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Improving production capacity at ElectroHeat Sweden AB by utilizing existing resources

Master's thesis in Production Engineering

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Abstract

The purpose of this master's thesis is to investigate how the capacity can be improved at ElectroHeat Sweden AB, a small family firm producing industrial oven solutions. The project followed an adaptation of the methods engineering approach. Through work sampling studies of the utilization of the oven builders and machines at the company, combined with qualitative data an analysis of the current state was performed. The results from this analysis was used to identify issues and develop improvement suggestions. These improvement suggestions focus on three areas; the organization at the company, the layout of the facility and the planning function. An implementation plan was developed to support the company in implementing the improvements based on a literature study. All improvements should help the company reach their goal of 20% increased turnover in three years. The results of this study was well received when presented at the company, that already had started the implementation process of some of the earlier ideas.

Keywords: Productivity, capacity, work sampling, family firm, implementation.

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1
Introduction

This chapter introduces the master's thesis, providing a brief background of ElectroHeat Sweden AB's business and the motivation for the thesis. The purpose, objectives and delimitations are also presented.

1.1 Background

ElectroHeat Sweden AB, henceforth known as the company, is a small family firm of approximately 25 employees offering industrial ovens and equipment for heat treatment for industrial companies across the world. They base their operations in Gothenburg where they produce the customized products. The company also has an additional facility situated outside Gothenburg. Throughout the years the company has grown and are now at the point where there is a need to produce more efficiently as they aim to increase turnover by 20% in three years.

The products produced are large, customized industrial ovens with accessories as needed to fit the customer's need. For example the company will arrange for an industrial robot to cooperate with the oven or a conveyor belt to transport material in and out of the oven. The company also produces other smaller heat treatment products. The company's main competitive factors are high quality and quick deliveries combined with a high product flexibility. Three oven types produced by the company is shown in figure 1.1.

(a) A chamber oven **(b)** An oven installation **(c)** A conveyor oven

Figure 1.1: Examples of products

As the company has grown without adapting their production they no longer feel that their current main production facility is sufficiently large. However, the company does not have the turnover required to invest in a new facility. Due to an experienced lack of space in the main production facility combined with the aim of further growth the company needs to improve their capacity in the current facility.

1.2 Purpose and objective

The purpose of this master's thesis is to analyze and improve the company's capacity through analysing the current state of the company and identify improvement potential. The solutions shall not only improve the company's capacity but also help them achieve long term success. Capacity can be improved by either increasing the resources, such as work-hours, or improving productivity, for example by increasing the resource utilization. In order for the company to grow without investing in a new facility, the productivity must improve since the facility isn't large enough to support more resources. There are many tools and theories which can aid in increasing productivity, such as manufacturing planning, material and production flow, workshop and visual control. Improvements always comes with a change that requires management to be succesful. To sustain the improvements and further improve the company, organizational management is required.

Factoring in the background and purpose the following research question is proposed:

- How can the company's capacity be improved?

1.3 Delimitations

The scope of this master's thesis is focused on the production of the customized industrial ovens, except operations performed in the laser cutter, the production of fan inserts and the cabling station. Other internal processes will not be investigated in particular. The individual performance rates of the workers are excluded from this thesis as they are expected to vary heavily depending on which work is done. The weekly cleaning performed every Friday afternoon is excluded from the study due to being so different from the rest of the production. Due to a large product variation the thesis will not include any studies on product level, as the effect of these would be minor unless the product is produced in larger scale.

2

Frame of reference

The following chapter presents the frame of reference used in this master's thesis. In order for the authors to make the best of this opportunity, a literature study was conducted to deepen the authors' knowledge. The most important subjects from this study are described here.

2.1 Capacity & productivity

Capacity
Zandin (2001) defines capacity as "The maximum amount of customer demand that can be satisfied over a certain period of time". Capacity can be adapted through for example changes in personnel or technology (Bellgran and Säfsten, 2010). It is also affected by productivity, as changes to the utilization of the resources also affect the capacity.

