CHALMERS
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Decision Support Model for Production Layout Improvement

A Case Study at Brose Sweden AB

Master's thesis in Production Engineering

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ABSTRACT
This report is a master thesis from Chalmers University of Technology's Production Engineering master program. It was written for Brose Sweden AB and supported by ÅF AB. The purpose was to investigate the prospects of developing a supportive model that facilitates the process of developing layouts in production systems. Providing a common structure for the layout development process gives clarity to a process containing many sources of information and a large amount of parameters. Streamlining the process could also lead to potential time savings. The research was conducted as a case study consisting of a literature review, familiarization of Brose's production system, data gathering, layout generation, different methods of evaluating layouts and lastly the generation of a decision support model. The model was developed based on existing academic researches of production systems and production layout development in combination with an actual layout improvement case at Brose Sweden AB. The resulting model is in the form a flowchart describing which steps to take in order to develop an existing layout. The model emphasizes evaluation of solutions and iterative stages of evaluation and correction. While the model yielded positive results for Brose further testing at other facilities is required in order to verify the model's effectiveness. Production facilities in other industries than automotive is of particular interest.

Keywords: *Case study, layout problem, layout evaluation, layout generation, production simulation*

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Terminology

The following list consists of terms and abbreviations that are used in the thesis report.

BMT = Basic Motion Time Study
CAD = Computer Aided Software
DSM = Decision Support Model
DSS =Decision Support System
ERP = Enterprise Resource Planning
KPI = Key Performance indicator
MODAPTS = Modular Arrangement of Predetermined Time Standards
MTM = Methods Time Measurement
SLP =Systematic Layout Planning
SWAG = Scientific Wild-Ass Guess
WF = Work Factor

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1 Introduction

The purpose of this initial chapter is to introduce the thesis. It includes a background of the research area followed by a description of the company Brose Sweden AB upon which a case study is performed on. In one of the final parts the objective of the thesis is stated along with the research questions. A final section of the chapter lists the limitations of the thesis.

1.1 Background

The frequent occurrence of technological innovations has led to continuously changing markets and companies have to quickly adapt in order to stay competitive (Weck et al., 1991). The ones who are able to change along with the market are consequently the ones that are able to acquire a competitive edge. For the manufacturing industry this has resulted in changed requirements of the production processes. Studies show that there is a need for flexibility in the production, which is due to the frequent changes of the market (Benjaafar et al., 2002). Facilitating the process of developing factory layouts could support this notion. A streamlined development process that incorporates important considerations could potentially shorten the time that it takes for manufacturing industries to adapt to the prevailing circumstances of their markets. Furthermore, studies suggest that production layout development for manufacturing companies is an area where great reductions in operational expenses can be achieved when done correctly. According to Drira et al. (2007) the cost reductions can be as significant as 50%. Finding the optimal layout is however a complex matter and as a result a vast amount of studies has been carried out on the subject during the last decades. The issue has come to be known as the "facility layout problem", where "facilities" refer to the production units such as machines, workstations, and buffers (Drira et al., 2007).

The potential cost reductions combined with a streamlined layout development process suggest that a decision support model with the application area of production layout development, could be a potential tool for the manufacturing industry. The model would facilitate the process of developing a layout while simultaneously making sure that no important considerations are mistakenly excluded in the development process.

Brose Sweden AB is a first-tier automotive supplier that manufactures door systems and window regulators. The company is undergoing changes in their production system and demands an efficient production layout that performs on a level that meets the needs of their customer. The improvement process at Brose is therefore a suitable foundation upon which a decision support model can be based on.

1.2 Purpose statement

The purpose of the thesis is to investigate the prospects of developing a supportive model that facilitates the process of developing layouts in production systems. Layout development can be a complicated and time-consuming endeavor. Streamlining the process with a structured model could save time and support effective decision-making.

1.3 Case description - Brose Sweden AB

The subject of the thesis is the German automotive supplier Brose Sweden AB in Torslanda, which will be referred to as just Brose during the continuation of this thesis report. The company is located in multiple countries, but the facility in Torslanda works exclusively as a supplier for the automotive manufacturer Volvo Car Corporation. Working close to the automotive industry means that Brose is active in a competitive industry where it is crucial that the performance of a supplier is up to par. Not being able to deliver the expected performance could potentially make the customers choose rivaling suppliers. As a part of the improvement process Brose has invested in a machine with shorter cycle time and that takes up a smaller area than the preceding machine. The extra space that it clears up should be utilized in an optimal way with regards to production performance. The transport distance between storage and production is long and some consecutive stations are placed far apart. Brose believes that a redesign of the layout is in order. They have made similar changes in the past with positive results. However their changes were often made based on “gut feeling”, often without any data to support the improvement work. As a result the full capacity of the production might not be captured. Brose desires the new layout to be based on facts and in order to do so a deeper understanding of the produced data is required.

1.3.1 Product descriptions

Brose’s production facility in Torslanda supplies two types of products to Volvo Car Corporation. The first product is a door module that handles a number of door and window mechanisms such as the window regulators, locks, and loud speakers (Brose.com, 2016). This thesis is concerned with two components of the door module, namely the rails and the plates. See *Figure **1*** and *Figure **2***.

Figure 1. An assembled rail. The two pulleys on each end of the rail guide the wire that enable the window regulation system.

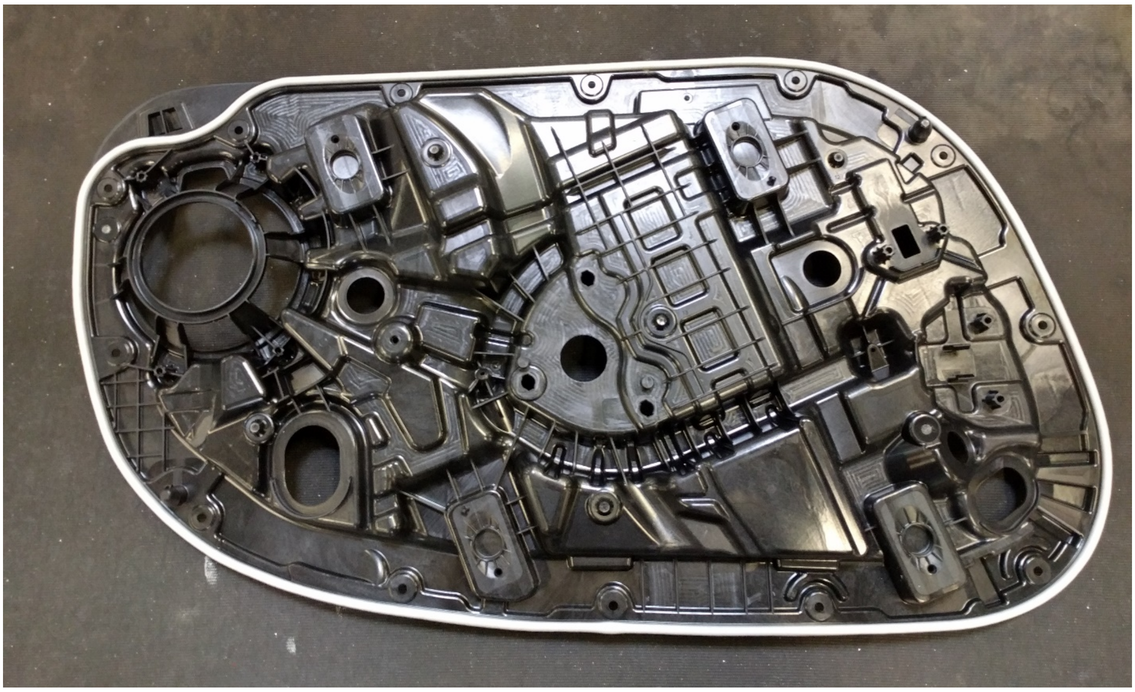

Figure 2. A sealed plate. The thin line along the edge of the plate is the applied sealant that protects the components of the door module from getting damaged by external moist or dirt particles.

The second product that Brose produces is a cooling fan (CF) that cools down car engines, see *Figure **3***. Processes involving both of the products are included within the scope of the thesis.

Figure 3. A complete cooling fan. An electrical motor in the center of the module drives the rotation of the fan.

1.3.2 Brose's Production System

The thesis covers three production processes. Two of them manufacture components for the car door module. They are called the *sealing process* and the *rail-riveting process*. Both of them are semi-automatic. The required manual work consists of feeding material into the machines and handling the material after it has been processed. The third production process is the *cooling fan* (CF) process, which involves assembling the cooling fan and is followed by a quality control.

1.4 Objective and Research Questions

The objective of this thesis is to create a Decision Support Model (DSM) that is generally applicable to any production system.

In order to achieve the purpose and objective of the research the two following research questions and their respective sub-questions are to be answered.

RQ1: How is a production layout optimized?

- How is Brose's production system optimized?
- How to maximize the utilization of processes with regards to production layout?

RQ2: What should be included in a decision-making model for layout improvements?

- How are the essential parameters with regards to production layout identified?
- Which methods can be included in a Decision Support Model for layout improvements?
- How is a layout developed in a structured manner?

The questions will be answered through a case study at the automotive supplier Brose. The thesis group will propose a new production layout of Brose's production system by considering a number of factors such as the placement of machines, level of workforce, material storage, etc. Based on the improvement process, a model will be developed to help support future decision-making related to layout improvements.

1.5 Limitations

The following list includes the limitations of the thesis:

- The thesis does not cover Brose's complete production system. Only a limited section of the system is the subject of study.
- Relocation of material storage locations outside of the production is not considered.
- The time scope of the thesis is limited to five month.
- The thesis group has not been provided with any monetary resources. Used equipment and tools are borrowed from the faculty office and/or the external supervisor.
- The development of the Decision Support Model is only based on a single development process, which is the one done at Brose. Therefore the resulting model is only a first draft.
- The amount of previous studies on the area of Decision Support Models in combination with production layout development is limited.

2 Theoretical framework

This part of the report covers theories that together create the theoretical framework for the thesis. The theoretical framework includes theory about production layout, which is the main topic of the thesis. The theory also includes means of assessing the performance of a production system followed by descriptions of software that is used for evaluation and analysis purposes. The final chapter is about theory related to DSMs.

2.1 Production Layout

Wu (1997) observed that most production system development processes were carried out through two main approaches. The first approach is to design a production system based on predetermined objectives for the design. This approach does not consider any previous design systems. As a result the generated system might require an extensive system redesign, which is not always financially viable. The second approach considers the current system. The positive effect of this approach is that it takes into account historical system development processes, thus previously gained experience is not lost. The downside is that it impedes creativity since the development process is solely based on previous work. In order to capture the benefits of both approaches Wu (1997) suggests a general framework, see *Figure **4***.

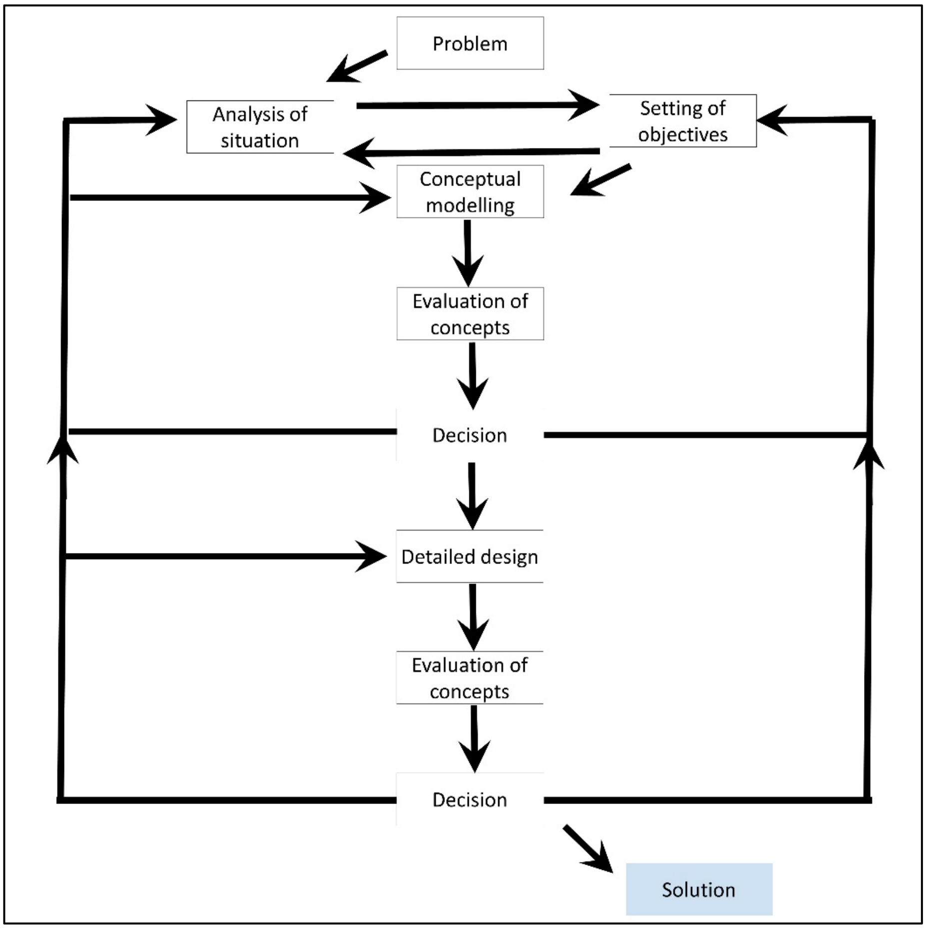

Figure 4. Wu's (1997) general design framework.

The framework is made up of a number of phases where the working process goes back and forth between the phases iteratively in order to generate an optimal solution.

The method that was used in the research is called Systematic Layout Planning (SLP) (Muther & Wheeler, 1977) and comprises features that match the first approach where the current production system is not considered in the development process. Following section explains the method and breaks down each of the steps.

2.1.1 Systematic Layout Planning (SLP)

Systematic layout planning, or SLP, is a structured approach to layout design. It was developed by Richard Muther in the 1960's, but is still widely used as a tool and is still cited by others even though it was developed decades ago (Kusiak & Heragu, 1987)(Bellgran & Säfsten, 2010)(Meller & Gau, 1996). SLP is a system of six steps that, when followed, will result in a systematic and objective layout (Muther & Wheeler, 1977). The six steps are the following: (Bellgran & Säfsten, 2010)

1. **<u>Clarify the connection</u>**
   In the first step all affected functions, areas and activities are identified and their connections noted in a so-called *triangular connection chart*. See *Figure 5*

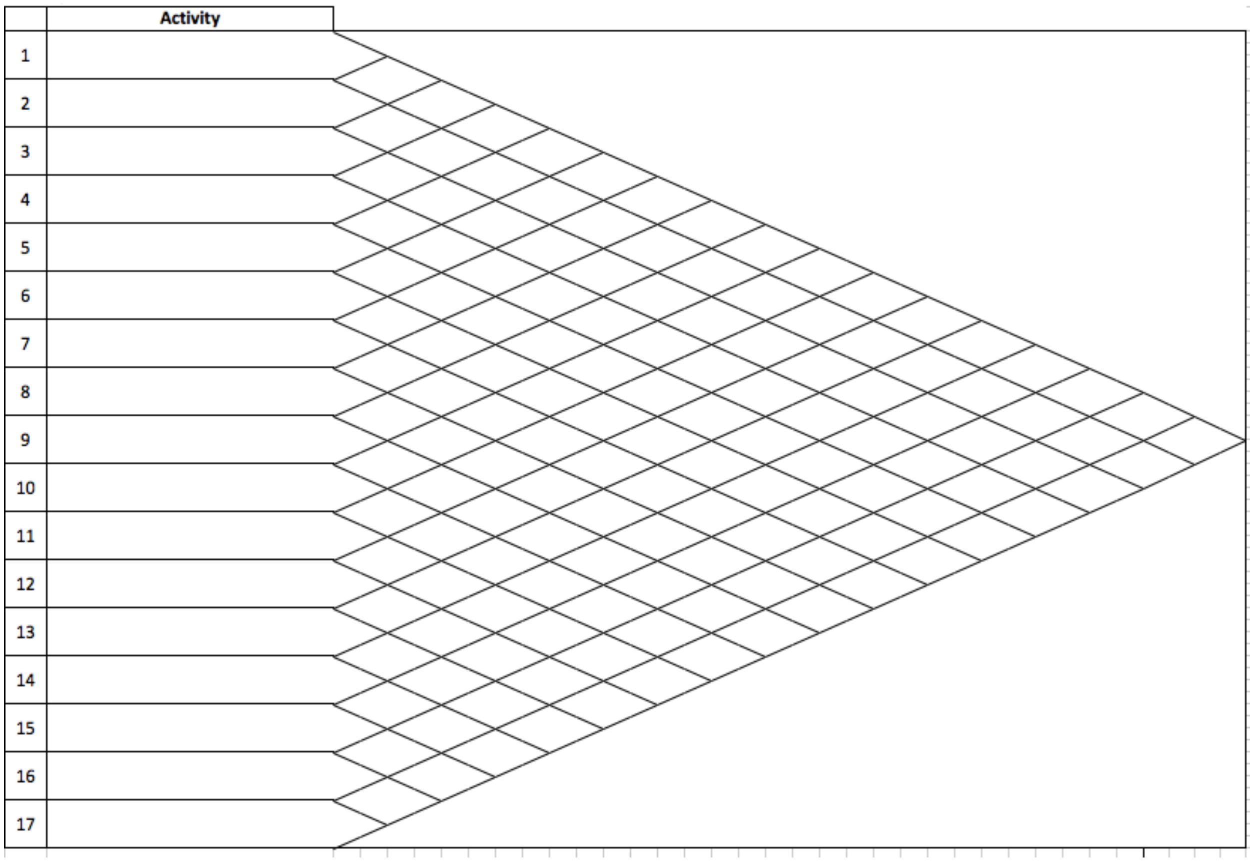

Figure 5. A triangular connection chart. The functions, areas, and activities are listed in the column to the left. The desired distances between them are graded in the squares.

The functions are listed in sequential order. Then the desired distance between said functions is decided. The desired distance is graded in the scale of A,E, I, O and U, which describes a scale from “absolutely necessary” to “not necessary”. A distance can also be graded X, which implies that the two functions must be placed far apart from each other. In addition, the reason for the grading shall be explained for each function, enabling follow-up later.

2. **Establish functional demands**

   Step two notes the demands of the functions from step 1. Considered demands can be related to the work area, constructional factors, service needs, sensitivity to vibrations etc.

3. **Line functional connection**

   In this step, a visual drawing of the functions linkage is made while considering the connections and requirements from step one and two. The drawing is made by linking the functions with different number of lines, corresponding the demands of closeness, where more parallel lines represents a linkage of higher importance, i.e. four lines represents an A-grading (absolutely necessary), while three lines represents an E-grading (highly influential), etc. The only grading that does not follow this pattern are the X-connections, which are represented by wavy lines. The process starts with the A-connections and proceeds in a descending order until all connections have been drawn. The chart is iterated until all functions are placed in a structured manner. Finally, the area requirements of each function are written out next to every function. See ***Figure 6***.

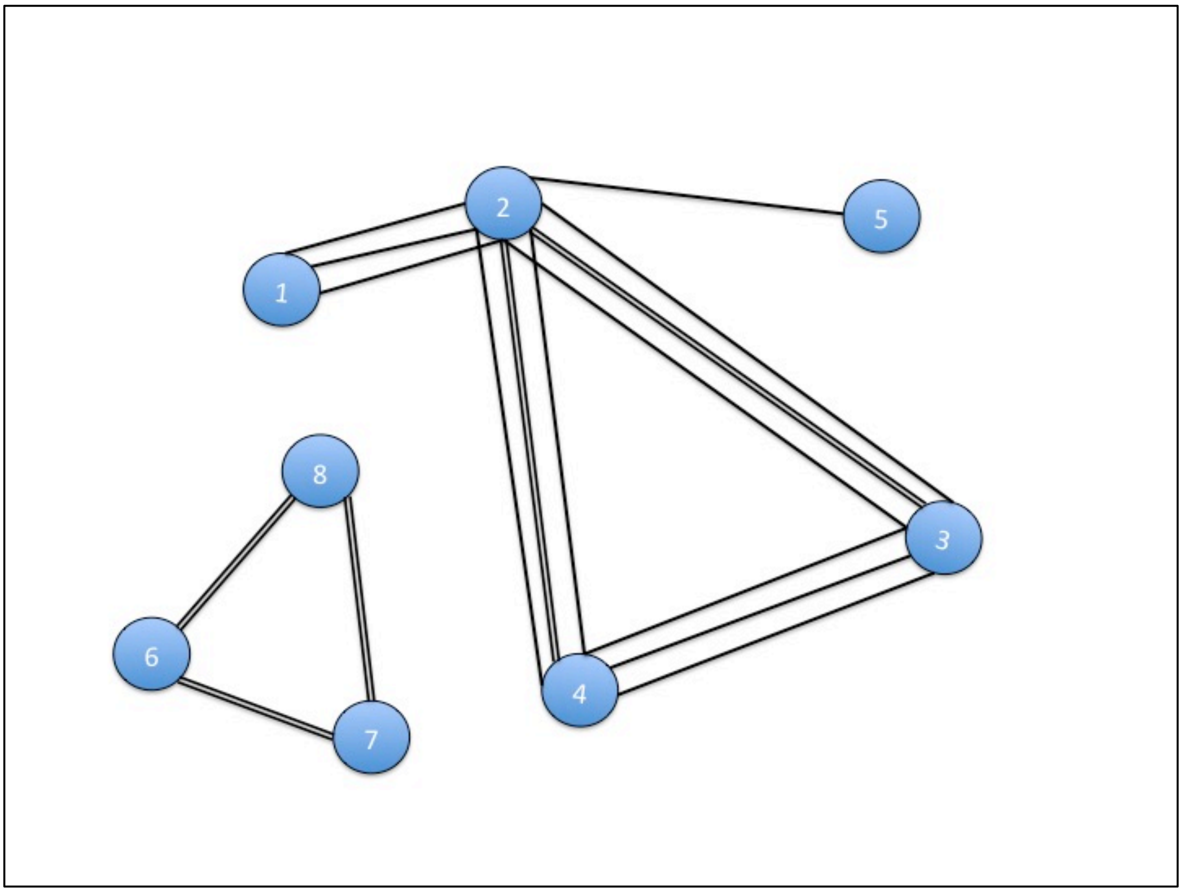

Figure 6. Example of a simplified line functional connection diagram. The circles with numbers are the various functions. The lines are their connections and the number of lines correlates to how close they should be placed to each other; more lines represents a bigger need for close placement.

