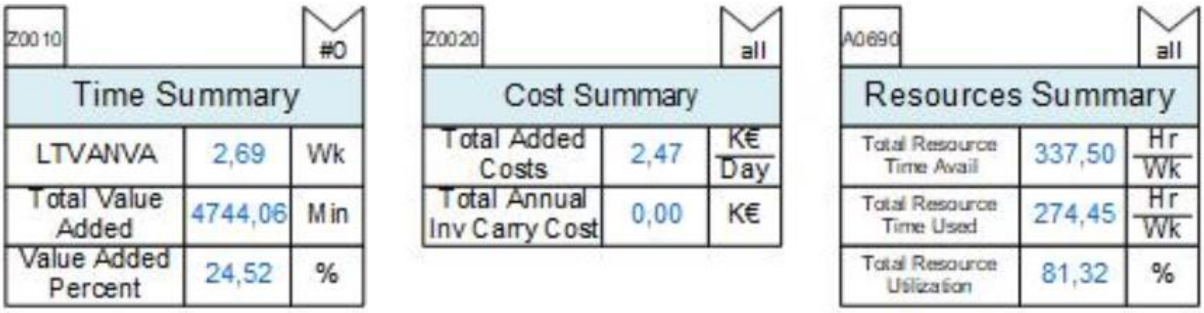

Figure 62: Summary VSM Concept situation

Appendix F: Current location WIP carts

In this appendix the red dots visualise the places where beer filtration products are store in between manufacturing steps. This figure is based on observations

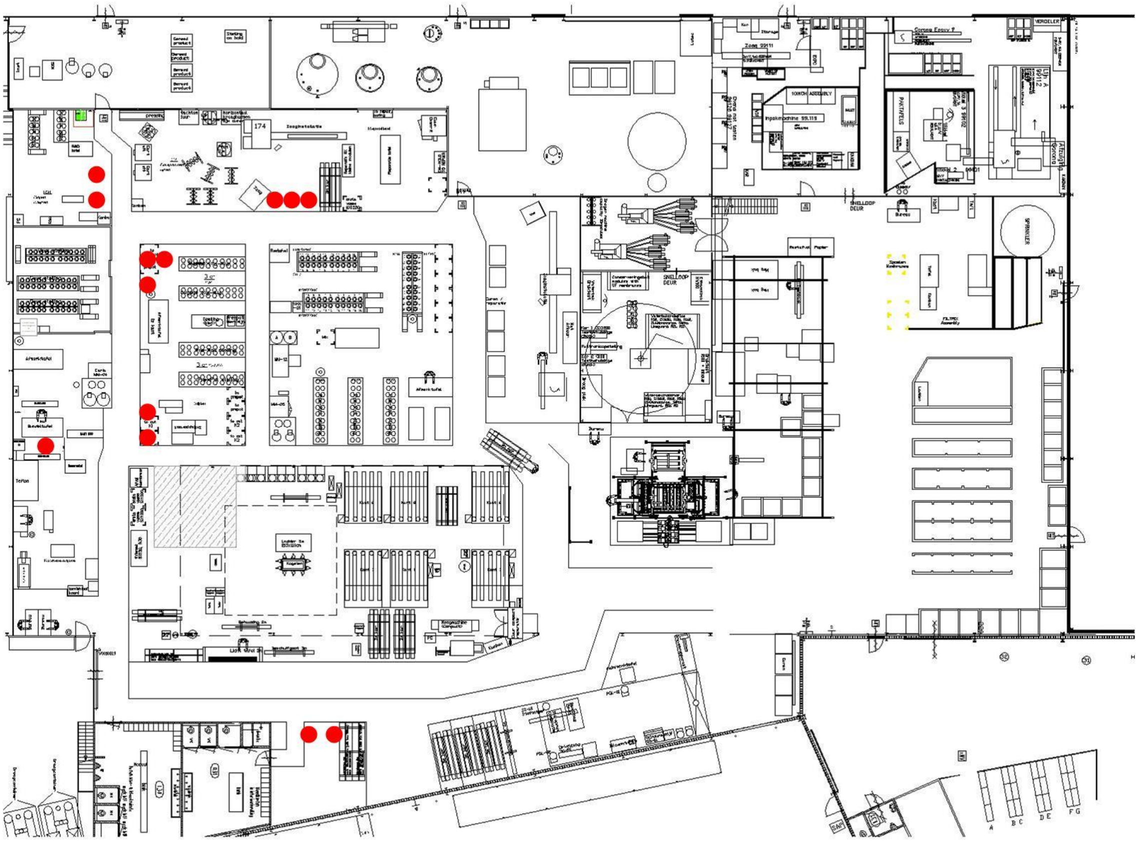

Figure 63: Location of Carts with WIP (beer modules)

Appendix G: Summary/Outcomes of interviews & events

Summary of outcomes interview cobot sanding (personal communication, Production technician lead, 2022):

At the moment the only beer module that is sanded is product type C

Benefits of a sanding cobot:

- Higher quality than when an operator sands it with an “haakse slijper”
- “Haakse slijper” is danger when cobot does this no risk of harm to people
- Moreover, the coot can have an extraction mechanism close to the product. Earlier at Pentair there was research done on how harmful this substance in the sanding cell was. The result was on the threshold which means that is it allowed and legal however not desired and dangerous for the operators.
- A benefit of the implementation of the cobot for sanding of product type C would be the possibility to do it in line. Because extraction is built in it can be placed lose and is not restricted to the sanding cell anymore. This brings us a step closer to achieving one-piece flow.