Productivity
Zandin (2001) defines the concept of productivity as the relationship between output, such as goods produced, related to the quantity of input, such as labor or capital (equation 2.1).

$$Productivity = \frac{Output}{Input} \tag{2.1}$$

Measuring productivity
One problem according to Bellgran and Säfsten (2010) is how to define the input and output. This problem is commonly solved by using time as both input and output, as it is easy to both measure and understand and facilitates comparisons between both plants and countries. However there are some disadvantages, for example that the definition of value-added tasks is a subjective process that affects the result (Bellgran and Säfsten, 2010). Productivity can be measured in three different ways, partial productivity, total-factor productivity and total productivity (Bellgran and Säfsten, 2010). The differences between these three is the number of inputs and outputs. In partial productivity only one input and one output is measured, total-factor productivity includes several inputs and outputs, while total productivity includes all outputs and inputs (Bellgran and Säfsten, 2010). The different measures have their own strengths and weaknesses, as the more inputs and

outputs that are included the better totality is given but it becomes more difficult to measure (Bellgran and Säfsten, 2010).

The MPU-method

A method to determine productivity called the MPU-method describes that productivity can be improved in three ways; through method improvement, performance improvement or utilization improvement (Saito, 2001). This method describes that productivity is equal to the product of Method (M), Performance (P) and Utilization (U) as shown in equation 2.2 (Almström and Kinnander, 2011).

$$Productivity = M \times P \times U \tag{2.2}$$

The three factors can be explained as follows (Almström and Kinnander, 2011; Saito, 2001);

- The Method factor is how smart the work is done, the ideal standardized work method performed at the normal speed. Improvements in this factor focus on opportunities in raising the level of the work standards.

- The Performance factor is the speed and accuracy of which work is performed, usually determined through an accepted predetermined time system for manual work. Improvements potential in this factor can be identified by comparing actual operating time to the standard time.

- The Utilization (Planning and Control) factor is the amount of non-conformities in regard to planned time, or in other words how large part of the available working time is spent on the intended method. Further investigation can help estimate how much productivity could be improved through more effective operation management, as production time could be increased through improved planning and control.

Efficiency & effectiveness

Two other measurements that affects the productivity is efficiency and effectiveness (Bellgran and Säfsten, 2010). Efficiency means to do the things right and is related to the input to the system while effectiveness is about doing the right thing which affect the output of the system (Bellgran and Säfsten, 2010).

Wastes in production

Wasteful activities are activities which doesn't aid in creating value to the customer. The eight types of wastes as formulated by Liker (2004) is presented in table 2.1.

2.2 Production theory

This sub-chapter covers the theory and tools related to production that were used in this thesis.

Table 2.1: The eight types of wastes as formulated by Liker (2004).

Waste	Description
Overproduction	Producing items for which there are no orders, which generates such wastes as overstaffing and storage and transportation costs because of excess inventory.
Waiting (time on hand)	Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, part, etc., or just plain having no work because of stockouts, lot processing delays, equipment downtime, and capacity bottlenecks.
Unnecessary transport or conveyance	Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes.
Overprocessing or incorrect processing	Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary.
Excess inventory	Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
Unnecessary movement	Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc. Also, walking is waste.
Defects	Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort.
Unused employee creativity	Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

2.2.1 Manufacturing planning

According to Jonsson and Mattsson (2009) manufacturing planning can be divided into three different levels; sales and operations planning, master production scheduling, and order planning. In smaller organizations the two top levels, sales and operations planning and master production scheduling can be merged together (Jonsson and Mattsson, 2009). The master production scheduling process consists of plans for both sales and production operations which shows the quantities that should be produced and delivered during a set period of time (Jonsson and Mattsson, 2009). The order planning level can according to Jonsson and Mattsson (2009) be divided further into material planning and capacity requirements planning. The goal with material planning is according to Jonsson and Mattsson (2009) to create efficient material flows with respect to tied up capital, delivery service to customer and the utilization of resources. Material planning is used to answer the following questions (Jonsson and Mattsson, 2009):

- For what items must new orders be planned?
- How large must the quantity of each item in the order be?
- When must the order for each item be delivered to stock, directly to another manufacturing department or directly to a customer?
- When must the order for each item be placed with the supplier, or when must it be started in internal manufacture?