4. **Draw alternative master plans**
   Step four groups the functions geographically on a drawing with regards to space requirements. Constructional and technical demands are also considered. Several plans are made, desirably with different solutions of material and product flows.

5. **Assess the different alternatives**
   Step five is the evaluation stage. Here, the different layout proposals are assessed according to several criteria identified as important for the final solution. Typical criteria could be:

   - Investment cost
   - Effectiveness of flows
   - Flexibility
   - Utilization of floor area

The criteria are given a certain weight depending on their relative importance. The layout proposals are assessed according the identified criteria to a scale of absolutely perfect (A=4), efficient solution (E=3), interesting solution (I=2), ordinary solution (O=1), unimportant (U=0), unwanted (X=-). The appropriateness of the solution is gained by multiplying the criteria weight with the layout proposals solution for said criteria. For example, if the criteria low investment cost is given the weight 3 and solution A is regarded as an efficient solution (E=3) for that aspect, then the resulting value will be 3x3=9. The same procedure is made for all the different criteria and solutions. At the end of the assessment the score for the different solution is summed, with the highest scoring solution as the most appropriate. For the purpose of assessing a chart such as the one below is typically used.

6. **Design the chosen plan solution**

   The sixth and final stage is where the chosen layout becomes the final drawing of the solution. Machines, equipment and buffers are all clearly marked. Construction details are checked, truck paths, door clearance, etc. Details are investigated and then corrected, resulting in the complete layout drawing.

2.1.2 Studies of impact of layout design on work

There are several studies of the effect of layout design and its influence on the work efficiency (Kamarudin et al., 2011)(Cohen et al., 2008). Kamarudin et al. (2011) investigate the effect of headcount and layout type on the performance of a layout. The study found that for small batch and high variety a higher headcount is needed to counteract the increased number of set ups and other required tasks. Cohen et al. (2008) investigate the effect of layout and work allocation on the “makespan” of batches of different products characterized by a learning curve. “Makespan” is a common term in manufacturing meaning the time difference between start and finish of a task (Cohen et al., 2008). The study researches potential guidelines for reducing the makespan for a set number of workers. The results showed that small batch production of a high variant number could be effective if repetition is high thus shortening the learning curve. Best result is when there are stations in a line producing the product, further increasing the repetition for the workers.

2.2 Production Evaluation

Evaluating the performance of a production is important when determining if conducted changes on a production system yield positive or negative results. Appropriate measures can then be taken in order to improve the performance. This chapter covers previously developed theory that is used for these types of performance evaluations and measures for improving it.

2.2.1 Measuring work

Measuring and quantifying work is a way of determining if a process is balanced. A process is balanced with the purpose of creating work standards that enhance the workflow. Standards are in general developed through one out of three ways: estimation, direct observation, and the use of standard data (Lawrence, 2004). Further explanation of the three ways can be found in the section below.

Estimation

Estimation can typically be done in two ways. The first way is when an individual, believed to be knowledgeable about the task or work to be evaluated, gives his or her estimation of how long it will take. The flaws are many, as it is not an accurate method and problems such as bottlenecks are often formed due to the inaccuracy. This type of estimation is known as the acronym SWAG (Scientific Wild-Ass Guess) (Lawrence, 2004). The second way of estimation is to look at historical data and make a comparison. Historical data is however subject to Parkinson's Law (Lawrence, 2004). Parkinson's Law applied to industrial engineering states that the amount of time required to complete a task is directly proportional to the time available. Which implies that the standard time increases or decreases based on the amount of available time.

Direct observation

Another way of measuring work is through direct observation. Direct observations are differentiated between *time studies*, *work sampling*, and *physiological work measurement* (Lawrence, 2004).

In time studies an operation is analyzed and necessary steps of the operation are identified. The chronological order of the steps and the time that it takes to perform each of the steps effectively are also observed (Lawrence, 2004). Time studies are usually performed using a time measuring device and is most suitable when applied on highly repetitive tasks where the cycle time is relatively short. The method can be combined with computational simulations, which enable more advanced analysis of the work tasks. Section 2.3.3 goes into further detail on computational simulations of work tasks. Before the time study is performed it is important to know that the quality of the results is dependent on the operator that is selected for the study (Lawrence, 2004). The operator is preferably skilled and works according to the established work method in order to reduce the variance of the work performance. When introducing the time study to the operator it is important to consider the way that it is conducted. Lawrence (2004) emphasizes being transparent with the study. Conveying honesty and clarity about the purpose of the study makes the operator more receptive to it.

Work sampling is the second standard that is based on direct observation. It is a statistical method that is carried out by making a large number of observations at random intervals (Lawrence, 2004). Based on the observations a probabilistic conclusion is drawn concerning the work tasks. The method is suitable for work that has a relatively long cycle time and is normally more time consuming compared to time studies due to the large number of samples that is required (Lawrence, 2004). The third and final way of measuring work through direct observation is by doing physiological work measurements. The method is based on the fact that the human body consumes different amount of energy depending on the work task that is performed (Lawrence, 2004). The energy consumption is regarded as an "energy cost" which means that it is desired to keep the energy levels on a low level. According to the method the energy consumption can be derived from a person's heart rate and oxygen consumption. Thus by measuring these two parameters while the worker is performing varying work tasks the energy costs can be determined.

Standard data systems

The third way of measuring work is to use standard data systems (Lawrence, 2004). A standard data system is essentially a database with a list of standard movements that often occur in manual work and the time that it takes to perform each movement. The system is then used for creating a time standard for a specific work. If the person measuring the work knows which movements are needed the time consumption for each movement can be collected from the standard data system and a time standard can be developed. The data in the data system has been compiled through previous studies of manual work. The fundamental idea of standard time systems is that it is a relatively easy and quick way to set standard times since it does not require any time measurements of the work tasks. (Lawrence, 2004)

There are two types of standard data: *macroscopic standard data* and *microscopic standard data* (Lawrence, 2004). Macroscopic standard data consists of work elements that occur in different works. Lawrence (2004) uses the example of walking as such a work element. Walking is an element that is performed in the same way no matter which type of work it is required in. The only difference will perhaps be the distance that the worker walks. Instead of measuring every "walking element" the time data for walking can be easily acquired from the data system. The alternative, microscopic standard data, emphasizes motions. The standard data type is also known as *predetermined time systems*. By analyzing a work task and its movements, entire processes can be evaluated using predetermined time systems. The most widely recognized predetermined time system was first developed in USA during the 1940s and is called Methods Time Measurement, commonly known as the abbreviation MTM-1 (Lawrence, 2004). MTM-1 is made up of a list of "basic motions" together with a description of each motion and the time that it takes to do these motions. When an operation is analyzed using MTM-1 it is broken down into smaller basic motions that fit with the basic motions that are described in MTM-1. The time data in MTM-1 is then assigned to the movements in the operation and a time standard can be developed. Examples of different basic movements in MTM-1 are reach, move, turn, position, and grasp. The effectiveness of this predetermined time system is supported by the fact that systems that were developed after its introduction were heavily based on it. Other predetermined time systems according to Lawrence (2004) are Work Factor (WF) system, Basic Motion Time Study (BMT), and Modular Arrangement of Predetermined Time Standards (MODAPTS). These time systems are generally accepted as alternatives for MTM-1, but are not as internationally recognized. The WF system was the first predetermined time system that was ever developed. It includes a "work factor" that is added to the basic motion time in order to factor in the additional work time caused by any weight or resistance in the work task. BMT also includes a factor that it calls the "force factor", making it similar to the WF system. The difference is how they define what a basic movement is and what the force factor is supplemented for. MODAPTS is a system that is oriented towards human work rather than mechanical work. The work times that MODAPTS are comprised of are based on the fact that a larger part of a human body takes a longer time to move than a smaller body part.

2.2.2 Production flow evaluation

In a layout the flow efficiency is a crucial criterion. What values flow efficiency actually constitutes of, varies depending on literature. Lin & Sharp (1997) have identified three criteria:

- Material flow
- Space relationship
- Robustness & flexibility

For the *material flow* subgroup digital simulation tools can with advantage be applied, see section 2.3.2. Space relationship and robustness & flexibility on the other hand have a more qualitative nature as opposed to the material flow's quantitative nature (Lin & Sharp, 1997). *Space relationship* is concerned with the visibility and accessibility of the production, which is an effect of the machine and material placement. In practice it means that paths should not be obstructed or too narrow for neither trucks nor operators (Lin & Sharp, 1997). *Robustness & flexibility* describes the level of future proofing and readiness for changes in the flow layout in terms of capacity for changes in both space capacity for an increased number of variants as well as increased production capacity (Lin & Sharp, 1997).

2.3 Digital Tools

For the purpose of evaluations and analysis digital tools can be used. Presented in this section are the digital tools utilized in the thesis.

2.3.1 Computer Aided Design - AutoCAD 2016

A tool that is used for technical drawings is the software tool Computer Aided Design (CAD). It is a design tool that is used for creating, modifying, analyzing, and optimizing engineering designs (Lalit Narayan et al., 2008). CAD-softwares facilitate the product development process and reduce the time that it takes to synthesize, analyze, and document designs.

There are a variety of different CAD-software developers in the market. CAD-softwares include AutoCAD, CATIA, and Solidworks just to mention a few (AutoCAD.com, 2016a) (3DS.com, 2016) (Solidworks.com, 2016). The relevant software in this study is 2016's version of AutoCAD. It is a design and drafting software that can be used for creating visual and virtual representations of products in either 2D or 3D depending on the purpose of the drawing (Autodesk.com, 2016a). The software is created by the company Autodesk that develops software for 3D designs, engineering, and entertainment (Autodesk.com, 2016b). AutoCAD can be used for facility drawings, which makes it suitable for the study.

2.3.2 Material flow simulation- ProPlanner: Flow Planner

In order to evaluate the eligibility of the material flow in a factory layout, simulation can be applied. Flow Planner by ProPlanner is one of such tools (ProPlanner, 2016a). The software is an add-on to AutoCAD and can be used for analyzing tasks such as:

- Aisle design (location and sizing)
- Dock quantity and placement
- Off-line storage placement
- Work station placement and replenishment design
- Indirect labor requirements estimation
- Plant traffic for intersection/aisle safety evaluation
- Efficient handling methods selection (Fork, Conveyor, Crane, etc.)

(ProPlanner.com, 2016b)

Flow Planner can handle and simulate a set of input data for a material flow simulation. The complexity of the simulation depends on the amount of input parameters and which parameters that are selected. Examples of input information are transportation paths, quantity of products/material per flow, transportation type, and number of containers per delivery, just to name a few. By applying this information to a technical drawing where the locations and paths are defined flow diagrams and numerical results can be generated.

2.3.3 Work balancing - AviX resource balance

The software AviX resource balance uses MTM-based standard times for quantifying work tasks creating data that can be used in calculations and analyses when balancing production systems. With the aid of AviX the production process can be planned for a conceptual system evaluating the possibilities and optimizing the effectiveness. (AviX.com, 2016)

2.4 Decision Support Model

In this thesis report the Decision Support Model will be referred to by its abbreviation DSM. Most commonly, a DSM is used in the form of digital tools known as DSSs (Decision Support Systems). Two of the most common and classical definitions for DSSs are:

"Interactive computer-based systems, which help decision makers utilize data and models to solve unstructured problems." (Scott Morton & Gorry, 1971)

It was later described by Scott Morton & Keen (1978) as a system that couples individual's intelligence with that of a computer to further improve the quality of a decision. A computer-based support for decision makers who deal with semi structured problems. However the term DSS and DSM are content-free expressions. There is no official definition, meaning that it can be defined differently by different people (Turban et al., 2014).

These definitions can be misleading. A DSM is not strictly a digital tool, it can also be a non-digital tool. For example:

- Evaluation matrices
- Quality function deployment (QFD) (Bergman & Klefsjö, 2010)
- Kano model (Bergman & Klefsjö, 2010)
- Muther's SLP method (Muther & Wheeler, 1977)

2.4.1 The definition of a decision problem

A decision problem arises when a person or group has an idea of a possible future state. The imagined future state is different from the current or will be different in the future. In order to achieve the future state the differences of the future and current state need to be eliminated or minimized. This alone will not make a decision problem. To be considered a decision problem there must be several ways to eliminate/minimize these differences (Grünig & Kühn, 2013). In short, a decision problem is when there are several ways of achieving a target state.

Decision problems can be classified into two groups of difficulty. It can be either a *simple* choice decision of what color to choose for a car or it can be a *complex* design question such as "what features should be included in our product" (Grünig & Kühn, 2013). According to Grünig and Kühn (2013) a problem can be considered to be complex if it fulfills two or more of the following criteria:

- Several targets are trying to be reached simultaneously
- There is a large number of decision variables. Resulting in many possible problem solving options and thus solutions.
- The future development of several uncontrollable situation variables is unknown.
- The decision maker is inexperienced and/or lacks the appropriate tools to determine the consequences of the decision.

Simple problems are often well-structured. All the background information required for making a sound decision is given. Further the options are clearly defined and their influence is known.

2.4.2 Different approaches of decision problems

There are many ways of solving a decision problem. Choosing at random, relying on a past solution, unquestioningly choosing an expert's solution, choosing by intuition, or by rational and systematic research. These approaches can be gathered into two groups, "heuristic" and "analytical" approach. These can be further subdivided into "general" and "specific" approach. (Grünig & Kühn, 2013)

Heuristic approach

The word "heuristic" originates from ancient Greek and roughly translates to "to seek" or "to find". The main difference and advantage of working heuristically is the minimal amount of formal application restrictions (Grünig & Kühn, 2013). A heuristic way of working is to simplify, use rule of thumb and use tricks to reach a good enough solution. Which means that since it is not an exact method there is no need to follow strict templates to confirm accuracy. Approaching a problem heuristically is a way to reduce effort or complexity. As a result the optimal solution cannot be found; only satisfactory solutions are possible (Grünig & Kühn, 2013).

Analytical approach

The opposite of the heuristic approach is the analytical "rational" approach. For applying an analytical solution the problem needs to be well-structured according to Simon & Newell (1958). A problem can be considered well-structured if it fulfills three conditions:

1. The problem contains only quantitative aspects or that the qualitative aspects can be reduced to quantitative.
2. What an acceptable solution constitutes is clearly defined in a quantitative manner.
3. It is possible to develop a procedure which lets the actor find the optimal solution within a certain time-scope and expenditure.

An analytical approach finds the optimal solution through metrics. This allows solutions to be compared objectively and improvements to be quantified.

General and specific approaches

A general decision making procedure can be adapted for many problems and a particular situation. A specific procedure on the other hand is narrowly defined and is specifically designed for a problem in a particular situation.

2.4.3 Flowchart

As mentioned, a decision support tool can take many forms. One of the forms is a flowchart. A flowchart graphically displays a sequence of activities or actions, creating a chain. The purpose of the chain is to create, provide or produce a specific output. However it can have several inputs and outputs that are requirements for, or as a result, of the actions (Damelio, 2011). *Figure **7*** shows an example of a flowchart. The questions-box in the chart is called a "decision point".

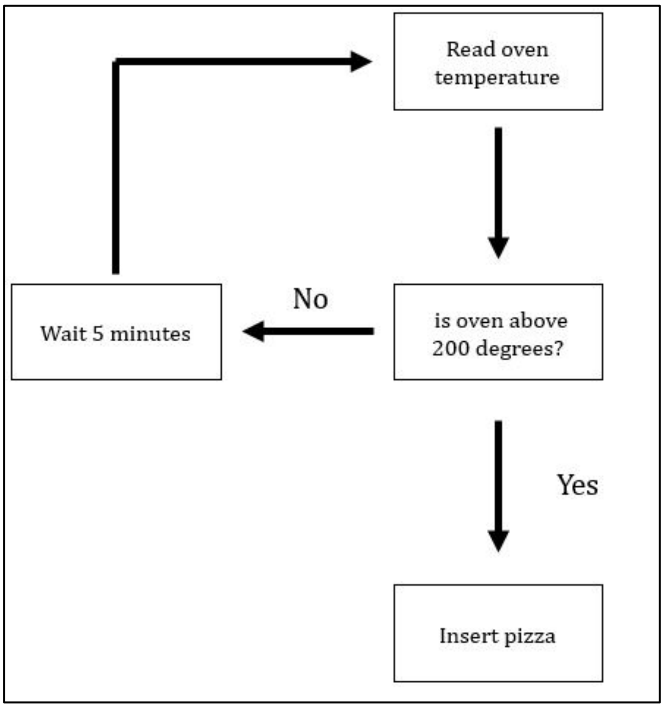

Figure 7. A schematic example of a flowchart. The questions-box is a decision point that determines the following step of the process.

Why use flowcharts? The phrase "A picture tells more than a thousand words" is familiar to most people. This is also the strength of flowcharts, an accessible visual representation of a process description. Instead of reading pages of words a quick glance of a well-designed flowchart is enough to decide the next step in the process. Furthermore a flowchart is an excellent method of presenting a new process to an audience. (Andersen, 2007)

Flowchart design

There are many ways of drawing a flowchart, there is no unified practice. There are however commonly used symbols. According to Andersen (2007) a typical generation of a flowchart goes by the following steps:

1. Define the boundaries, start & end points
2. Map activities
3. Construct the flowchart graphically
4. Resolve any issues
5. Redraw

The start and end point of the flowchart together define the *boundaries* and should be well-defined outputs or events. The *activities are identified* by finding out all of the necessary steps that need to be included in the flowchart. Once the activities have been identified the *graphical construction* of the flowchart is created by placing the activities in the sequence in which they are performed. Eventual "decision points" are identified at this stage as well. Once the first draft has been created the development team *resolve any issues* that the chart might have. The final step is to *redraw the flowchart* with the purpose of increasing the readability.

2.4.4 Quantitative data and Qualitative data

The data that is used when creating the DSM is categorized using the common categorization of data where the data is deemed to be either *qualitative* or *quantitative*. Qualitative data is the data type that is collected in a *qualitative research* (Bryman & Bell, 2003). The following features of qualitative data are defined as described by Ebling Library (2016): In contrast to a quantitative research, a qualitative research is based on something that is impossible to accurately and exactly measure. The collected data of this type is normally used to form a theory, compared to quantitative data, which is used for testing existing theory.

Quantitative data is the data type that is collected in a quantitative research (Bryman & Bell, 2003). Following features of quantitative data are defined as described by Ebling Library (2016): As implicated by its name, quantitative data is quantifiable and exactly measurable. A further feature of quantitative data is that it is used for testing an existing theory as opposed to developing a theory, which is the case for qualitative data.

3 Methodology

This chapter describes the work process of the study and includes the various methods that were used throughout the project. In cases where there are alternative methods, a motivation of why certain methods were chosen is also stated. The chapter consists of eight parts that describe the methodology in chronological order except for chapter 3.7 which was given its own chapter due to its extensiveness. The methodology chapter includes detailed explanations of the research design, the preparatory work, the data collection process, the buffer replenishment rate, the work task analysis, the generation of future layouts, the material flow simulations, and the process of developing the DSM.

3.1 Research design

The research design that was used throughout the research was the *case study* method, as explained by Yin (2003). The method is commonly used for creating an understanding of complex phenomenon about individuals, groups, organizations, social situations, political situations, economics, and related phenomena (Yin, 2003). It consists of six sequential stages: plan, design, prepare, collect, analyze, and share. The method was not followed strictly in the research, but served merely as a guideline that structured the work. The reason for choosing case study as the method was its applicability to research projects concerning social, organizational, and managerial systems. Further, a case study is appropriate in cases where the research group has no ability to control the system that the research is studied upon (Yin, 2003). This fit the research since the production system that was studied at Brose was an established system that the thesis group had no ability to control or manipulate. Another factor that is required for case studies is that the research is carried out on the current state of the study subject, as opposed to its historical states (Yin, 2003). The thesis group will be studying the existing production system solely in its current state and base the findings on it, which is in line with the requirement when selecting a case study as a research method. The list below follows the activities that took place in each of the stages of the case study, including short descriptions of each stage based on Yin's (2003) definitions of them.