  So, more quality and more safety
  Investment will be around 220K

  Now Pentair expects that a lot of defects on product type C are due to bad gluing or sanding. Therefore, this solution could offer to reduce this waste. By improving the quality of one step Pentair achieve more quality and less defects however to ensure a big decrease in waste of defects Pentair also has to look into increasing quality at the gluing step. This solution also will reduce the likeliness of working in batches since it can be placed in a convenient place and favours processing modules one after one

Summary of outcome of interview R&D engineer (Resin specialist, 2022)

Inleiding eigen onderzoek

PCE van een product was laag. Aan de hand hier van de PCE van de beer value stream berekend. Huidige combineerde PCE is 13.37% wat overeenkomt met een low end batch assembly process. In mijn analyase blijkt dat dit vooral komt door de waste of transportation, waste of waiting en the waste of defects. Onderzoek heeft als doel om deze gecombineerde PCE van 13.37% zoveel mogelijk te verhogen. Ik zit nu in de fase van mijn onderzoek dat ik oplossingen wil genereren en de feasibility van oplossingen moet testen.

Vragen aan R&D Engineer:

- Ik hoorde van Patrick dat er op het moment gekeken wordt naar een coating hars van de levensmiddelen industrie, kun jij mij hier meer over vertellen?

  Testen met andere hars is lastig. Nieuwe hars is precies hetzelfde qua droogtijd uren. Verwarmen is voor het hars uitharden

- Wat voor andere dingen zijn er eventueel nog mogelijk om de droog/uithard tijd van de coating hars te reduceren? (anders drogen oid)

  Niet naar de hars kijken meer naar de hitte bron eronder. Dus niet zozeer zoeken naar een nieuwe hars maar naar een installatie die past bij de hars.

- Ik wou ook proberen te testen om te kitten ipv prepotten zodat modules niet meer apart voor beide kanten verwerkt hoeven te worden. Wat is op het moment het probleem van prepotten en wat zouden nieuwe problemen kunnen gaan worden wanneer we zouden kitten?

  Is mogelijk wel uitdagender, quality risk voor open membranen of slechtere bundelvorming. Hiervoor zou misschien een controle manier bedacht kunnen worden. Kitten brengt niet meer risico voor andere processomstandigheden. Handling→ randjes om en op membranen

- Voor de lange termijn zat ik denken aan een productieproces in lijn. Om dit te realiseren zou de hars zo veel mogelijk hetzelfde zijn. Hoe is het huidige verschil tussen de harsen van de beer modules en zou die gelijk getrokken kunnen worden?

  De drie bier modules hebben allemaal dezelde coating en giet hars. Coating hars is lastig te veranderen je zit met goedkeuring etc voor de hars omdat (gemiddeld 3-5 jaar tot goedkeuring)

- Zijn er nog lange termijn oplossingen die de efficiency van het beer cell gedeelte zouden kunnen verbeteren?

  Product type A en C laag coaten, zoals ook al met de een ander moduul gedaan is. Lager coating betekent minder coating aanmaken. De potting zit dan wel gwn normale hoogte. Quality issues zijn er waarschijnlijk niet kans is dat membranen knappen.

- Ik zat zelf te denken aan het in lijn coaten. Kan dit ook in lijn door middel van een warm water bad oid?

Membranen rondbewegen tijdens het coaten of gieten is lastig.

- Overig

Bundels voorbereid juiste lengte maat snijden kitten coaten. Kracht van statisch kleine variatie. Warmte moet beheerst worden, dus centrifuge wordt al snel veel te warm giethars wordt veel warmer dan coatinghars. Coating misschien een stap eerder dus voordat de housing of spacer er is dus gwn coaten van membraanbundels. Gietcel klimaatbeheersing warmte en luchtvochtigheid leed tot luchtbellen.

Komt veel warmte vrij tijdens het gieten dit maakt het moeilijk om gecentreerd te koelen.

Om gieten in one-piece flow te doen vergt hoge investeringen. Ten eerste moet dan elke cup individueel temperatuuraangestuurd worden. Op dit moment gebeurd dat per 10. Idee is dan per cup een temperatuur in te stellen

Per stuk prepotting en coating aanmaken is opzich geen probleem het enigste is dat je dan misschien met meer material waste zit. Emmer die je vormt naar de module resulteert niet perse in veel winst. Nadat de twee componenten hars aangemaakt is kun je hem een uur lang aanbrengen. Dit kan dus wel een uitkomst qua one-piece flow zijn.