Capacity planning handles the balancing of the supply of capacity and the demand for capacity (Jonsson and Mattsson, 2009).

2.2.2 Material & production flow

A continuous and clear flow of materials in production can help shorten lead times, lower costs and improve quality (Liker, 2004). According to Liker (2004) flow is a vital part of reducing waste over time as it brings problems to the surface since any interruption to a continuous flow is easy to identify.

U-shaped flow
In a U-shaped production line the equipment is organized in the order of production operations required to transform material into a product (Liker, 2004; Miltenburg, 2001; Hong et al., 2013). The equipment are then placed in a u-shaped line (Liker, 2004; Miltenburg, 2001; Hong et al., 2013) and the different workstations are balanced between the operators. The U-line is flexible enough that any number of operators can run the lines to fulfil the required output, however when changes in required output occurs the U-line needs to be rebalanced (Miltenburg, 2001).

The U-shape improves the communication between the operators (Liker, 2004) as the space inside the U is shared by all the operator which also improve the knowledge sharing as the operators can learn another operator's skills (Miltenburg, 2001). It also improves the efficiency of the movements of both material and operators in the system (Liker, 2004) which is one reason for the increased productivity, reduced work in progress, reduced lead time and reduced defective rates stated by Miltenburg (2001). To reduce the impact of breakdowns in the line and further increase the productivity Hong et al. (2013) states that small buffers were more effective in a U-shaped line than in a serial line.

2.2.3 Visual control

Ortiz and Park (2011) defines visual controls in manufacturing as "a means of presenting key business, product, and process information in such a way that it is "visible" at the right time, in the right place, to the right employees, throughout the factory". Liker (2004, p. 152) defines it as "any communication device used in the work environment that tells us at a glance how work should be done and whether it is devising from the standard". Visual control is a system which helps keep wastes off the production floor. It is based on the power of vision and its connection to comprehending and reacting both quickly and properly. By making issues easy to identify, they also become easier to deal with. Manufacturing companies which implement visual control can improve the ability to better meet commitments to customers (Ortiz and Park, 2011). Liker (2004) explains the reason for using visual control as making problems easier to spot.

5S

One tool that improves the visuality in the facility is the lean tool 5S, which stands for sort, straighten, shine, standardize and sustain (Liker, 2004). The steps are defined by Liker (2004) as:

- Sort - Get rid of unnecessary items and categorize remaining items based on frequency of usage.
- Straighten - Find a good position for all remaining items from the previous step.
- Shine - Clean and inspect all items and the premises.
- Standardize - Develop rules and systems to maintain the first three steps.
- Sustain - Maintain the new order and continuously improve it.

There are many reasons for why implementing 5S could prove beneficial for a company, for example;

- it helps make problems visible (Liker, 2004; Bayo-Moriones et al., 2010)
- it improves productivity (Bayo-Moriones et al., 2010; Lamprea et al., 2015; Becker, 2001)
- it supports a smooth flow (Liker, 2004; Bayo-Moriones et al., 2010)
- it improves quality (Bayo-Moriones et al., 2010; Liker, 2004; Becker, 2001)
- it reduces waste (Liker, 2004; Lamprea et al., 2015; Bayo-Moriones et al., 2010)
- it improves safety (Liker, 2004; Lamprea et al., 2015; Bayo-Moriones et al., 2010; Becker, 2001)