1. Plan

The first stage of a case study is to plan the research. This is a crucial stage for structuring the consecutive work that follows in the research. The steps that were taken in the planning phase of the thesis are listed below:

- Problem definition
- Research questions
- Time plan
- Deliverables

2. Design

The design is the link between the initial question and the collected data, which ultimately results in the conclusion of the study. It works as a guide for the research group and facilitates the process of achieving the research goal. Steps of the thesis are listed below:

- Literature study
- Familiarization with Brose's production system
- Identify gaps and required data
- Identify information sources

3. Prepare

The preparation stage regards the preparation of the data gathering process. The degree of which the data matches the reality is heavily depending on how well the preparations are made prior to the data collection. Measures that were taken in order to assure a fully prepared data collection can be found in the list below:

- Design interview guides
- Construct time study

4. Collect

The fourth stage of a case study is to collect the data that will be used as a foundation and evidence for the future results. There are six major data types: documents, archival records, interviews, direct observations, participant-observation, and physical artifacts. The methodology that is used when collecting the data varies depending on the type of data that is meant to be collected. The data collecting steps that were carried out in the project are listed below:

- Time studies
- Interviews
- Collection of data from internal documents

5. Analyze

Following the data collection stage is an analysis where the collected data is analyzed in order to form a result of the research. There are many different approaches for doing it and the problem is deciding which strategy is the best suited for the research. If lacking a strategy there is the option of "playing around" with the data as an introduction to a more systematic approach. The steps that were taken in order to analyze the data can be found below:

- Combine data and generate layout proposals
- Evaluate eligibility of proposed layouts by simulation and requests of Brose representatives.
- Analysis of previous work where the results are used as a base for constructing decision support model.

6. Share

The sixth and final stage of a case study is to report and share the results of the research. This is the closing stage of the research and concerns the way that the results are presented. This stage involves a number of considerations such as determining the target audience, structuring the report, and following certain procedures. To work on the report as the research progresses is generally recommended. The means of sharing the findings of the thesis are listed down below:

- Report
- Oral presentation for Brose and the institute

3.2 Preparatory work

Before any actual design of a new production system started a background study of the current and future requirements had to be established (Bellgran & Säfsten, 2010). The importance of the preparatory work was to avoid too rapid conclusions and making the wrong decisions. If the current layout were not considered there was a risk of good solutions being lost. A background study typically entails evaluating the current system (if any), identifying the needs of the future system, and studying other productions systems. (Bellgran & Säfsten, 2010)

3.2.1 Literature review

A literature review was conducted in order to create a theoretical framework for the research. The main scope of the review was to find methods of structured layout planning. General knowledge of production systems was already established. The literature examined was mainly practical guides and industrial engineering handbooks with topics such as evaluation techniques, interview guides, and software tools. More theoretical topics were also examined, such as theory of data collection and research methods. The following online databases were searched for literature:

- Books24/7
- AccessEngineering
- Emerald

Keywords that were used when searching on the online databases were: *Functional, layout, structured, planning, problem, method.* Besides online catalogues Chalmers' (physical) library was frequently visited for access to reference literature and other copies that were not available online.

3.2.2 Introduction to Brose's production system

The first analysis of the production system was conducted in the early stages of the study. A few days were spent at Brose's production facility with the purpose of getting familiarized with the studied production system. An overall picture of the processes was established and the general characteristics of the various processes were captured by working side-by-side the operators. Furthermore, the thesis group performed some of the work tasks. The flow of material in between the processes was also examined. In addition, a blueprint of the facility was provided by Brose, which helped to further improve the understanding of the factory.

3.3 Data Collection

Data works as the foundation for any research, thus the outcome of a research is heavily dependent on the quality of the collected data (Yin, 2003). Following subchapters cover the data collection activities of the thesis.

3.3.1 Interviews

One part of the data collection process was to interview employees of the company that were affected by the layout of the factory. The purpose of the interview was to acquire information for three areas: (a) *the SLP*, (b) *the manufacturing processes*, and (c) *the material flow simulation of the layouts*. The following sections include more detailed information about the performed interviews.

Interviewees

The chosen interviewees were employees that were affected by the layout of the section of the production that was within the scope of the research. These included (a) the production manager, (b) the supply chain manager, (c) machine operators, and (d) truck operators. Machine operators from all three concerned production processes (i.e. sealing, railing riveting, and CF assembly) were also selected.

Interview type

Before an interview guide could be developed, the interview type needed to be determined. In theory there are three types of interviews (Qu et al., 2011). These are:

- **Structured**
  This interview type is characterized by using a set of prepared questions with a limited amount of answers. Open-ended questions are avoided.
- **Semi-structured**
  A semi-structured interview is formal and uses a guide of topics to be covered. Usually these topics follow a specific order and when appropriate allows for more in-depth discussion. In this type of interview the interviewee is normally only interviewed once.
- **Unstructured**
  This approach, while still formal, uses strictly open-ended questions, trying to get the respondents to open up.

The type that was chosen in this research was the semi-structured approach. This was appropriate for two reasons. The first reason was due to (a) the time-limit of the research. Since the interview was only one part of the data collection process, the thesis group sought to use a time-efficient interview form in order to fit in the other data gathering processes into the time plan. Semi-structured interviews are in line with this reasoning since they are designed for cases where each interviewee is only interviewed once. The second motivation for selecting semi-structured interviews was (b) its mix between structure and flexibility. Semi-structured interviews are normally structured with a prepared interview guide, but the included questions are often open-ended in order to enable the interviewer explore areas that were previously unknown. The structure was necessary since one of the goals of the interview was to acquire information that could be used in the SLP-method and the simulation, thus specific questions needed answer. The open-ended questions were necessary when forming a deeper understanding of the production system, which was one of the three purposes of the interview. As a result, some received answers were not relevant for the research. They were documented, but not further considered during the project work.

Interview guide development

The development process of the interview guide can be broken down into three major steps. In the first step a draft of the guide was formed. The second step was to have an external person go through the interview guide and give his or her opinion on its content and structure. It was preferred that this person was experienced with interviews. The academic supervisor of this thesis was therefore chosen for the task. Once the supervisor's opinion had been taken into consideration it was time to move on to the third and last step of the interview guide development process, which was to adjust the initial guide in a way that incorporated the supervisor's feedback.

Interview guide structure

The interviews were carried out with the purpose of collecting information for three areas: (a) the SLP, (b) the three manufacturing processes, and (c) the simulation of material flows related to the three manufacturing processes. Consequently, the interview guide was structured based on these three purposes. The purpose of the first section was to acquire information that was necessary for the SLP-method. The questions were formed after studying the method thoroughly and needed data was identified. The purpose of the second section was to get both a general and a deeper understanding of the three production processes. The questions were formulated based on the preparatory work that took place prior to the data gathering stage of the research. The third and final section of the interview guide was made with the goal of obtaining information that could be used for the simulation of the production flow. These questions were formulated based on the type of input data required for Flow Planner.

3.3.2 Time studies

Another chosen method for collecting data was a time study. The alternative method, work sampling, requires many observations before an estimation can be made on the system. This makes the method excessively time consuming for the time scope of the thesis. It was therefore not chosen as the means of collecting time data of the production system. In order to attain time data that accurately reflect the real production system the involved work tasks were video recorded and timed using the recorded footage. Thus, the time studies were performed on the footage rather than on the physical production system. In addition, a limited amount of time data was provided by Brose. This data was used as a complement to the measured times from the recordings.

3.3.3 Distance measurements

In order to place objects at the right distances from each other accurate distance measurements were needed. This includes width and length of machines, buffers, equipment etc., but also the metrics of the factory itself. Exact measures of pillar and path placements were needed for preventing any misplacement. These distances can be measured by a variety of methods, measuring tape, optics, and scaled drawings to mention a few. In this project the measures were gathered from the Brose plant blueprint, measured in AutoCAD 2016, and later controlled by measuring tape at the actual facility.

3.3.4 Machine data

Machine data such as downtimes [%] and faulty products [%] were partly acquired from the automatic logging programs of the machines. Further data were gathered from production records. Cycle times and set up times were acquired from machine and task specifications.

3.3.5 Data collection from ERP system

Data for the three production processes were collected from Brose's Enterprise Resource Planning (ERP) system. The data that were collected were the number of variants that were in production for the years 2018. The total amounts that were produced for each variant were collected as well.

3.4 Buffer replenishment rate

The replenishment rates of the buffers affect their placement in the layout. Buffers that need to be replenished more frequently should be placed in a way that is easily accessible for the logistics. The replenishment rate could be derived from the buffer capacities, the received order quantity, and the product specifications; a buffer with a low capacity and a high consumption rate (based on orders) needs to be tended to more frequently than a buffer with a high capacity relative to its low consumption rate. This means that it is not the replenishment rate of the buffer themselves that are relevant, but rather their magnitude in relation to each other.

The replenishment rate required both data collection and some calculations. Buffer capacities were measured by simply observing the various buffers in the production. Data regarding the order quantity were collected from the ERP system. Data for some components were not available in the system, but were derived from the order quantity and the product specification. The product specifications show the number of components that go into each product and the order quantity shows the consumption rate of the products, enabling the consumption rate of the various components to be calculated. Once the replenishment rates had been calculated they could be compared and the buffer prioritization was conducted.

3.5 Work balance and Work design

In order to make sure that the workload of the workers is set to an appropriate level and to analyze the possibility of a worker to service several machines on his or her own, work balancing was used. This step was carried out in parallel with the flow simulation. Part of the analysis was based on work sampling in the form of video recordings. The recorded activities were broken down into tasks in the software AviX. This allowed for exact estimations of work operations. Tasks that do not yet exist and are going to be implemented in future solutions were estimated using MTM-codes. Movements such as walking and turning were also estimated using MTM-codes.

In order to measure the operator' performances in the layouts, the required work tasks and movements were calculated with mentioned methods and later also activity classified. As the future demands of Brose's products were known it was possible to calculate how many operators that were needed for running the sealing and railing processes. Granted that the placement of the machines enable the operator to move efficiently between them. Different solutions were tried and evaluated, thus covering several possible layout variants.

3.5.1 Method Time Management (MTM)

In this project the MTM-1 system was employed as it allows for the most exact estimations, although at the highest time cost of the MTM-systems. All operator movement between processes and workstations were estimated with this method. Also some minor tasks that were not captured by the recordings were estimated using MTM-codes. In addition, some new solution-specific tasks were constructed in the same way.

3.5.2 Recording activities

For achieving best possible result with AviX, the analyzed operations should be video recorded. Videos can be directly imported into AviX. They can then be edited and cut into parts for better analysis directly in the program. When recording the activities there are certain things to keep in mind for achieving the best result: (Solme AB, 2015)

- The operators should be informed beforehand so that the recording does not come as a surprise.
- The video should be focused on the object being manipulated. A good rule of thumb for not accidentally missing any handling is to focus on the area between the operator's chin and waist.
- If the operator is moving long distances remember to record his feet.
- Do not just record one production cycle, do several in order to capture the natural variation.
- If possible let the operator talk about what problems that might occur.

Furthermore, the used method should be recorded and not the one defined in instructions. However, it is important to make sure that the correct production aids are being utilized. The operator might have a better method of doing things than described in the instructions. The method should only be considered if it is ergonomic and of sufficient quality.

3.5.3 Calculation of workforce

For calculating the workforce the work balancing suite of AviX was used. In AviX the workstations are first defined and then operators and machine resources can be assigned to it. These operators and machine resources can then be assigned tasks. By setting rules for the tasks such as "start after" and "end before" interrelationships between the resources can be set. The frequency of the tasks can be derived from the demand.

Some support tasks such as quality checks and container changes can however occur irregularly as in the case of this project where there are tasks that are not as frequent as the main value-adding tasks that seemingly occur at random. The possibility of tasks occurring beneficially as well as colliding needs to be investigated, a "best case" and "worst case" scenario. Unfortunately, unplanned production stops such as material shortage, lacking quality and machine failures are hard to include due to their random nature. Thus, appropriate time margins should be set. This margin should be based on historic data as well as a desired safety factor.

For the purpose of analyzing where time could be better utilized for the workers of the current state, all work processes were set up in AviX. Due to the tasks repetitive nature patterns quickly emerged. In these patterns reoccurring time gaps could be found. They are the result of an internal process working faster than others or due to waiting for a machine resource to finish processing. By moving the processes closer workers can support other processes while their time gap occurs. Another scenario analyzed this way was the possibility of letting an operator be in charge of two processes.

3.6 Generating proposals for future layout

SLP was used as a method for generating provisional layout proposals. It worked as a foundation for the layout development process. Material flow simulation was added to the method and is explained in detail in the next chapter. SLP was chosen for its general acceptance within the field of layout development; the literature studies in this thesis showed that Muther's (1977) SLP method was frequently cited. Furthermore, its structured "step-by-step" approach facilitated the advancement of the method where additional steps could be added relatively easy. This chapter covers the six steps of the method that were followed in order to generate the provisional layout.

Step 1: Clarifying the connection

The purpose of the first step of the SLP-method is to identify the concerned functions and assessing the connections between them. Information needed for this step was collected through interviews in the data gathering process and through communication with Brose via e-mail. The analysis of the data was visualized using a triangular connection chart. The chart lists the involved functions and rates the connections between them. The ratings show which functions that needed to be placed in close proximity to each other.

Step 2: Establish functional demands

The second step of generating a layout proposal was to identify the demands of the different functions. This information was collected during the interviews just like the previous step.

Step 3: Line functional connection

The third step was conducted to create a visual representation of the function connections that were established in the first step. The established demands of step two need to be considered as well when doing this. The functions are placed one by one and rearranged until a clear layout has been generated.

Step 4: Draw alternative master plans

The fourth step is a creative process where the actual layouts were generated and different solutions and ideas could be tested. The creating process was steered by the demands and function connections found in previous steps. By the end of this step a number of different layout solutions with varying approaches had been generated. This step is largely creative. To support the process, the plant floor was drawn in scale on a white board. All objects of the facility, machines, buffers, and support functions, were drawn in the same scale as the floor, cut out with scissor, and fastened to the whiteboard with adhesive putty. Truck paths were drawn with a whiteboard pen.

Step 5: Assess the different alternatives

A large number of layouts were generated in step four. As the focus of this stage was to create as many and as different solutions as possible many were of insufficient quality. These solutions were screened during the fifth step in order to narrow them down. The screening process was made based on the wishes and demands that were initially stated by the company during the interviews. The most suitable layouts were then decided upon and brought to the next step of the layout assessment process.

In the next step iterative screening meetings were held with a focus group of stakeholders. The group consisted of the CEO of Brose, the production manager, the logistics manager and the chief industrial engineer. At these meetings the generated layout proposals were discussed, those of insufficient quality were discarded. Other solutions that showed potential were discussed and issues were brought up. Before the next meeting layouts were updated according to the given feedback. This screening process was done iteratively until only one approved solution remained.

Step 6: Design the chosen layout plant solution

The selected layouts were further developed based on the feedback that was received from Brose in the previous step of the layout generation process. Complete CAD-drawings of the factory floor with the proposed layouts were drawn in order to get more accurate measurements of the layouts. The CAD-software that was used in this study was AutoCAD 2016. It was chosen for two reasons. The first reason is that (a) it was Brose's choice of CAD-software. The digital drawing of the factory that was provided by Brose was in the file format that is used in AutoCAD. Using the same CAD-software was thus time efficient since the files did not need to be converted before they could be used. Furthermore, once the proposed layouts had been finalized they could be delivered to Brose in a format that they are already familiar with. The second reason for choosing AutoCAD instead of other CAD-softwares is that (b) there is a large amount of external add-on tools for it such as Flow Planner, which was used in the next stage of designing the layout.

3.7 Material Flow Simulation

As a part of assessing the different layout proposals' eligibility material flow simulations were carried out on the layouts. This is an added part of the development that is not considered in SLP. However, it is relevant to consider since the layout does have an effect on the material flow. The software that was used for the simulation was Flow Planner. The software was chosen for its compatibility with AutoCAD. The purpose of the simulation was to see how the material flow was affected by the layouts by using the current state of the factory layout as a reference, i.e. the simulation was a way of assessing if the layouts resulted in improved or worsened material flow.

The extent of which the simulations were done was kept rather simple since Brose was only interested in how activities of the manufacturing processes were affected by the various layouts. The analysis was therefore limited to one significant parameter, which was the transportation time between different pickup and delivery points. Furthermore, the generated results of the simulations were analyzed by comparing them with each other, thus the individual results were of lesser importance. Consequently the simulations could be kept simple and the amount of input data that was needed could be limited to a select few. Detail-level data that did not need to be included were for example the acceleration of the trucks, the dimensions of the containers, and the efficiency of the transportations. The used input information for the simulations were limited to pick up/delivery points, truck speed, and operator walking speed (for transportation of material by foot).

3.8 Development of the Decision Support Model

The layout proposals of the case study laid the foundation for the DSM. The development included defining the characteristics of the DSM and finding an appropriate form for presenting the model. A theoretical development instruction for the chosen presentation format was used for creating the DSM. Following two sections explain the development process in detail.

3.8.1 Defining the characteristics of the DSM

Before the DSM could be developed its characteristics were defined based on the theory that was collected during the literature studies. The characteristics dimensions include a *classification of the decision problem* and choosing an appropriate approach for solving the decision problem.

<u>Classification of the problem</u>

As explained in the theory chapter of this report, decision problems are classified as either simple or complex. A problem is considered to be complex if it fulfills two out of the four criteria listed in the theory. The facility layout problem was therefore analyzed for the criteria in order to classify it.

The first criterion is if *several targets are attempted to be reached simultaneously*. A production system of a high performance that is caused by its layout is not characterized by one value, but rather by a palette of variables. As such when developing a layout, the goal is to reach multiple targets simultaneously. This results in a complex problem where several goals, some of them even contradictory, are targeted.

The facility layout problem further fulfills the criteria of *having a large number of decision variables*. There are many decision variables in the layout problem. Some variables are shared among all production layouts such as distance and cycle time. There are also variables whose importance depends on the situation. Health and safety regulations can differ depending on the industry. Medical and food industry for example have strict restrictions on cleanliness. In a layout this could influence the placements of processes and machines (Motarjemi & Lelieveld, 2014). With two criteria fulfilled the facility layout problem can already be classified as a complex problem. However, an analysis was done on the remaining two criteria as well in order to cement the classification. The third criterion of the layout problem was analyzed with regards to *if the future development of several environmental variables is unknown*. Environmental variables for a manufacturing company could constitute variables related to the market. The behavior of a market might be possible to predict within the near future, however the market gets harder to predict further into the future, thus the third criterion is fulfilled as well. The fourth and last criterion is not as simple as the previous ones. It is about *the decision maker's ability to determine the outcome of a made decision with his or her possessed experience and tools*. The answer is highly depending on the individual that is making the decision and the company that the decision maker works for. Since the DSM that was developed in this study is meant to be generally applicable there is not a specific decision maker or company that it is made for. The decision maker that is responsible for a facility layout is most likely a production manager of some sort. Although the manager possesses the general experience on production management, the experience of the specific production system at hand could be limited, thus it is not possible to give a definite answer on the criteria. Furthermore, the available tools for acquiring knowledge about the outcome of made decisions depends on which tools the company has made available to the decision maker. The analysis shows that the facility layout problem fulfills three of the four criteria, which classifies it as a complex problem.

Chosen approach to the problem

As explained in section 2.4.2, there are two approaches for solving a decision problem: *analytically* or *heuristically*. The suitable approach was determined by evaluating the three conditions that characterize a well-structured problem, which indicates that an analytical approach is most suitable. Although these goals may not traditionally be measured in a quantitative manner their qualitative aspects can be reduced into quantitative ones allowing for a structured approach. Reducing qualitative measures into quantitative ones also helps setting the requirements for an acceptable solution. As can be concluded by the theory chapter of this report, a layout problem is a *complex* problem therefore a general *analytical* problem approach is best suited.

Certain parameters identified by Brose stakeholders and the project groups research serve as measures of eligibility.

- Amount of workforce required
- Efficient logistics transport
- Production works independently from logistics
- Minimize non-value adding tasks (walking etc.)
- Accessibility
- Visibility

Since an analytical approach is applied these qualitatively expressed parameters need to be converted into a quantitative value which allow solutions to be compared in a structured manner.

By conducting interviews on the affected personnel qualitative information of the production system was gained. Opinions on current situation and of proposed future states. In the interviews mainly the opinion based parameters, such as visibility and accessibility, are touched upon. The qualitative information was then converted into quantitative through ranking. In practice this is done by presenting alternatives then asking the interviewee to rank them from best to worst.

The amount of workforce required is already a quantitative measure, although one that is complicated to measure or calculate. For this purpose a mix of time studies, MTM-1 and work balancing was used. This project used the work evaluation software AviX to organize evaluate the processes of the involved areas. Activity classification, i.e. value adding/non-value adding, is included in the AviX evaluation.

With the AutoCAD add-on Flow Planner all transport distances in the layout could be measured and analyzed. Highlighting where the largest transport losses are located and giving indications of where possible congestions might be as well as supporting the aisle design and machine placements.

3.8.2 Finding a suitable DSM structure

Finding an appropriate form for presenting the DSM in a way that fits the model's purpose was crucial for its usability and effectiveness. The model structure that was chosen for the DSM was a flowchart due to its clarity and structure that it is able to provide with its visual representation of work processes. Furthermore, the sequential process representation of flowcharts suits the inherently sequential work process of layout planning. The case study on layout creation at Brose showed that it essentially consisted of a sequence of activities that were done step by step, which is the same way that flowcharts are structured.