Horizontaal coaten is waarschijnlijk te lastig om te kunnen realiseren.

Bedankt voor de meeting, en mocht ik nog vragen hebben mag ik je ze dan mailen?

Description and outcome impact/effort matrix event

On the 12th and 13th of April an event was held to rate the solutions generated in chapter 5 of the report. During this event the following employees of Pentair attended:

- Lean manager
- Lean specialist
- Production technician lead
- Manufacturing engineer

During the event I introduced the generated solutions while holding a PowerPoint presentation. Then after the introduction of each solution everyone showed their view of the feasibility of the solution and the impact it has on the PCE%. After that, I used the different point of views to come to an effort. Once we come to a result, we put the solution (if it is feasible) onto the impact effort matrix. During this event four solutions are parked outside of the matrix because the stakeholders did not favour these due to quality risks or better alternatives, respectively:

- Lowering coating height
- Automation gluing/sanding step
- Coating piece by piece instead of batches

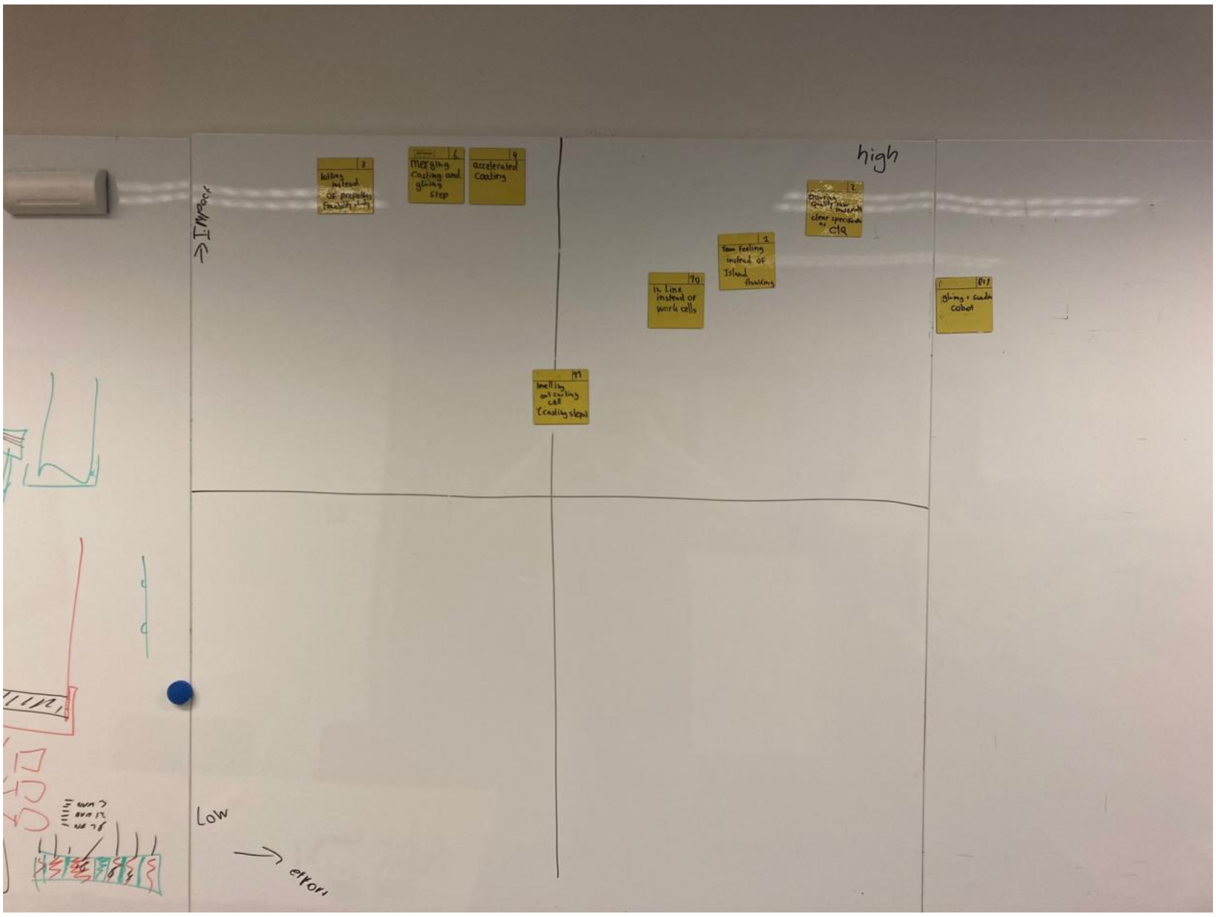

Figure 64: Impact/effort matrix meeting

Appendix H: Pictures of the work cells (confidential)

Confidential

Appendix I: Waste of defects (confidential)

confidential

Appendix J: Accelerated coating (confidential)

Confidential

Appendix K: Test accelerated coating (Resin specialist, 2014) (confidential)

Confidential