2.2.4 Workshop

Workshops can be defined as “means by which groups of people can work on or explore specific issues and problems in order to learn or acquire more information and possibly seek solutions” (Gilgeous, 1995, p. 1), while being interactive, participative and practical (Gilgeous, 1995). Groups of people can explore specific issues while learning and acquiring information and seeking solutions through workshops (Gilgeous, 1995). A workshop can be applied to many various topics and for numerous reasons such as to air disagreements or as an icebreaker, and should take the opportunity involve the participants (Gilgeous, 1995). Workshops are valuable vehicles for development and an effective way of improving a company’s manufacturing effectiveness, which can be achieved through workshops in two main ways (Gilgeous, 1995);

- To develop managers and supervisors by for example focusing on developing competence and skills for the related area or emphasizing on relevant subjects such as customer care and leadership.
- To improve manufacturing effectiveness through for example simulation or role play in order to help understand and tackle the range of problems the company has to face.

2.3 Change management

Change management is according to McDeavitt et al. (2012) “an effort to get individuals and groups ready, willing, and able to implement and sustain new ways of working”. To describe the importance of change management Atkinson (2014) uses the formula

$$E = Q \times I \tag{2.3}$$

where Q stands for the quality of the initiative, I is the implementation success rate and E is the effectiveness of the change. This means that if you have a solution with 100 % quality but only 5% implementation success rate you would still not have a successful change. To be able to lead an organization to successful changes these following eight steps should be followed (Kotter, 1996):

1. Establish a sense of urgency
2. Create a guiding coalition
3. Develop a vision and strategy
4. Communicate the change vision
5. Empowering employees for broad-based action
6. Generate short-term wins
7. Consolidate gains and producing more change

8. Anchor new approaches in the culture

Miltenburg (2005) describes the implementation plan as the means by which the change is put into practice. The first step is to determine what to change and why it should change followed by how and when the change should be made, and by who (Miltenburg, 2005). Miltenburg (2005) also suggests that changes should be implemented in the following order:

1. Set Course Projects – a few simple project which should be implemented smoothly to set the course for the rest on the change process.
2. Shoot and Aim Projects – essential and visual projects to get started with the implementation without spending too much time on analysis.
3. Main Projects – The rest of the projects that needs to be implemented.

2.4 Organizational Management

This sub-chapter presents important theory and management principles related to organizational management.

2.4.1 Continuous improvement

The process of improving continuously can be achieved by using the Deming cycle, also known as the Plan-Do-Check-Act (PDCA) cycle, to solve problems. Bergman and Klefsjö (2010) defines the four steps in the cycle, which is repeated continually, as follows:

1. Plan - In this step the problem causes are broken down into manageable ones. This is also where a plan for the problem solving is created.
2. Do - The measures required to solve the problem is implemented as planned in the previous step.
3. Check - Follow up on the measures to see if they had the intended effect.
4. Act - Learn from the process and either standardize the solution, if it worked, or understand why it didn't work as planned in order to avoid performing the same mistake next time.

2.4.2 Organizational learning

Argyris (1977, p. 116) defines organizational learning as “a process of detecting and correcting error”, where error is “knowledge or knowing that inhibits learning”. According to Argyris (1977) there are two kinds of organizational learning processes;

- Single loop learning, which can be compared to a thermostat learning if it is too hot or too cold in order to turn the heat on or off.

- Double loop learning, which can be compared to a thermostat questioning if it is properly set-up as it in that way not only detects errors but also questions the goal itself.

Single-loop organizational learning, where an organization is merely correcting errors, is a faulty type of organizational learning (Argyris, 1977). It can lead to an inability to discover errors and allow companies to hide its problems, but can be solved through double loop learning (Argyris, 1977). Argyris (1977) explained that there are several reasons for why such information doesn't reach the place where it needs to be to get the treatment it requires, for example that issues are not welcome news at top management if not accompanied by a solution. Double loop learning is difficult to achieve, but when achieved will help organizations become more efficient and take better decisions quicker (Argyris, 1977).