Developing the flowchart

The flowchart development process combined the gathered experiences from the case study at Brose and Andersen's (2007) flowchart development process as explained in the theory. *Figure **8*** illustrates the five steps of the flowchart development. A grouping of the activities was added to the flowchart. The groups of activities are called stages and their purpose was to clarify the progress of the layout development process. Further, an additional element was added to the flowchart that was given the name "secondary objective". These are objectives that affect the layout development and should be considered during the development process.

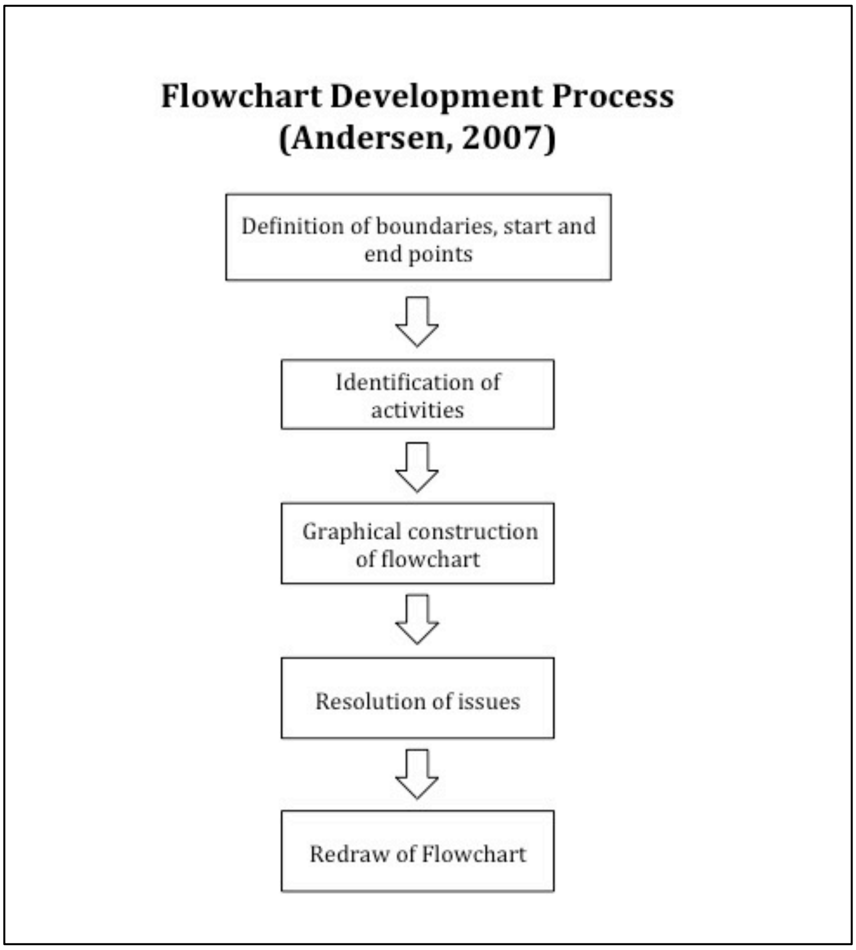

Figure 8. The included steps of developing a flowchart as described by Andersen (2007).

4 Results

This chapter presents the results of the thesis. The information that is presented here are the generated results of the events that are explained in the method chapter. This includes results from the data collection, Brose's production system, the SLP, the logistics, the work design, the layout generation, and the resulting DSM.

4.1 Data collection

The resulting data that was collected during the data collecting activities are presented in this section.

4.1.1 Interviews

The results of the interviews can be found in Appendix A. Below is a list that roughly summarizes the results:

- All of the interviewees considered it most important to keep material and machine close to each other.
- There are few restrictions.
- Expectations of the project is improved material flow and higher operator utilization.

4.1.2 ERP-system

Variant data for the three production processes collected from the ERP-system is presented in this part of the report.

Variant data rails

The produced rails are for four different car models where three of the car models require six different rails and one car model requires four different rails, resulting in 22 rail variants that are in production year 2018. Appendix B shows the demand for each of the rail variant.

Variant data sealing

The plates are sealed for four car models where each car model requires four different plates, resulting in a total of 16 plate-variants. Appendix B shows the demand for each of the plate variant

Variant data CF

In year 2018 there will be four variants of CFs in production. All four variants have different motors, two of them share the same type of shroud and all of them share the same type of fan. Appendix B shows the demand of the different CF-variants and the resulting demands of their components.

4.2 Brose's production system

This chapter describes Brose's production system based on the information that was collected during the preparatory work and the data collection stage. The first section explains how and if the three processes are connected. The remaining sections cover each of the processes in detail.

4.2.1 The production system

Three production processes are included in the study: the rail riveting process, the sealing process, and the CF process. *Figure **9*** illustrates the flow of the three processes. The rail riveting station and the sealing station process components that are parts of the door modules. As a result their flows converge into the line assembly as seen in *Figure **9***. The CF station processes a different product and is therefore decoupled from the two other flows.

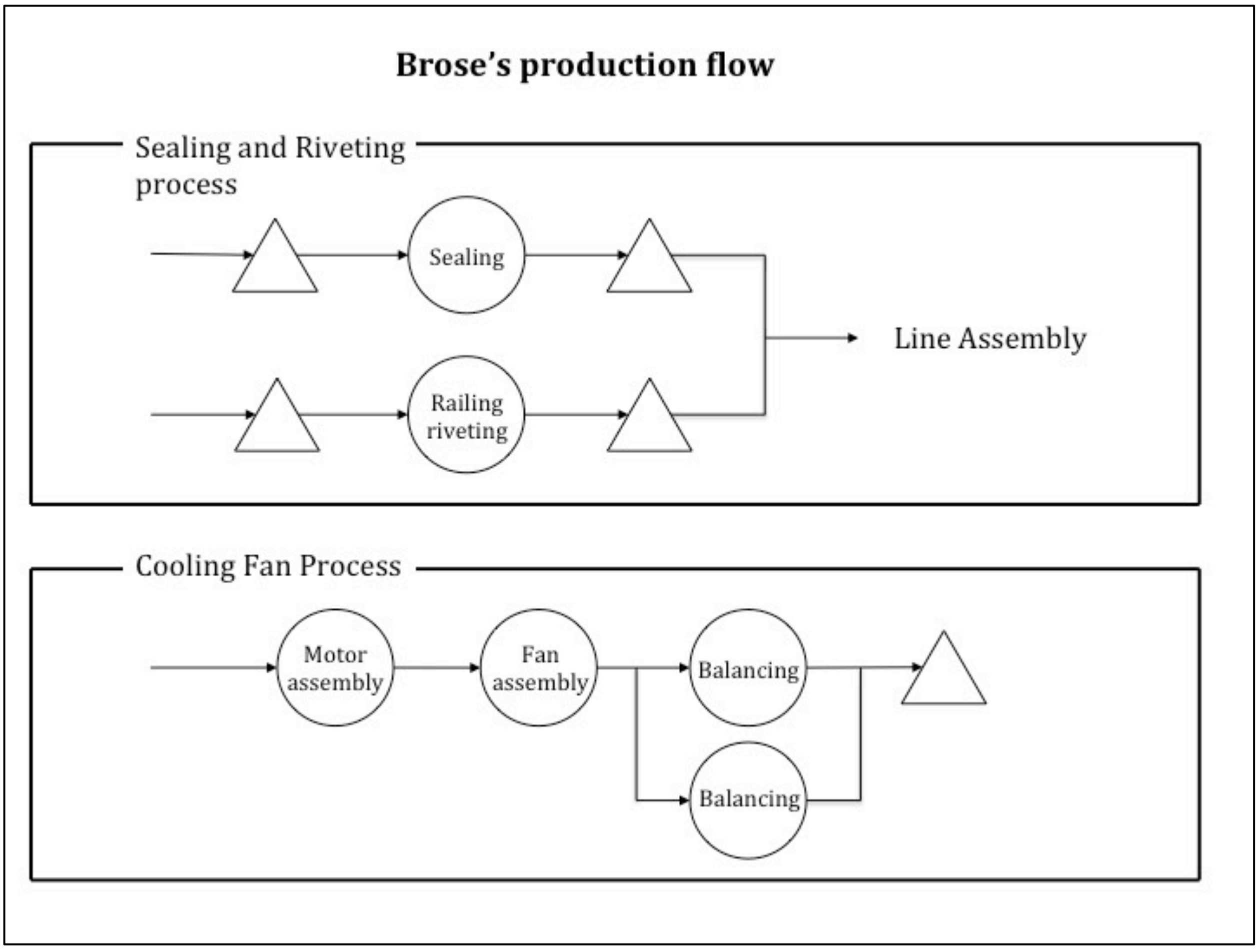

Figure 9. The mapped flows of the three production processes. The circles in the figure represent the processes and the triangles represent buffers.

4.2.2 Rail Riveting

This section presents the results regarding the rail riveting process. This includes descriptions of the processed part, the process, the processed part variants, the logistical activities related to the process, and the buffer prioritization.

Rails

The part that is processed in the rail riveting process is a component of the door modules that enables the window regulation function. It is a metal rail with one plastic pulley on each end of it. The pulleys can rotate and lead the wire that regulates the windows, see *Figure **1***.

The process

A machine in the process rivets the pulleys onto the railings in order to keep the pulleys in place. This is the main part of the process and it is almost completely automatic. The manual work that the workstation requires consists of fetching unriveted railings (stored in large boxes called "gitterboxes"), feeding them into the machine, packing the riveted railings into bins, and moving the bins to a buffer where the logistics department transports them to the assembly line. One operator performs the whole process. *Figure **10*** visualizes the flow through the rail riveting process.

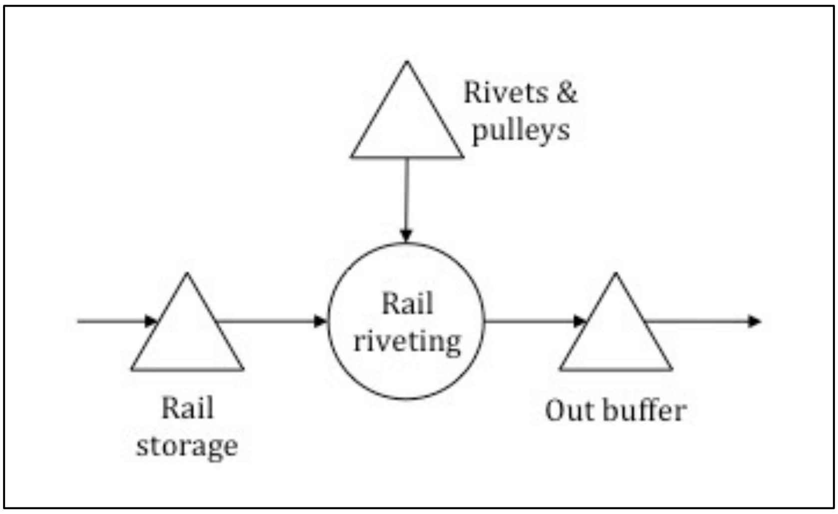

Figure 10. The rail riveting process.

The manual work further includes manual quality controls of the riveted rails is done in two different intervals. The first quality control is done at the beginning of a new variant. At that point, the control is performed on five riveted rails. The control interval is done once every 80th riveted rail and is only performed on a single rail. The count to 80 rails starts at the beginning of the production of a new railing variant. The quality control is done by rotating the pulleys manually to make sure that they rotate smoothly. Further, the height and the diameter of the rivets are measured with a caliper. All of the measured values are documented.

Rail variants

The process handles a number of different rail variants. The goal of the operator is to build up a stock for all of the variants. It is handled through a system that uses the bins that the rails are transported in. Each variant has its own designated bin and by looking at the number of empty bins for a variant the operator can determine which type to process next; a large stack of empty bins is more urgent to fill. *Figure **11*** shows what the rail bins look like. The unriveted railings are stored near the work station. The operator uses the amount of unriveted railings that is needed to fill up the stock and returns the remaining railings to the storage.

Figure 11. The bins that are used for transporting riveted rails.

Logistics

Below is a list of responsibilities of the logistics workers that are related to the rail riveting process:

- Transport bins filled with riveted rails to the assembly line
- Deliver pulleys and rivets
- (Empty recycling bins)
- (Deliver gitter boxes)

According to the supply chain manager the delivery of gitter boxes and emptying recycling bins could be excluded from the study since they are seldom handled and the location of the gitter boxes are fixed.

Buffer prioritization

The required times for the rail riveting process to empty the buffers for incoming material and to fill the buffers for outgoing material can be found in Appendix C. The used rail demand and work hours are shown below.

Rail demand 2018: 33 000 pcs/week
Work hours: 108,75 hrs/week

Appendix B shows that the buffer for outgoing rails is filled significantly faster than consuming the incoming rivets and pulleys. Thus the accessibility to the rails should be prioritized.

4.2.3 Plate Sealing

This section presents the results regarding the plate sealing process. This includes descriptions of the processed part, the process, the processed part variants, the logistical activities related to the process, and the buffer prioritization.

Plates

The plate is the part of the door module that the components are mounted onto in the assembly line. It is made of plastic and has a rubber sealing that goes along the edges of the plates in order to prevent the electronics on the module from getting damaged by external moist. *Figure **12*** shows a close-up of a plate's sealing.

Figure 12. A close-up of the plate and the sealant. The sealant is the substance that can be seen on the edge of the plate.

The process

Much like the riveting station the main process is automated. One operator performs all of the manual work. The manual work consists of surrounding supporting activities. This includes fetching the unsealed plates from a buffer, feeding them into the sealing machine one at a time, unload the sealed plates from the machine, and move them to a buffer zone where the logistics department transports them to the assembly line. *Figure **13*** illustrates the flow of the sealing process. The transportation of plates is enabled by racks that can hold 132 plates each. *Figure **14*** shows a rack filled with plates.

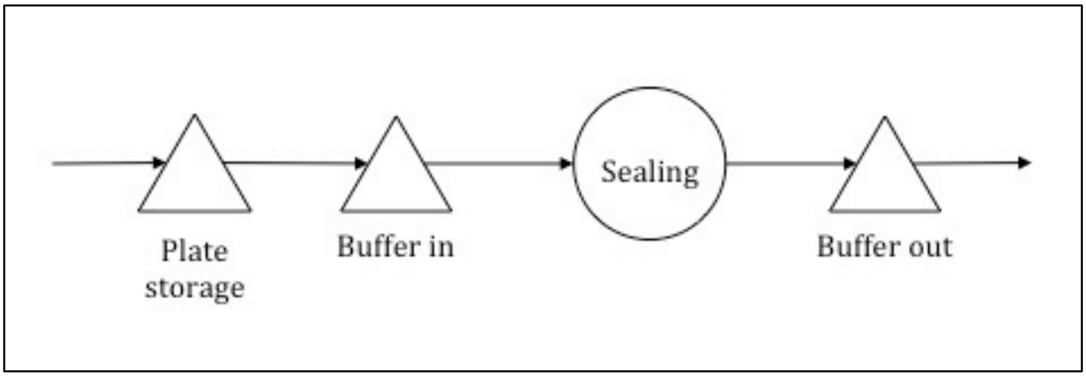

Figure 13. The flow of the sealing process.

Figure 14. A rack full of plates.

The manual work tasks also include a quality control of the first two plates in each rack. The quality control consists of taking various measurements of the plates in order to detect any irregularity. The results of the controls are analogically documented in binders. The company is however planning on doing the documentation digitally on a computer in the future.

Plate variants

The system used for deciding which plate variant to process next works in a similar fashion as in the riveting process where the goal is to keep the stock level full. Racks with sealed plates are placed in buffer queues where each queue is reserved for a specific variant and depending on the amount of empty slots in the queue the operator knows which type to process next.

Logistics

The logistics department is responsible for three areas in the sealing process. These are listed below:

- Transport unsealed plates from the storage and placing them in the buffer for the sealing station
- (Replenish the barrels that contain the sealant)

According to the production manager the sealant barrels can be excluded in the study due to the infrequency that they are replenished. Note that the queues with sealed plates are transported to the assembly line by the workers in the assembly line and not the truck drivers.

Buffer prioritization

The required times for the rail riveting process to empty the buffers for incoming material and to fill the buffers for outgoing material can be found in Appendix C. The used rail demand and work hours are shown below.

Plate demand 2018: 24 000 pcs/week
Work hours: 108,75 hrs/week

Appendix C shows that the incoming plates should be prioritized in terms of accessibility since its buffer is emptied significantly faster than the outgoing plates.

4.2.4 Cooling Fan Assembly

This section presents the results regarding the CF assembly process. This includes descriptions of the CF, the assembly process, the CF variants, the logistical activities related to the process, and the buffer prioritization.

The cooling fan

The CF is a second product type that Brose produces. It is an electric fan whose purpose is to cool down car engines. A CF consists of a shroud, an electric motor, and a fan.

The process

The cooling fan process consists of two assembly processes, followed by a quality control station. The process is relatively manual compared to the railing riveting and the plate sealing. The first step of the cooling fan process is mounting the shroud onto the motor. The process is manual, but is facilitated by a fixture that holds the motor and the shroud. A screwdriver suspended above the workstation is used for fastening the motor, which further facilitates the assembly process. *Figure **15*** shows the screw station where the motors are screwed onto the shrouds.

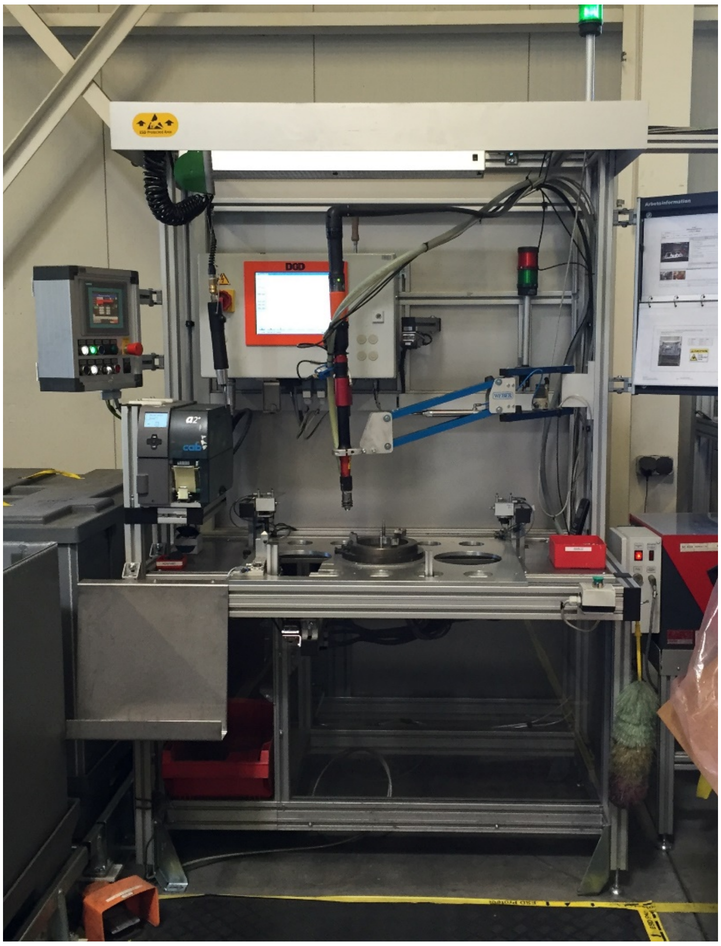

Figure 15. The cooling fan screw station.

After the first assembly process the partially assembled CFs are placed in a buffer where a second operator takes and places them in a press machine that presses the fans onto them. It is a semi-automatic process; the assembler places a fan onto the machine, places the shroud and the motor on a fixture, and executes the pressing function that presses the fan onto the shroud. *Figure **16*** shows the press machine.

Figure 16. The fan press machine.

The last and final stage of the cooling fan process is a quality control. It is performed by one out of two identical machines that work in parallel. The assembled cooling fans are placed in one of the machines where it is accelerated in order to detect rotational imbalances that are caused by production defects. Whenever the machine detects an imbalance, the operator manually attaches clip-on weights in a way that counters the imbalance. The balance control is then executed once again and eventual additional balancing adjustments are performed until the fan passes the balance control. See *Figure **17*** for the two balance control machines.

Figure 17. The two balance control machines.

Once the cooling fans are balanced, they are loaded onto a container in which they are stored while being delivered to customers. The operator places cardboard boards in between the cooling fans to prevent them for getting damaged during the transportation. Once the containers have been loaded they are transported to storage by the logistics before they are sent to Brose's customers. *Figure **18*** shows the process flow of the CF process.

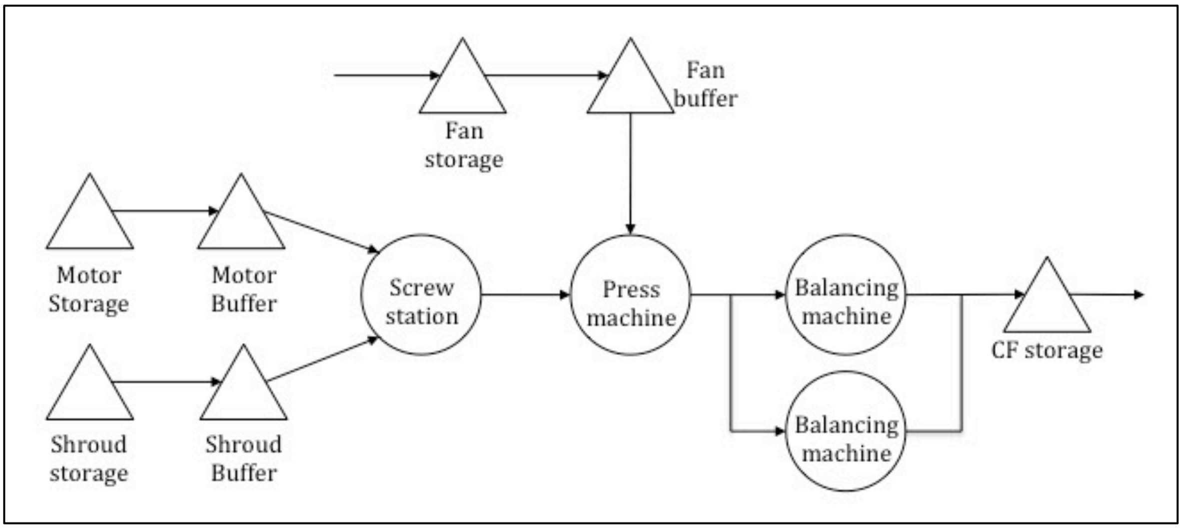

Figure 18. The cooling fan process.

Cooling fan variants
Only one type of cooling fan is processed in the current process. However additional types are to be introduced in the future. A digital system will inform the worker on which variant to produce, as opposed to the stock-filling system that is used in the riveting process and the sealing process. Further information about the variants can be found in section 4.1.2 where variant data from the ERP system are presented.

Logistics
Compared to the riveting and sealing processes the logistics department has more responsibilities regarding the CF process. Following is a list of their responsibilities:

- Deliver motors
- Deliver shrouds
- Deliver fans
- Deliver small and large cardboard boards for the packaging of the finished goods
- Deliver empty containers for finished CFs
- Transport finished CFs to a storage for outgoing goods

Buffer prioritization
The required times for the CF process to empty the buffers for incoming material and to fill the buffers for outgoing material can be found in Appendix C. The used CF demand and work hours can be seen below. Based on the replenishment/fill rate of the buffers, the prioritization of the buffers is presented in *Table **1**.*

CF demand 2018: 4040 pcs/week
Work hours: 108,75 hrs/week

Table 1. Prioritization of the buffers in the CF process. The highest ranked buffers need to be tended to more often by the logistics.

	Buffer
1	Finished CFs
2	Shrouds
3	Empty CF containers
4	Fans
5	Motors
6	Small cardboard boards
7	Large cardboard boards

4.3 SLP

This section covers the resulting triangular connection chart and visualized functional connections that are created during the process of generating layout proposals using SLP. The diagrams can be found in Appendix D and Appendix E.

4.4 Logistics simulation

The logistics simulations show that the three layouts in the final stages of the layout development had approximately the same transportation distances compared to Brose's current layout. A table of the various transportation distances can be found in Appendix F.

4.5 Work design

One of Brose's wishes for the layout proposals is to investigate the possibility of rationalizing the parts of the workforce. Although the investigation requires a number of assumptions, hourly demand is derived from yearly demand divided by the total yearly effective working hours. The balancing time span is set to 30 minutes in order to make it manageable. For tasks that do not yet exist, as well as walking, MTM-1 is used. In order to increase the certainty of the calculations a small time margin is applied to most tasks. Furthermore all acceptable balance set-ups should have a time margin of at least one minute per half an hour (the investigated time span). This helps as a precautionary measure for unplanned events such as machine failure and material shortage.

4.5.1 Operator responsible for both rail and sealing machine

One of Brose's identified areas for improvement is the rail process. Since the rail machine only requires periodical handling, unloading/loading and occasional quality controls, there is a potential of better utilizing the operator, see *Figure* ***19***.

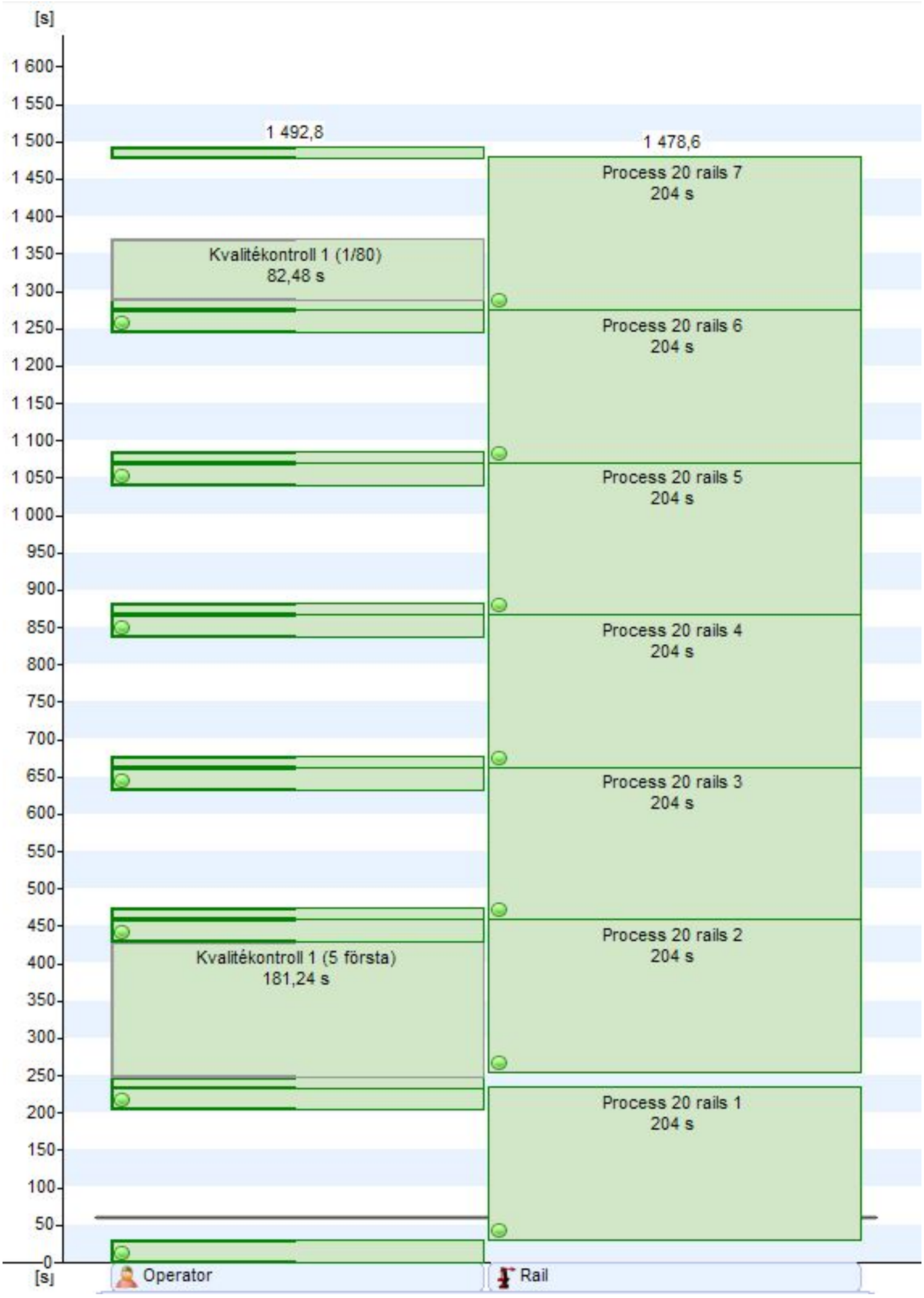

Figure 19. The current state work balance for the rail riveting process.

The idea is to use the same operator for both the sealing and rail process. The plan is to move the railing processes close to the sealing, minimizing the distance, and introducing a loading buffer for the sealing in order to also make the process need periodical handling. This enables the operator to tend both processes, while one machine is processing the operator can load/unload the other.

Several scenarios with varying buffer sizes and distances are tested in order to counter this. They all however share the same result. Due to lengthy and frequent quality controls the machines cannot be properly utilized and the demand is not reached. If the two most time consuming quality control processes of the sealing and rails would coincide there would be almost ten minutes of downtime, see *Figure **20***.

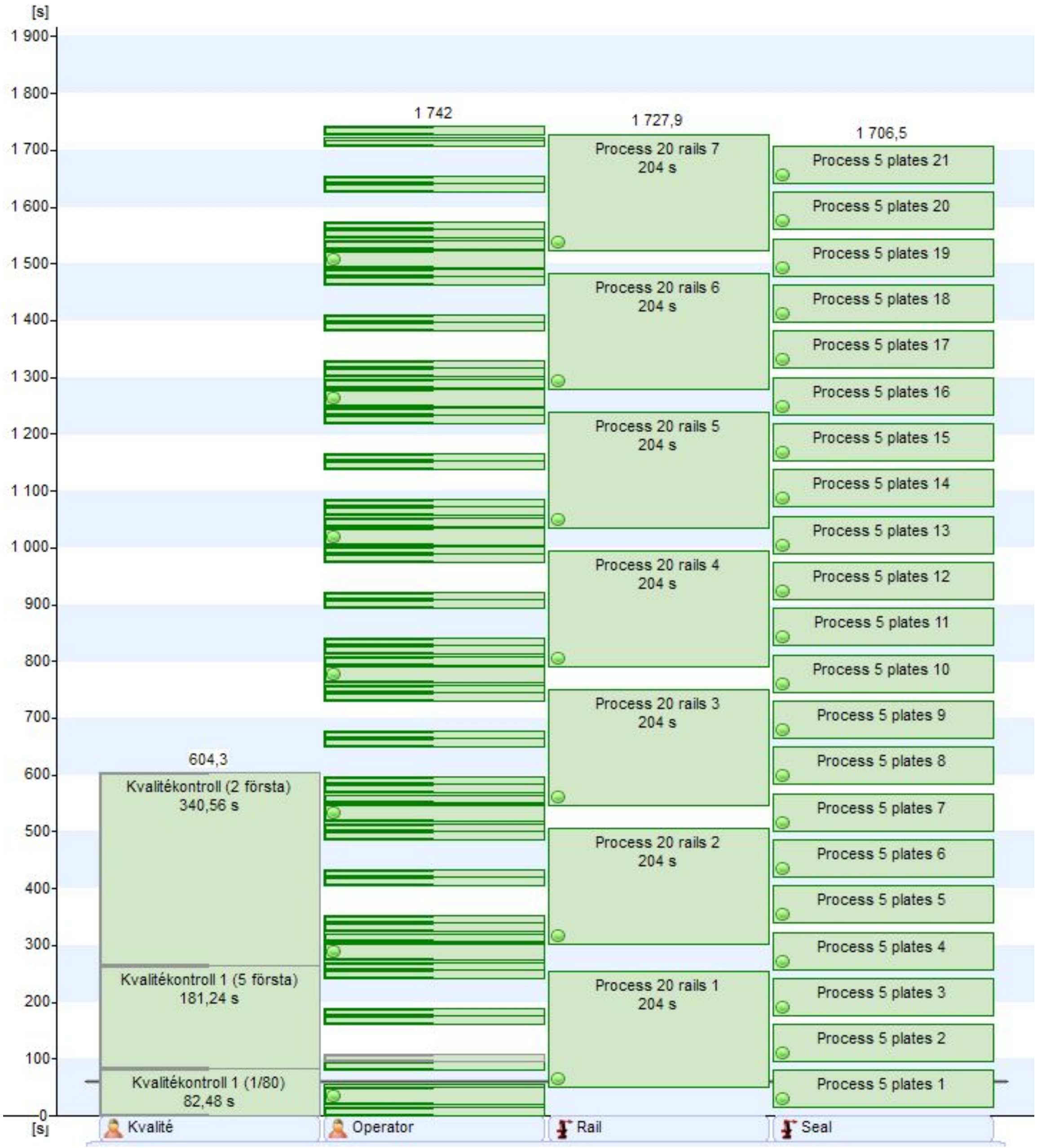

Figure 20. The work balance of one operator for both the rail and the sealing process.

Even if the quality processes could be rationalized such as allocating them to another worker or removing them all together, the scenario would still only barely reach the demand level. In order to realize this idea more extensive automation improvements are needed.

4.5.2 Rail operator supporting cooling fan process

Another attempt at better utilizing the rail operator is to instead support the cooling fan process. See *Figure **21*** for the current state. Two solutions are investigated. The first solution entails using the rail operator as support for operator 2 of the cooling fan in an attempt to even out the workload. The second solution is that the rail operator completely takes over operator 1's tasks at the screw station.

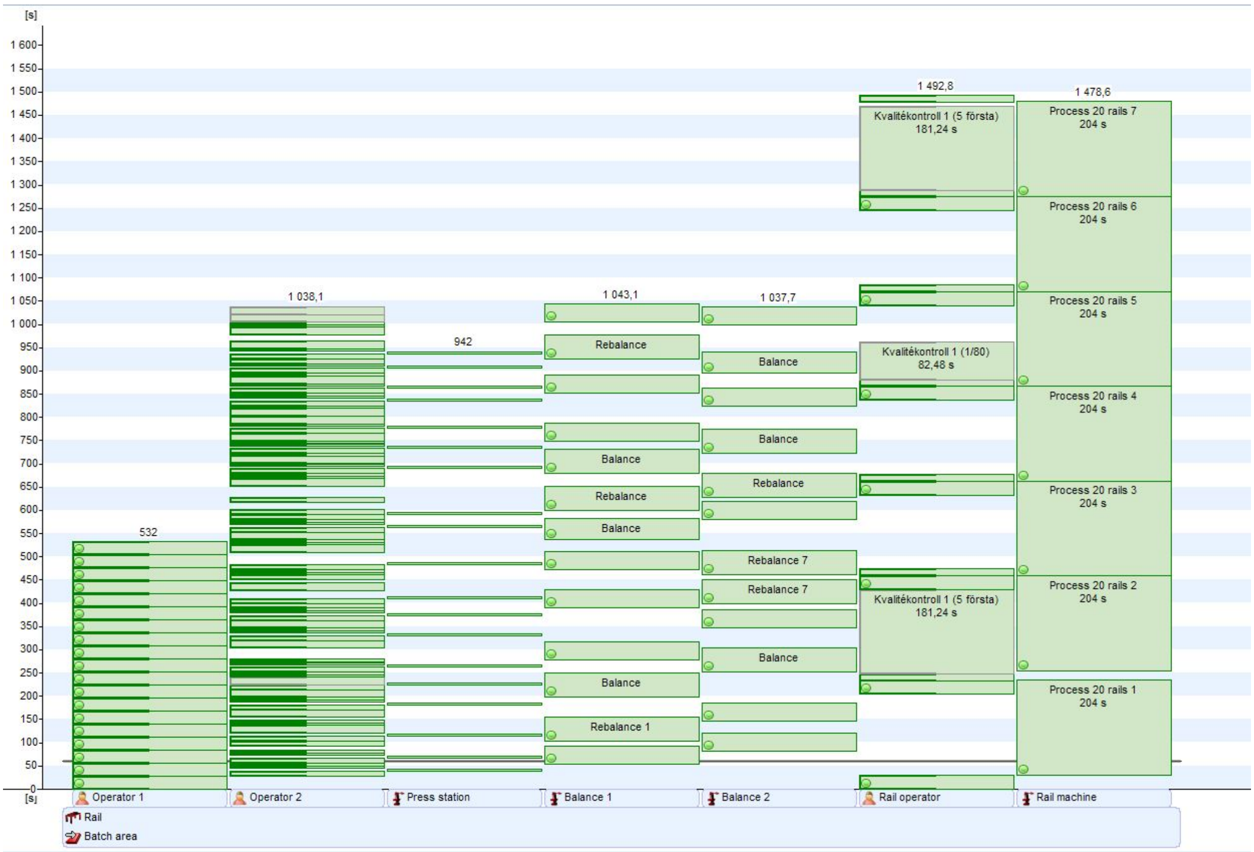

Figure 21. The work balance of the current state cooling fan.

The first solution aims to even out the workload for cooling operator 1 and 2 by letting the rail operator support operator 2. The calculations shows that letting the rail operator support CF operator 2 could potentially increase the output of the cooling fan without affecting the rail process output significantly, see *Figure **22***. The disparity between operator 1 and 2 is still too high however.

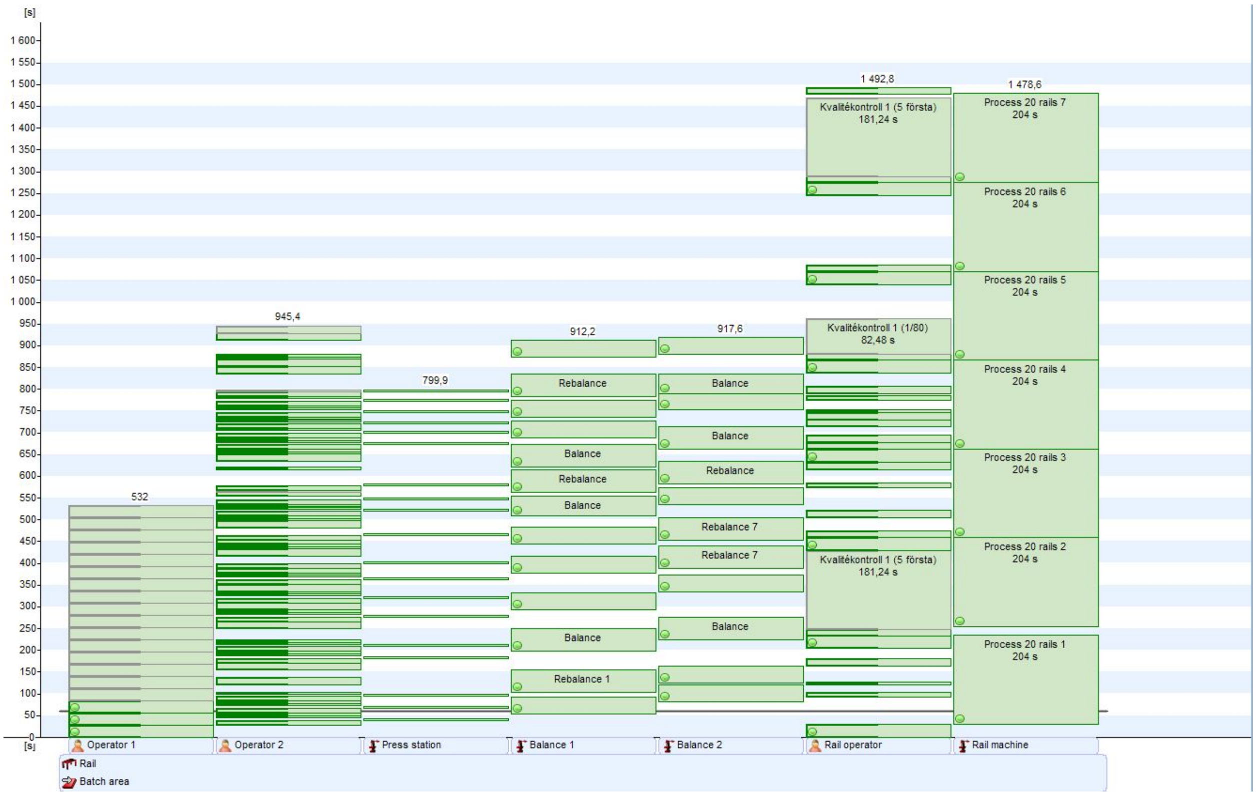

Figure 22. Solution one.

The second solution removes CF operator 1 altogether. Instead the rail operator will manage the screw station. See *Figure **23***, the results show that this is a realistic solution. Demand is met, the operators fewer and the utilization of the operators is significantly higher.

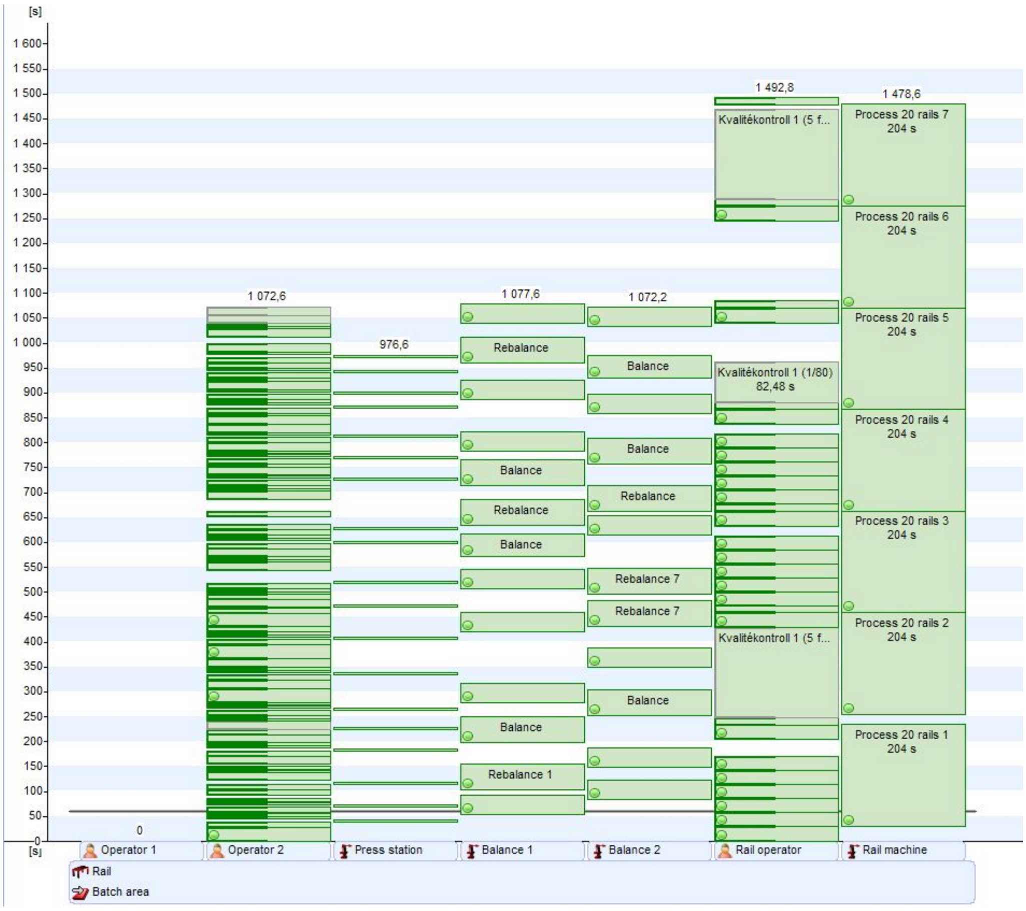

Figure 23. Solution two.

4.6 The layout development

The layout generation was done roughly through five steps. Presented here are the different generations of layouts and their development processes.

4.6.1 Creative generation

The first step in generating layout proposals was the creative process described in section 3.6. These proposals are created with a focus on quantity. Thus many fall outside of specified requirements and can be discarded immediately in an internal screening process.

4.6.2 First generation

The first generation of solutions presented at Brose. These solutions are the ones that pass the internal screening. These six solutions are presented in the form of drawings on a whiteboard and are still in a concept stage. See Appendix G for complete list and description.

4.6.3 Second generation

Out of the 8 solutions of the first generation 5 are deemed insufficient. The 3 solutions that pass are fully drawn in CAD and performance evaluated. The 3 solutions that pass are also updated according to feedback given during the assessment meeting. At this stage closer investigation also shows that the idea of using one operator for the sealing and railing processes is not possible. One further request by the focus group is made, to use the production data for 2018 instead of 2016, since the number of variants will increase by then. See Appendix H for complete list and description of this generation.

4.6.4 Third generation

In the third generation only 2 solutions remain. One of the solutions investigates how the rail process operator can support the CF process with great success. The other solution, which includes no added truck paths, shows flaws. With 2018's production data all variants cannot fit in the designated area. Therefore it is swiftly discarded and a winner emerges. Some feedback is given for a final update. See Appendix I for complete list and description of this generation.

4.6.5 Fourth and final generation

The final layout is the result of four iterations of assessment and feedback. It fulfills the needs and requirements of not only today, but also 2018, see *Figure **24***.

Figure 24. The final layout.

The winning solution captures many of the needs and wishes of the stakeholders. Due to the added truck path the accessibility with truck is significantly improved. The added path allows racks being delivered close to the sealing process, reducing the walking distance for the operator. Even the doubled number of rack variants for 2018 can be delivered close to the process. Furthermore the close placement of the rail and cooling fan processes allow the rail operator to support the cooling fan process, increasing the utilization of the workforce.

4.7 The DSM for production layout improvements

The DSM for layout improvements is made up of four stages. Each stage consists of a number of activities. The improvement process can only proceed to the next stage once the previous one has been properly carried out. The general idea is to fulfill the purpose of the layout development with a concrete solution that is developed through the four stages and the activities that they include. Following sub-chapters give detailed explanations of the stages and the activities that they comprise. The finished DSM can be seen in *Figure **25***.

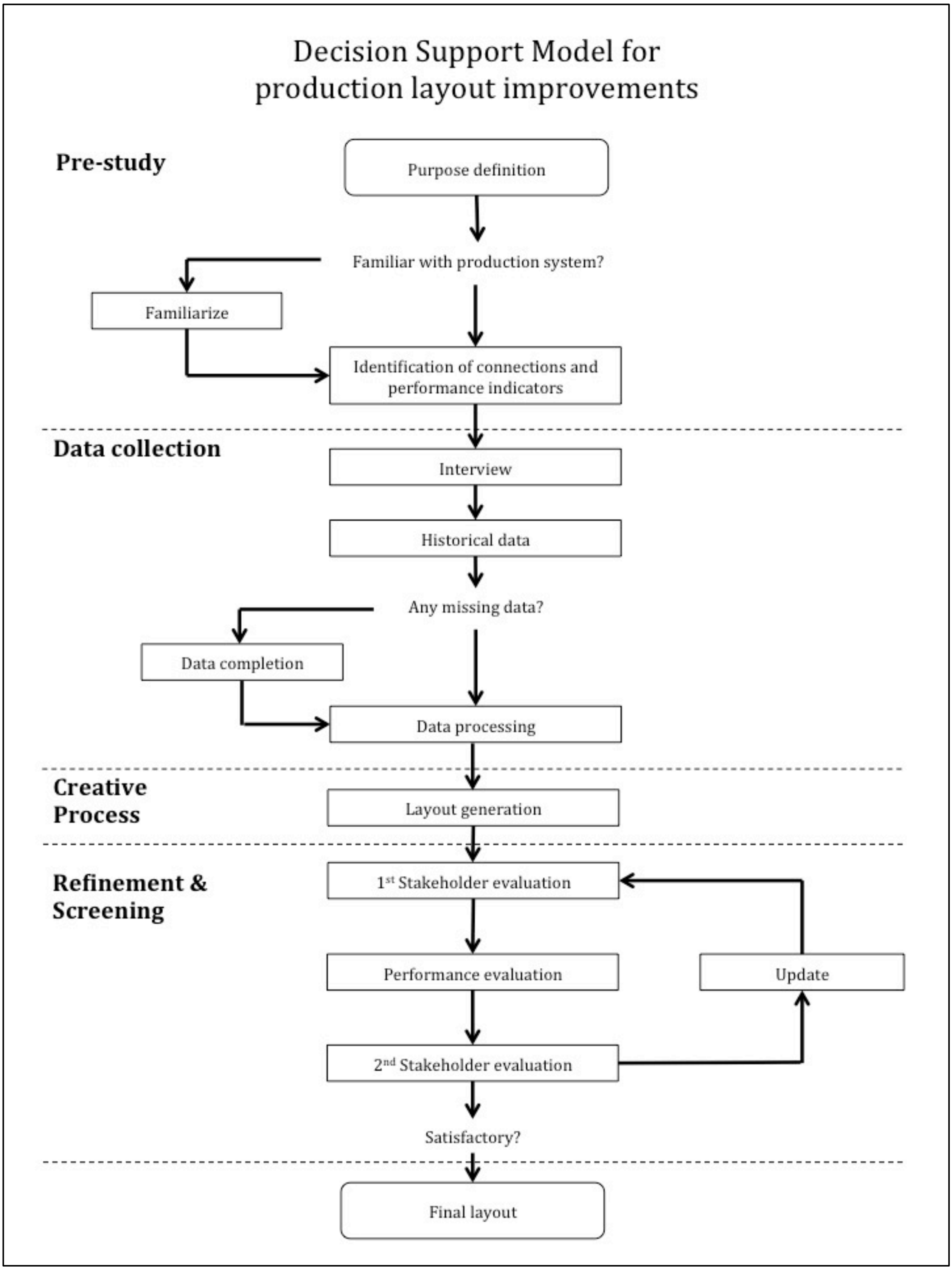

Figure 25. The resulting DSM, which consists of four stages. Each of the stage includes a number of activities. Once all of the stages and their activities have been performed correctly, a final layout is generated.

4.7.1 Components of the DSM

The DSM is a model that is based on a number of previously developed theories in areas that are related to production layout development. *Table **2*** lists the activities of the DSM and their origins.

Table 2. The activities of the DSM and their origins.

Activity	**Origin**
Purpose Definition	Case study
Familiarization	Case study
Identification of Functions and Relevant Parameters	SLP/Case study
Interview	SLP/Case study
Historical data	Case study
Data completion	Case study
Data processing	SLP
Layout generation	SLP/Case study
1st and 2nd stakeholder evaluation	Case study
Performance evaluation	Case study
Adjustment	Case study

4.7.2 Stage 1: Pre-study

The pre-study consists of activities that set up the groundwork and general structure of the improvement process. The expected outcome of the stage is to understand the premise of the process and to attain a general understanding of the production system.

<u>Purpose Definition</u>

The initial activity is to *define the purpose* of the layout improvement. It will provide guidance throughout the improvement process and facilitate any decisions that need to be made along the way. The decisions that are made correctly are the ones that take the process one step closer to fulfilling the purpose of the process. This activity also includes defining any secondary objectives that have an effect on the layout improvement process.

The purpose is defined by answering *what* the goal is, *why* the improvement is needed, and *when* the improvement process is due to be performed. The purpose of the three questions can be found below. The formulated questions were created based on the purpose defining process of the case study.

1. **What is the goal of the improvement?**
   Explicitly states the goal of the improvement. Could be to improve the performance of a certain KPI for example.
2. **Why is the layout improvement needed?**
   Understanding the root cause of the layout improvement, which will help guide the process. Can be used as support for making effective decisions.
3. **When does the improvement process take place?**
   Sets the deadline for the improvement process and determines how much time that is allocated for it. Connected to the "what"-question; a goal that requires extensive work will most likely also require more time.

Familiarization

The case study shows that it helps to be familiar with the production system before any improvement work is performed. It does not involve any deeper analysis, but the goal is rather to attain a general understanding of the system. Therefore, no specific data needs to be collected at this point. The improvement team can get familiarized with the production system simply by observing the production system and its workers, much like in the case study, see section 3.2.2. The need for the familiarization activity is determined through a decision point in the DSM.

Identification of Functions and Relevant Parameters

Once the general elements of the production system are understood it is time to map it. This is done through three steps.

1. Identify the various functions that are affected by the improvement process. This includes objects such as machines, buffers, and recycling bins.
2. Find the connections between the functions in order to see how they are related to each other by observing the material flows between the various functions.
3. Identify the parameters that are related to the functions such as cycle times, buffer replenishment frequency, demand level, various variant data, etc. Note that the parameters are only identified and not measured at this point.

It is possible that all the necessary information cannot be identified during this activity. The missing information can be found later in the data collection stage. The first two steps come from the initial stage of SLP, where functions and their connections are identified. The third step is based on the experiences from the case study.

4.7.3 Stage 2: Data collection

The data collection is where the information and data that the improvement work will be based on are gathered. It includes two to three data collection activities followed by a data processing activity. It also includes data that is needed for fulfilling any secondary objectives. The general idea is to collect information that determines the various relationship strengths of the functions since this is the type of information that the layout generation process primarily will use.

Interview

The first activity of the data collection stage involves conducting interviews on various stakeholders about the production system. The goal is primarily to collect qualitative data such as descriptions of various work tasks or product design information that affects the production. In order to provide guidance for the interviews, three interview topics should be covered. Step one and three were acquired from SLP. The second step comes from the case study.

1. **Stakeholder desires**
   Important to consider, as they will be used for selecting the most appropriate layout later in the layout generation stage.
2. **Product information that concerns the production**
   Highly correlated to the material flow of the components that are included in products. For example, it is important to know the number of components that goes into making the product since all of the material flows will be affected by the improvement process.
3. **Facility requirements.**
   Requirements of the facility that must be taken into consideration, but that the process is not able to change. It can include the placement of fire exits, width of truck paths, and placements of roof-supporting pillars.

The information that is collected through the interviews will indicate what type of quantitative data that is needed for the improvement process. The interviewer should be open-minded when conducting the interview and gather any data that is deemed to be useful for the layout improvement. The interview is therefore preferably done in a *semi-structured* fashion, as it opens up for conversations that enable the interviewer to discuss some topics in detail if it is needed.

Historical data

The collection of historical data primarily concerns quantitative data that can be gathered from various data systems such as an ERP-system. Based on the interview and the identification of important parameters the type of data that is needed should be known. The source for the data can be found through the interview in the previous activity. This activity originates from the case study.

Data completion
The interview and the use of historical data might not provide enough information and data. If this is the case, the data needs to be completed through other means. This activity is not strictly defined as it varies depending on the type of data that is missing. For example, missing information of a machine's processing time could be completed by timing it manually with the use of a stopwatch. The data completion activity is based on the experience of the case study.

Data processing
The final activity of the data collection stage is to process the collected data, which is done through the use of two of the tools that are used in the SLP-method. The tools that are used are the *triangular connection chart* and the *line functional connection diagram*. Instructions for the two tools can be found in section 2.1.1 of this thesis report.

4.7.4 Stage 3: Creative Process

The creative process is where the production layouts are created. The focus is on testing all possible ideas. The layouts are later narrowed down in the refinement and screening stage.

Layout generation
The generation is done similarly to the layout generation process of the SLP-method. The idea is to test various ideas and generate multiple. CAD-softwares are recommended as tools for testing the layouts visually, but simpler ways such as the whiteboard approach of the case study can also be used, see section 3.6. Once all ideas are exhausted, the layouts are brought to the next stage.

4.7.5 Stage 4: Refinement and Screening

The layouts that are generated in the creative process are screened in order to find the most optimal solution. This is done through an iterative refinement process that combines feedback from stakeholders with computational evaluations of the layouts' performances. Multiple iterations are made until a satisfactory layout is generated.

First stakeholder evaluation
The first screening activity involves an open discussion about the layouts together with stakeholders. The layouts are discussed one at a time and each layout is either discarded or kept for further evaluation. Evaluations are done until the layouts have been narrowed down to a few that need further evaluation before a certain decision can be made. The evaluation involving stakeholders is derived from the case study.

Performance evaluation
In order to be able to create a stronger decision basis the remaining layouts from the stakeholder evaluation are evaluated based on their performance. The means of doing it can be through computational flow simulation if the flow of material is in focus. The case study is the origin of the performance evaluation activity.

Second stakeholder evaluation

The consecutive step after the performance evaluation is a second stakeholder evaluation. This is another step of the screening process where the layouts are discussed once again, but by considering the generated performance results of the previous activity. The stakeholders should have more concrete information at this point for making a more educated decision compared to the first stakeholder evaluation activity. For each layout the focus group needs to do one of three things: exclude the layout from further development, choose it as the final layout, or keep it for further development through an iterative process. The DSM in *Figure **25*** shows the iterative process during the refinement and screening stage.

Adjustment

When a winning layout cannot be decided upon the stakeholders identify necessary adjustments. The layouts are then adjusted and aligned with the feedback of the stakeholders before they are once again evaluated, creating a iteration loop. The layouts are iterated until the stakeholders agree on a layout that best fulfills their desires, which is the one that will be implemented into the production. The adjustment activity is derived from the experiences from the case study.

5 Discussion

This chapter of the report covers the discussions of the thesis. It is divided into three sections that discuss the produced results, the used methods, and the thesis' contribution to the field of layout development.

5.1 Results discussion

This section includes discussions of the produced results. The discussed topics are the work design, the quality of the work sampling, the DSM's applicability, and the layout design's impact on work.

5.1.1 Work design

In the current state layout the rail process operator is under-utilized. Through work balancing potential ways of better utilizing the operator was investigated. The discussion of those results can be found here.

One operator for the rail and sealing process

As evident by the balance result in 4.5 Brose's wish of using the same operator for both the sealing and rail process is with Brose's current technology is not achievable. Both processes require frequent attention which long quality controls make impossible. If the need for quality control would coincide for the two processes the production could stop for up to six minutes. Investing in technology is needed in order to realize this idea. It could let the operator focus on the supporting tasks such as quality control, which today is very time consuming. One alternative solution would be to let only one shift work with one operator for the two processes and let the remaining two shifts work at a higher rate, making up for the losses. This scenario needs some further investigation however. As Brose needs to work on a just in time basis with Volvo the demand variation might make this idea null.

Rail operator supporting cooling fan process.

The solution, which gives the rail operator responsibility over the cooling fan screw station shows great promise. Being able to reach the average hourly demand with one less operator per shift is no doubt an expenditure saver. This solution is not however well adjusted to increases in demand as the rail machine already is running close to its capacity.

5.1.2 The quality of the work sampling

The quality of a work sampling is dependent on the number of samples for a task, the workers experience with the task and on which worker who is performing the task. (Lawrence, 2004) In this projects work sample study the number of iterative samples average at around four for each task. It is hard to say whether this is an adequate sample size but the variation between the samples was minimal. A potentially greater source of error is the fact that for most tasks only one operator was sampled. It is important to remember that different levels of experience and physical attributes exist. The variation in task time between workers was found to be greater than the internal variation.

5.1.3 The DSM applicability

As Wu (1997) stated that most production development processes are either approached through a predetermined set of objectives that do not consider previous designs, or approached by improving upon a system already in place. The model developed in this project improves upon an already existing system. A positive effect of this is that it takes into account historical system development processes, thus previously gained experience is not lost. The downside is that it impedes creativity since the development process is solely based on previous work (Wu, 1997). In order to counteract the impeded creativity and to give the layout generation structure SLP as described by Mutter & Wheeler (1977) was applied, which when followed should give a more objective result.

It is hard to comment the resulting DSM's applicability for layouts with no previous design, as no such scenarios have been tried. However according to theory the structure it provides should still make it relevant as a tool. There are of course other considerations that needs to be captured In order to consider the DSM as a tool for general layout improvement. Further development of the model should be based on a larger number of production systems. Basing the decision support model solely on a single system as in this study means that its general applicability ought to be limited. However, the created model in this study lays the groundwork for future studies in decision support models for production layout planning.

5.1.4 Layout design impact on work

The proposed layout for Brose requires less operators than the current. Kamarudin et. al. (2011) found that an increased headcount might be needed to counteract an increased number of variants. Due to more frequent set-ups and other required tasks. The proposed layout for Brose have an increase of variants across all the three investigated processes, as it includes the variant number of 2018, yet it requires a smaller workforce. This can be explained by the characteristics of Brose's production system. While it is true that the number of variants increase the set up process for all three processes is short. For the sealing process the time consuming first quality check might be troublesome, this process is however not affected by the new work balance. As Cohen et al. (2008) brought up the learning curve might be a problem with an increased number of variants. In the case of the proposed layout for Brose the rail operator tends to two processes further complicating. An increase of variants does not have to lead to an increased learning curve. The produced parts require the same type of work no matter which variant. The differences are rather in shape and size. It is therefore the project group's opinion that this is a non-issue.

5.2 Methodology discussion

This section discusses the used methodologies when developing the DSM. The discussed topics regarding the methodology are the effectiveness of the research design, the interview format, the buffer prioritization, SLP, the material flow simulation, and the choice of method for measuring work.

5.2.1 The effectiveness of the research design

The case study methodology was used as a way to structure the approach to the layout problem, but was not followed strictly. For that reason it only needed to provide some guidance for it to be satisfactory for its intended purpose. Its ability to provide the research with guidance was helpful as it helped setting the course of the project throughout its progression.

5.2.2 Interview format

A semi-structured format for conducting interviews was proven to be appropriate due to its time efficiency. Planning the interview and creating the interview guide merely required a few days of work. Additionally, the approach's combination of structure and flexibility was suitable as it helped acquiring specific information about the production processes at the same time as deeper discussions could be done in any of the interview topics. Normally it is sufficient to conduct a structured interview only once if it is semi-structured according to Qu et al. (2011). In the research, the interview enabled the acquisition of most data, but missing data had to be informally collected later through for example e-mail exchanges in order to fill out the missing gaps in the data set. This could potentially have been caused due to the research group's inexperience of development work of this kind. It should be added that an open communication flow with the stakeholders is not negative, but should be done with the purpose of updating them about the development progress and receiving feedback.

Regarding the topics of the interview guide, collecting simulation data through interviews was proven to be an inefficient way since concerned stakeholders do not possess the quantitative data that is sought after. Getting access to relevant data through an ERP system as done in the research was a significantly efficient way of collecting simulation input data.

5.2.3 Buffer prioritization

The buffer prioritization yielded a ranking of the various buffers regarding how often they needed to be tended to by the logistics. Buffers that need to be replenished more often were then placed more easily accessible. The method was supported by Lin & Sharp's (1997) theory about efficient production flow, where "space relationship" (includes accessibility and visibility of material and machines) is one out of the three important criteria for efficient flow.

5.2.4 Systematic Layout Planning (SLP)

This project is inspired by Muther's systematic layout planning (1977). While over half a century old approach it is still relevant today. The strength is in its simplicity. The method is accessible and structured. Step one to three, Clarify the connection, Establish functional demand and Line functional connection offer a structured start of a layout project, a categorization of the functions and their connections.

Step four to six, Draw alternative master plans, Assess the different alternatives, Design the chosen plant solution, is concerned with the generation, evaluation and selection of layout. (Muther & Wheeler, 1977) These steps is where the major development have taken place. Today digital tools help speed up the process. CAD programs allow redrawing of a layout in minutes. A model of a machine can simply be dragged in the layout rather than redrawn by hand as was needed before the digitalization. The methods of evaluation have also greatly developed. Today complex models can be simulated relatively quickly. Material flow and work design which was investigated in this project is only two of many possible simulations.

The accuracy of the simulations is dependent on the quality of the data input. Furthermore the data needs to be quantitative, putting emphasis on the data gathering and conversion of qualitative data into quantitative.

SLP describes an evaluation of applicability through subjective measures. Selected layout weighted criteria are valued according to the scale absolutely perfect, (A=4), efficient solution (E=3), interesting solution (I=2), ordinary solution (O=1), unimportant (U=0), unwanted (X=-). The appropriateness of the solution is gained by multiplying the criteria weight with the layout proposals solution for said criteria (Muther & Wheeler, 1977). Evaluating by estimation brings certain problems. As Lawrence (2004) states, estimations risk bringing problems such as the creation of bottlenecks. Furthermore making an estimation based on historical data makes the result prone to Parkinson's Law, which states that the amount of time required to complete a task is directly proportional to the time available. Which implies that the standard time increases or decreases based on the amount of available time. (Lawrence, 2004)

In the project there was also an emphasis on iterative evaluation and correction, trying to balance the wishes and demands of the stakeholders. SLP is a great tool for generating ideas but lacks in refining ideas. Step one to four in SLP is for developing a large number of ideas. Step five and six is selecting which idea should be realized. (Muther & Wheeler, 1977) As mentioned in the method chapter we had four iterating evaluation steps with improvements of the layouts at each step.

5.2.5 Material flow simulation

The material flow was evaluated for the logistics flow and the production flow. The material flow was evaluated through flow simulations using the software Flow Planner. Its effectiveness as an evaluation tool was satisfactory for its intended purpose in the research. Only simple simulations with a low level of detail were needed since the generated data was only used for comparing the material flow performance of the current layout with the material flow of the various generated layouts. The simulation's ability to mirror the real material flow's performance was therefore of lesser importance. The results that it was able to produce gave an indication of the flow performance of the different layouts, proving that material flow is indeed an effective parameter for assessing the production flow as stated by Lin & Sharp's (1997).

5.2.6 Choice of method for measuring work

As stated in theory according to Lawrence (2004) there are three ways of measuring work. Direct observation, estimation and standard data. The approach in this project was a hybrid of direct observation and standard data, namely a video recorded time/work study and MTM-1.

Using estimation as a way to measure the work was quickly ruled out. The flaws of using estimation are many. Problems like bottlenecks are often formed as a result of estimation. (Lawrence, 2004) If the estimation is made with historical data as basis the result is also prone to Parkinson's Law (Lawrence, 2004). The idea was to use work sampling for mapping the operator's tasks when possible. Tasks which did not yet exist were constructed by MTM-1. The operator's movement in the layout was also approximated with MTM-1. Few processes were also timed by stopwatch.

The work sampling was done mainly through video recording, even though stopwatch techniques are faster and require less analysis, thus allowing for more iterations. (Lawrence, 2004) The choice of using video recordings despite this is because it captures much more information, such as ergonomics. It is also possible to post-recording analyze the video for something that was missed during preparation. A further argument for video recordings is that AviX support frame by frame analysis, perfectly timing tasks (Solme AB, 2015). MTM-1 was selected due to previous experience of using the method. At Chalmers there are also certified MTM practitioners, which could support the project if any problems would arise. MTM-2 and -3 was ruled out because of their more basic nature. (Lawrence, 2004)

5.3 Contribution to the field

Previous research indicates that production layout development can yield potential savings of great magnitude (Drira et al., 2007). The most widely accepted method for supporting a development process is Muther and Wheeler's (1997) SLP-method. It is referenced often in the literature, which indicates that the method is widely accepted. It was however created decades ago and has not been updated ever since. The DSM uses the core parts of the SLP and further incorporates contemporary tools such as various computational simulations. Furthermore, the DSM developed in this research seeks to provide a more complete model that supports the whole development process. For example, SLP assumes that the user already possesses information that is necessary for assessing the relationship strengths of the various functions. The DSM guides the user through the data collecting activities that take place prior to assessment.

6 Conclusion

This is the final chapter of the report and it summarizes the findings of the performed study. The research sought to answer two research questions that were stated at the beginning of the research. These questions are answered in this chapter. The two questions are followed by a final section that includes suggestions for future work within the field of layout development.

RQ1: How is a production layout optimized?

It was found that a production layout could be optimized through using a structured approach, as proved by the projects resulting DSM. An optimization generally starts with a thorough preparation. The production system, which is to be developed needs to be understood. Why does a new layout need to be developed? What potential areas of improvements exist? Stating the purpose serves as an initial activity can help make the right decisions later. Following the purpose a benchmarking of the current layout will help define the current state. For this the data needs to be gathered. The data should reflect the production system's performance as well as the desires of the stakeholders. The Benchmarking should with benefit be done with the same evaluation tools intended for the new layout proposals. When the current state is defined a creative process of generating layout proposals can start. It can be a good idea to focus on quantity over quality at first. Through an iterative process of evaluation, filtering and refinement these layouts can be developed until a (or several) winner emerges.

How was Brose's production layout optimized?

Brose's layout was optimized in a way much like the DSM describes. In addition there was a focus on work design and how to better utilize the operators, the case's "special objective".

How can the utilization of processes be maximized with regards to production layout?

A way of maximizing the utilization of processes with regards to production layouts can be to minimize distances. Not only can it decrease the time spent on non-value adding tasks such as walking it also allows cross-process support. As in the case of Brose where the rail operator could support the cooling fan process so that one less operator was needed for the process.

RQ2: What should be included in a DSM for layout development?

The goal of the DSM was to support the layout development process from start to finish. That is, from an initial purpose statement of the improvement to the implementation of a final layout. The content of the DSM are the steps that turn the purpose statement into a tangible production layout. The developed model involves four consecutive stages.

1. Pre-study
2. Data collection
3. Creative process
4. Refinement

Each stage is made up of a number of activities. Explanations are given for each activity in order to create a tangible output that is needed when performing the subsequent activity. In addition, there are optional activities that are performed if the collected data is not sufficient. These can be found in the pre-study stage and in the data collection stage. A so called decision point is used for checking if the collected information is sufficient or not. If not, the user must perform the optional activities to fill out the information gaps. Once the user has performed all of the stages and their attached activities properly a satisfactory layout is generated.

How are the essential parameters with regards to production layout identified?
The way that important parameters were identified was by observing the purpose of the layout development. A simplified approach is to consider all parameters that are affected or affecting the purpose as relevant parameters. For example, if the purpose is to minimize the lead time then transportation distance is a parameter that should be considered essential.

Which methods can be included in a DSM for layout improvements?
The method that the DSM is based on is Muther & Wheeler's (1977) SLP-method. This is mainly since its intended purpose is the same as for the DSM, making it easily compatible. The various steps of the SLP were analyzed and the methods that could either enhance the existing steps or expand the method were included. Examples of enhancing methods is simulations and a method that expands the model are interviews.

How is a layout developed in a structured manner?
A layout can be developed in a structured manner by basing it on a pre-developed method. The method ensures that the necessary steps are taken and that no important considerations are left out. Another important aspect of structured work is to establish the core of the development properly during its initial stages. The "what", "why", and "when" questions in the purpose definition stage of the DSM were created for this purpose. All of the development activities throughout the project should be answered using the purpose statement. This will help guide the work and provide structure throughout the development work.

Further work suggestion

This section includes suggestions of future studies within the field of production layout development.

I. For the case at Brose

One initial wish of Brose was to investigate the possibility of using the same operator for both the rail and sealing process. Due to machines needing regular attendance and lengthy quality checks this was not possible. What can be done to possibly make it reality?

Lengthy quality controls

Do they need to be so lengthy? Could it be possible to shorten the processes? Most of the controls involve several samples, would it be acceptable to decrease the sample size and instead make more frequent controls? From a work balance perspective these are interesting questions. Whether it is possible or not unfortunately falls outside the scope of this project. But the topic could be interesting for further studies.

Possibilities for increased automation

Another way of solving the work balancing issues could be to automate the processes further. A pick and place robot for the railing processes could decrease the need for operator attendance drastically. Finding a way to automate the loading process of the sealing process is also an interesting topic. A solution where the plate rack is directly unloaded by a robot could benefit the work balancing of the operator greatly. Increasing the automation level could make it possible to keep the current level of quality control and use one operator for both processes.

II. Regarding further development of the DSM.

As of now the DSM has only been tried for one production system. In order to confirm its usefulness the priority should be applying it to other layout development cases. All cases are of interest but those which lack any previous design are of special interest, the DSM is meant as a general tool for layout development in factories. Facilities of varying sizes are also of interest. Brose is a medium sized production facility, if the DSM is fit for larger facilities remains to be tested.

Another interesting topic to investigate is the so called “special objective” of the DSM. Depending on the situation the stakeholders might have special requirements which require an investigation that is outside of conventional layout work. The Brose case involved work design and how operators can support each other across processes. How will other special objectives interact with the DSM? Some objective might even be beneficial to make permanent.

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APPENDIX

Appendix A

Interview results

Unanswered questions due to interviewees inability to answer is either marked with a dash-symbol (“-”) or completely excluded if none of the interviewees could give an answer.

<u>SLP answers</u>

Interview results of the production manager and the supply chain manager regarding SLP. Answers from either of the managers that are not considered in the layout development are listed in the column to the far right.

	Production manager	Supply chain manager	Not considered in the layout development (excluded)
Functions needed to be kept near each other	material, machine	material, machine	Truck charging station needs access to electric output and water
Structural requirements of factory	Few restrictions. emergency exits easily accessible. pillars, meeting corner and sealing machine are fixed. No restrictions for electric supply, ventilation, and open space.	two-way truck paths: 3,6 m wide, one-way truck paths: 2,7 m wide, emergency exits easily accessible, 0,8 m open space in front of electrical cabinets. Pillars are fixed. meeting corner preferably centrally located. No restrictions for electric supply and ventilation.	-
Expectations of the layout development	higher operator utilization, optimized material flow	optimized material flow for an increased amount of product variants, optimized assembly times, decoupling of production and logistics	-
Miscellaneous answers	-	production areas preferably accessible from multiple sides for logistics	-

Interview results of the operators regarding SLP.

	Operator
Functions needed to be kept near each other	material, machine, motor buffer in CF

Manufacturing process answers

Interview results of the production manager and the supply chain manager regarding the manufacturing processes. Answers from either of the managers that are not considered in the layout development are listed in the column to the far right.

	Production manager	**Supply chain manager**	**Not considered in the layout development (excluded)**
Buffer placement	Can be placed freely, but within the new production area.	Can be placed freely	More visual aids
Alternative means for transportation	If it results in savings	Does not result in any significant savings	-
Set-up times	-	Insignificant	-
Miscellaneous answers	Sealing plates might be fed in ten pieces at a time in future	-	An additional balancing machine will be installed in the future. Not considered due to uncertainty of the investment

Interview results of the operators and the logistics deoartment regarding the manufacturing processes. Answers from either of the workers that are not considered in the layout development are listed in the column to the far right.

	Operators	**Logistics**	**Not considered in the layout development (excluded)**
Eventual improvement areas	work area around sealing is cluttered, clearness of work space, place motors near assembly station of CF	bigger margins for trucks to turn	unergonomic loading/unloading of racks in sealing, hard to transport racks, fewer unbalanced fans, shorter cycle times of balancing machines in CF, unergonomic to pick cardboard boards, more and clearer floor markings
Work pace	good pace when there are no problems in sealing, stressful when working alone in CF, good pace in railing due to the long cycle time of the machine	requires experience of the production system before a reasonable work pace is achieve	-
Miscellaneous answers	path widths of sealing are good,	-	-

Appendix B

Variant data from ERP system

<u>Rail riveting</u>

Data on the demand of the rail variants.

Rail variant	**Demand 2018 (qty/variant/week)**	**Relative demand**
1-22	1 500	5% per variant

<u>Sealing</u>

Data on the demand of the plate variants.

Plate variant	**Demand 2018 (qty/variant/week)**	**Relative demand**
1-16	1 500	6,25 % per variant

Cooling fans

Data on the demand of the four CF variants.

CF variant	Demand 2018 (qty/week)	Relative demand
1	200	5%
2	2 100	52%
3	1 200	30%
4	540	13%

Data on the demand of the four motor variants.

CF variant	Motor variant	Motor demand 2018 (qty/week)	Relative demand of motors
1	1	200	5%
2	2	2 100	52%
3	3	1 200	30%
4	4	540	13%

Data on the demand of the two shroud variants.

CF variant	Shroud variant	Shroud demand 2018 (qty/week)	Relative demand
1	1	2 300	57%
2			
3	2	1 740	43%
4			

Data on the demand of fans.

CF variant	Fan variant	Fan demand 2018 (qty/week)	Relative demand
1	1	4 040	100%
2			
3			
4			

Appendix C

Buffer prioritization

Rail riveting

	Demand (pcs/hr)	Container capacity (pcs/container)	Required time to empty/fill a container (h)	No. of containers in buffer (pcs)	Required time for emptying/replenishing the buffer (h)

Rails	303,45	40	0,13	5	0,66
Rivets	606,90	40 000	65,91	4	263,64
Pulleys	606,90	40 000	65,91	4	263,64

Plate sealing

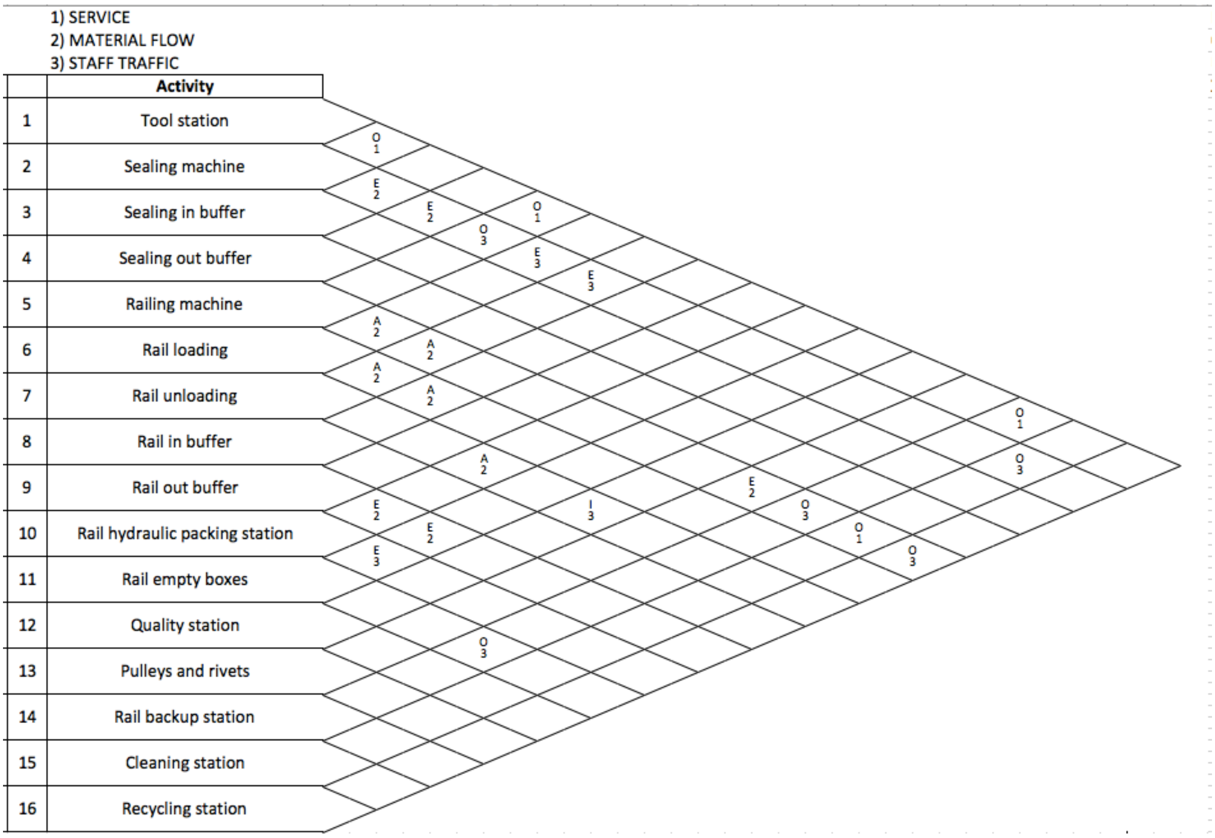
	Demand (pcs/hr)	**Container capacity (pcs/container)**	**Required time to empty/fill a container (h)**	**No. of containers in buffer (pcs)**	**Required time for emptying/replenishing the buffer (h)**
Incoming plates	220,69	132	0,60	1	0,60
Outgoing plates	220,69	132	0,60	5	2,99

Cooling fan

	Demand (pcs/hr)	Container capacity (pcs/container)	Required time to empty/fill a container (h)	No. of containers in buffer (pcs)	Required time for emptying/replenishing buffer (h)
Motors	37,15	180	4,85	1	4,85
Shrouds	37,15	22	0,59	3	1,78
Fans	37,15	60	1,62	2	3,23
Large cardboard boards	2,06	100	48,45	1	48,45
Small cardboard boards	19,26	560	29,07	1	29,07
Empty CF containers	0,69	1	1,45	2	2,91
Finished CFs	37,15	54	1,45	1	1,45

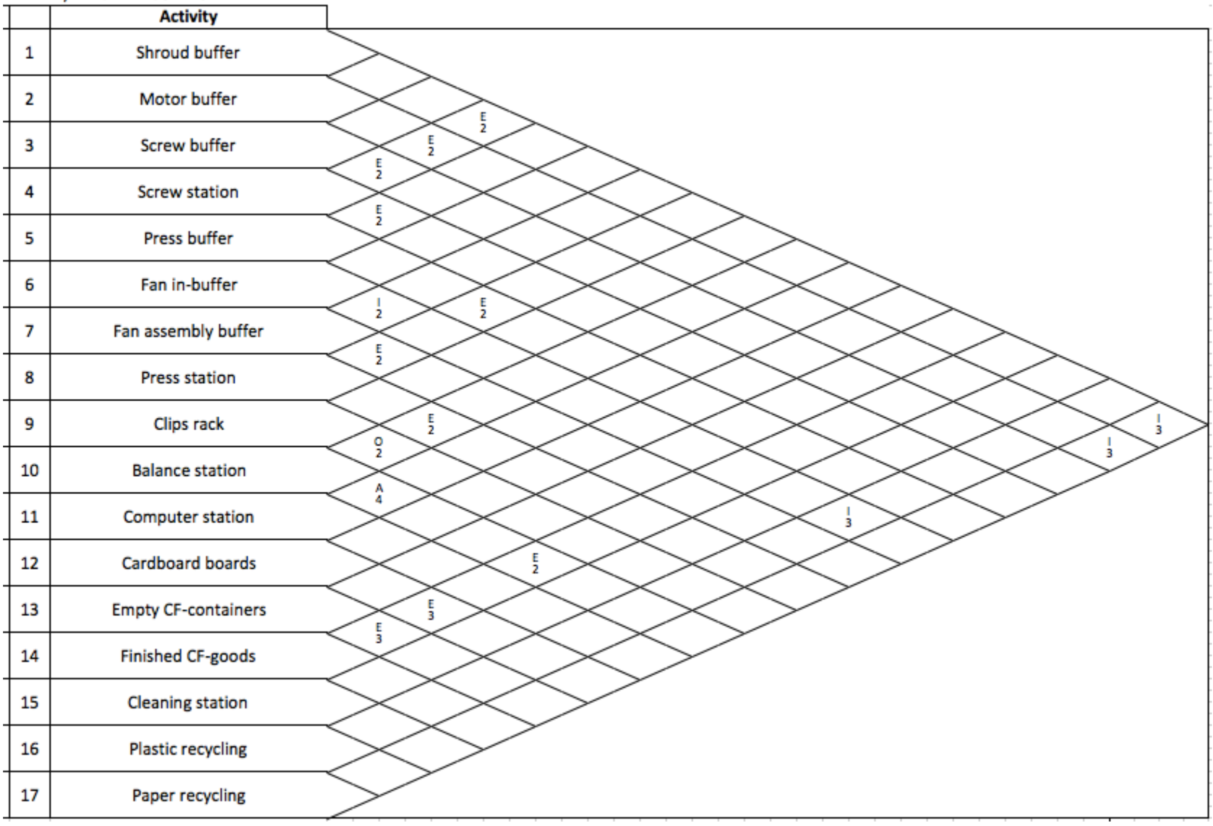
Appendix D
Muther triangle chart

Railing and Sealing process



Cooling Fan

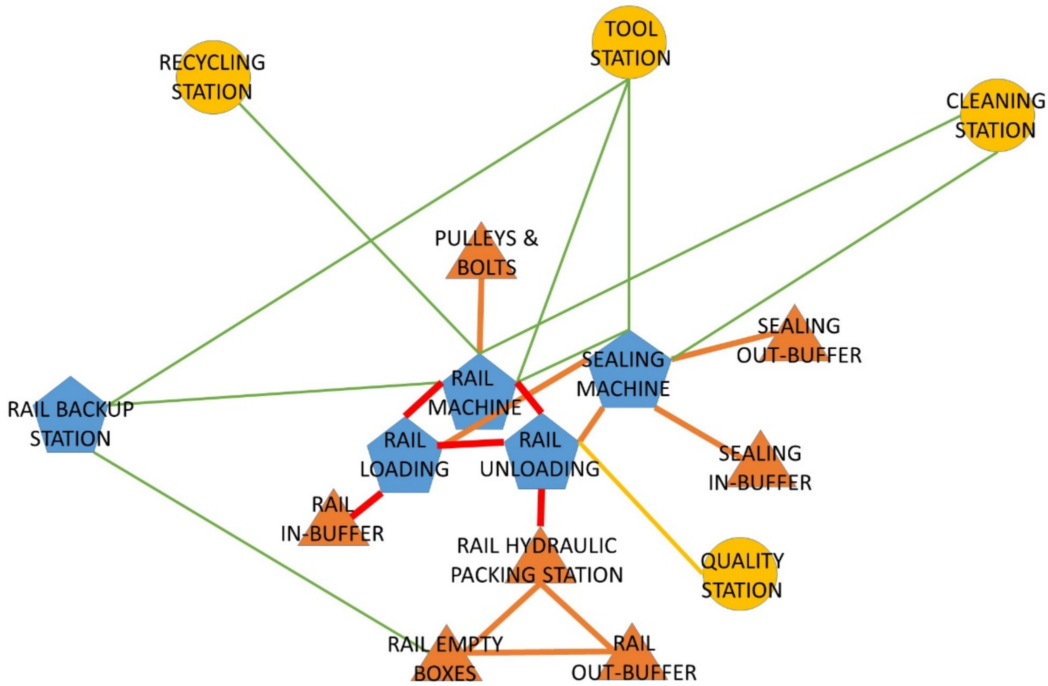
1) SERVICE
2) MATERIAL FLOW
3) STAFF TRAFFIC
4) MACHINE COMPUTER



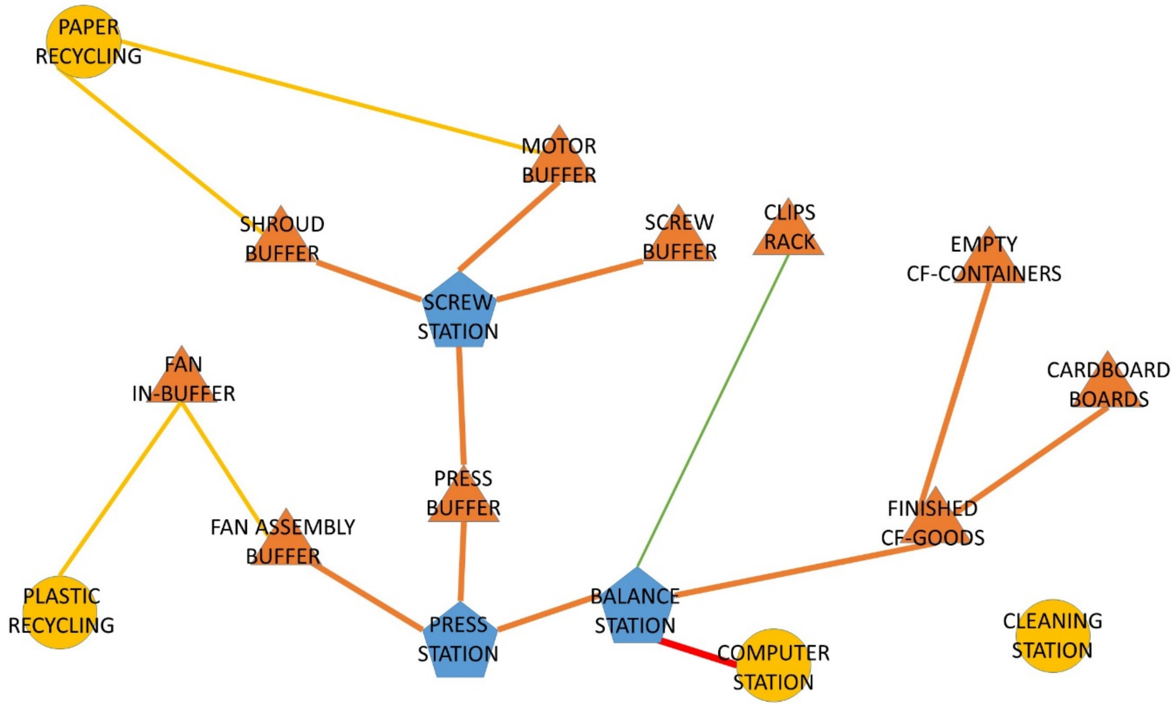
Appendix E

Line functional connection

<u>Riveting and Sealing process</u>



Cooling fan


PAPER RECYCLING
MOTOR BUFFER
SHROUD BUFFER
SCREW BUFFER
CLIPS RACK
EMPTY CF-CONTAINERS
SCREW STATION
FAN IN-BUFFER
CARDBOARD BOARDS
PRESS BUFFER
FINISHED CF-GOODS
FAN ASSEMBLY BUFFER
PLASTIC RECYCLING
BALANCE STATION
PRESS STATION
COMPUTER STATION
CLEANING STATION

Appendix F

Transportation times

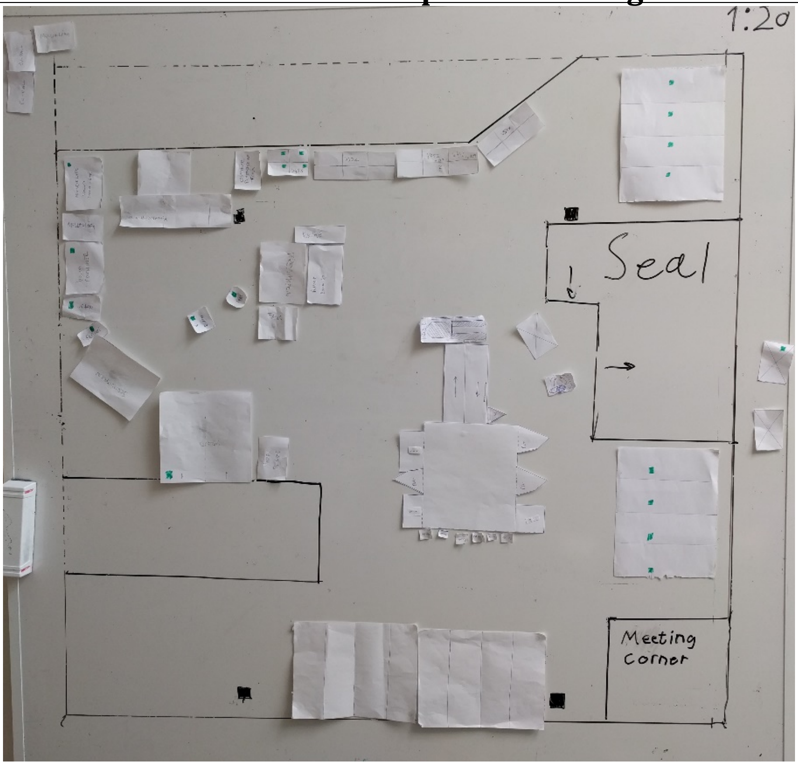
	AvgTripTime (Mins)			
Paths	Current	Layout 1	Layout 2	Layout 3
STORAGE_PLATES+BUFFER_SEALING	0.77	0,78	0,74	0,66
SEALING_OUT+ASSYLINE	0.46	0,47	0,47	0,47
STORAGE_RAILING+MACHINE_RAILING_IN	0.47	0,6	0,53	0,47
RAILING_OUT+ASSYLINE	0.53	0,64	0,53	0,6
STORAGE_MOTOR+BUFFER_MOTOR	0.39	0,43	0,4	0,52
STORAGE_FAN+BUFFER_FAN	0.44	0,4	0,43	0,61
STORAGE_SHROUD+BUFFER_SHROUD	0.53	0,51	0,46	0,43
CF_OUT+STORAGE_CF	0.37	0,57	0,48	0,52

Appendix G

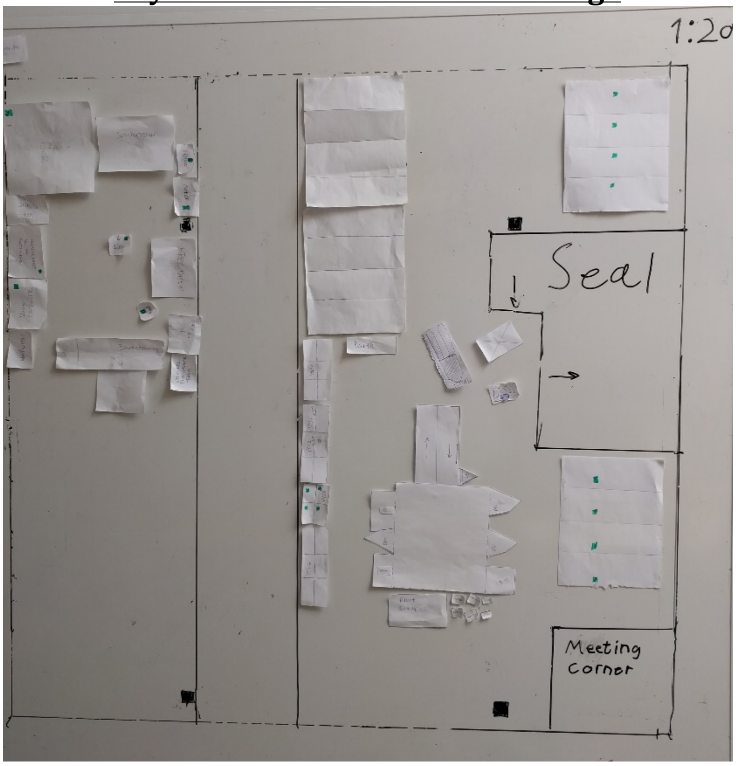
First generation and screening

The first generation of layouts. Here the focus was on quantity. The layouts were drawn in scale on a whiteboard. These layouts passed the requirements and were thus presented. See below for the first generation layouts which were presented at Brose.

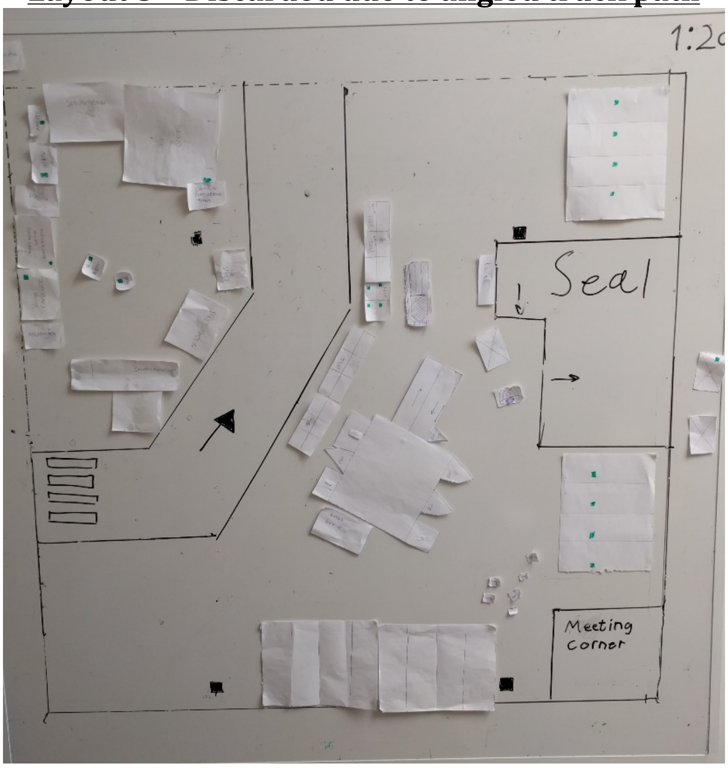
Layout 1 – Discarded due to unoptimized useage of floor area



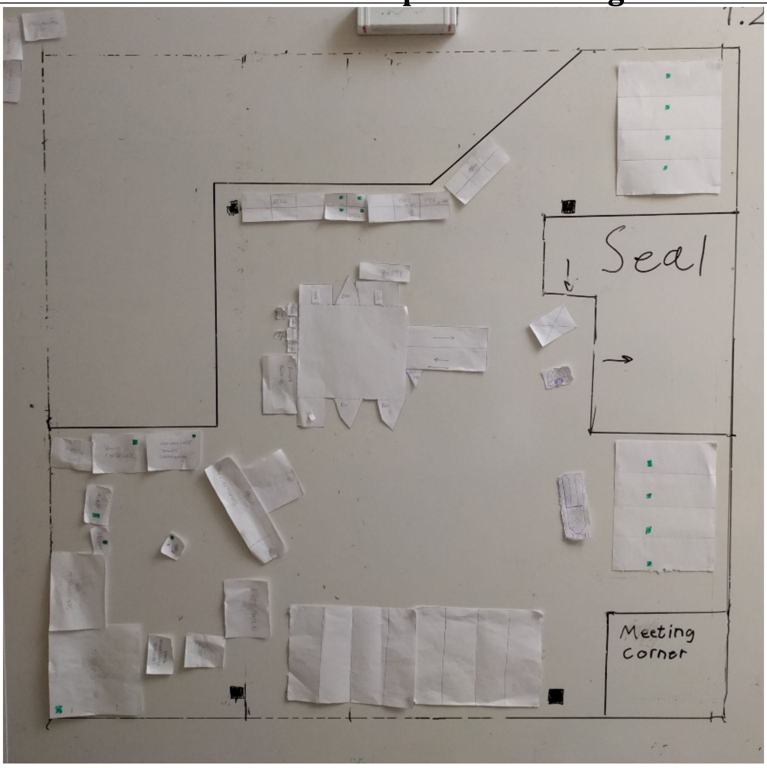
Layout 3 – Passed to the next stage



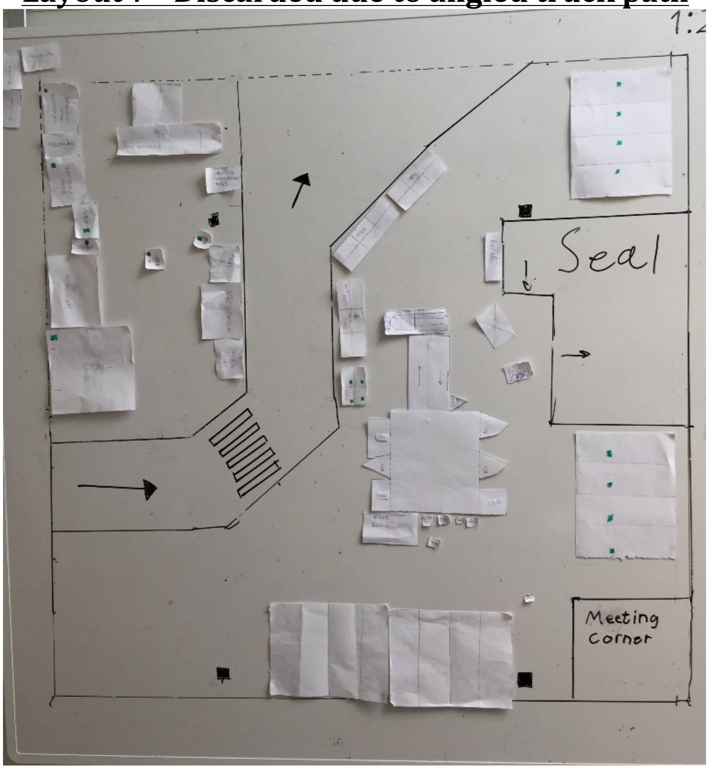
Layout 5 – Discarded due to angled truck path



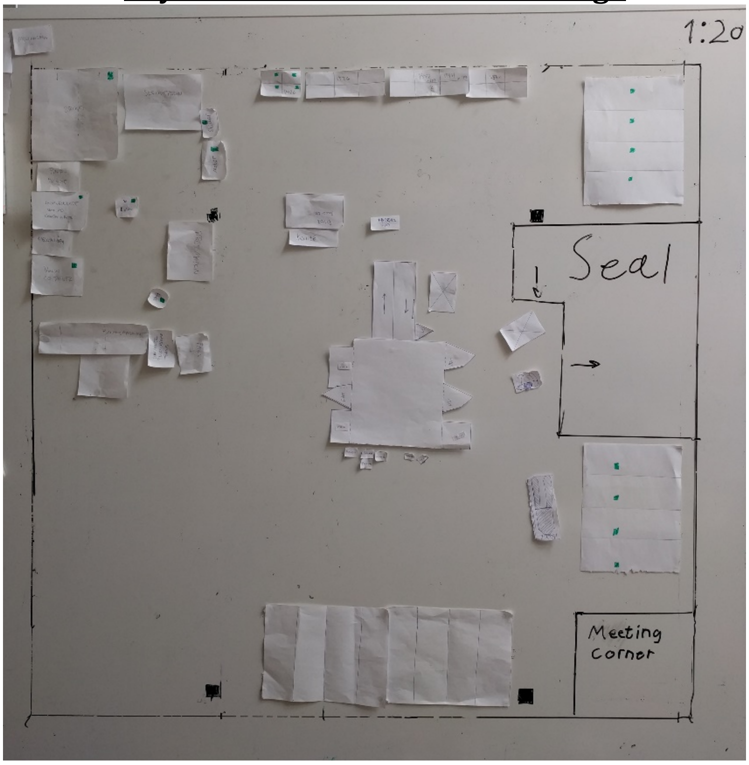
Layout 6 - Discarded due to unoptimized useage of floor area



Layout 7 - Discarded due to angled truck path



Layout 8 - Passed to the next stage



Appendix H

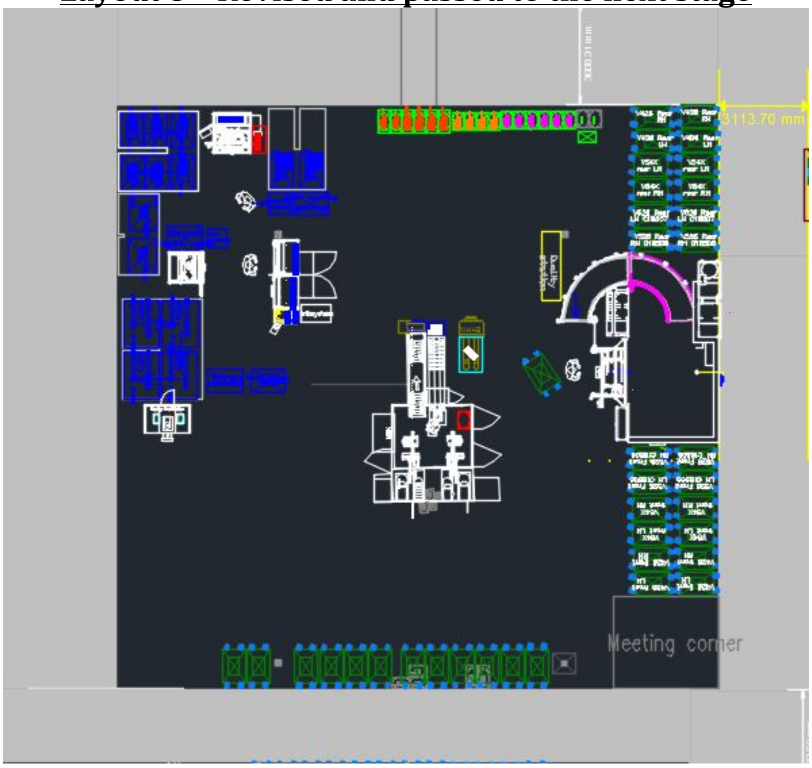
Second generation and screening

The second generation was completely drawn in AutoCad and included all current objects. In order to give more basis for evaluation the layouts were also performance measured through material flow simulation in Flow Planner and the work balance was checked in AviX.

Layout 3 – Discarded due to bad work balance

Reinvented layout 3 – Passed to the next stage

Layout 8 – Revised and passed to the next stage

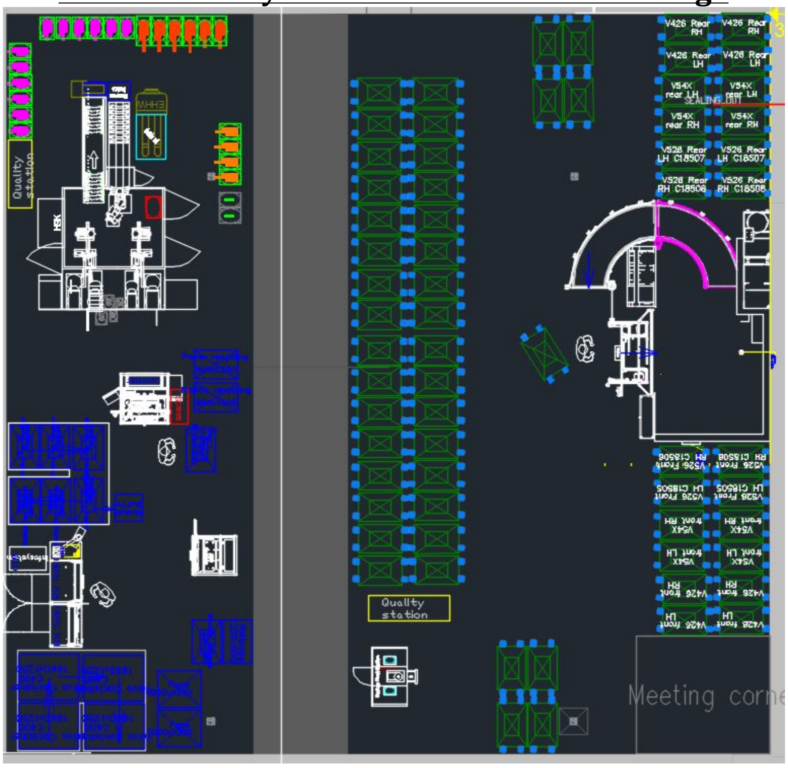


Appendix I

Third generation and screening

This is the last of the screening processes. Here the variant data of 2018 was added. Therefore there is a significant increase in objects in the layout. These solutions were just as generation two performance measured.

<u>Reinvented layout 3 - Passed to the next stage</u>



Revised layout 8 – Discarded due to lack of space for 2018 variant levels