2.4.3 Knowledge management

The discipline of knowledge management is a cornerstone for companies to develop and sustain competitive advantage in a market, providing new ways for organizations to acquire and share both tacit and explicit knowledge (Gharakhani and Mousakhani, 2012). Gharakhani and Mousakhani (2012) divides knowledge management into three capabilities:

- Knowledge acquisition - The capability to acquiring knowledge, both tacit and explicit, as a result of individual participation and interaction.
- Knowledge sharing - The capability to create new knowledge by combining existing knowledge or by improving at exploiting existing knowledge.
- Knowledge application - The capability of employees to use knowledge in work-related activities, such as efficiency improvement.

According to Gharakhani and Mousakhani (2012) the capabilities of knowledge management have positive effects on small and medium sized enterprises' (SMEs') operational performance, while North and Kumta (2014, chapter 2) show that knowledge management can be a competitive advantage and an asset for organizations. North and Kumta (2014) also stress the importance of establishing conditions to create collective knowledge in companies in order to take advantage of knowledge management.

Succession planning
The succession process is a challenge for a family firm which must be managed if the firm is to stay competitive (Durst and Wilhelm, 2012; Cabrera-Suárez et al., 2001). Cabrera-Suárez et al. (2001) states that acquiring key knowledge and skills from the predecessor could be one of the reasons for why it is a challenge. To handle this, succession planning and succession management can be applied. Appropriate successor training requires a good relationship between the predecessor and successor in order to encourage the transference of knowledge (Cabrera-Suárez et al., 2001). In order to achieve this in family firms, Cabrera-Suárez et al. (2001) states that

the predecessor must be willing to appreciate and be proud of the successor, while the successor must appreciate the knowledge and contribution to the firm from the predecessor.

Durst and Wilhelm (2012) stress the importance of succession planning as it reduces the organization's vulnerability if key members were to exit the organization in smaller firms. This could be managed through having staff work closely together to achieve tacit knowledge sharing (Durst and Wilhelm, 2012). If succession isn't managed properly, knowledge loss through unexpected absence or exits from the company would put the smaller companies at risk of losing competitive advantage and suffering financially (Durst and Wilhelm, 2012).

2.4.4 Company culture

Culture can be divided into four layers; artifacts, behaviors, norms/beliefs/values and assumptions, where artifacts is the outer layer and assumption is the core layer (Miconnet and Alänge, 1999). The artifacts and beliefs are the layers that are communicated between individuals and those who are affected by the company culture (Miconnet and Alänge, 1999). The two inner layers are the main driver for behavior in individuals and these layers are hard to change as they are developed early in a humans life (Miconnet and Alänge, 1999). According to Miconnet and Alänge (1999) the company culture can be seen as the glue that holds together local units while supporting universal policies and practices in multinational companies.

The company culture in Sweden is according to Miconnet and Alänge (1999) based on delegation of responsibilities and trusting employees to perform a good work, which is a result of the Swedish national culture.

2.5 The Hawthorne effect

A study carried out between 1924-1932 prompted by dissatisfaction with the conditions at a factory involved a group of experimenting researchers. One of these experiments investigated the correlation between the light intensity in the workplace and productivity, and showed an increase in productivity both with increased and decreased light intensity (Bergman and Klefsjö, 2010). The conclusion of those results was that productivity was increased due to the interest shown by management in the working condition, an effect now known as the Hawthorne effect (Bergman and Klefsjö, 2010). According to Bergman and Klefsjö (2010, p. 358) the overall conclusion of this study was that "the work output depends both on the social system and on the production engineering conditions".

3
Methodology

This chapter presents the methods used as well as the methodology behind the thesis. It follows the steps used in the project, and brings up the validity and reliability of the thesis' methodology.

3.1 Methods engineering

Methods engineering is according to Freivalds and Niebel (2009) a systematic procedure to develop for example a production unit. The method consists of two phases; the first phase, which describes the development and design of the production unit, and the second phase, which includes the restudy of the production units to improve the productivity and quality (Freivalds and Niebel, 2009). The outline of methods engineering is summarized according to Freivalds and Niebel (2009) in the following 8 steps:

Step 1 *Select the project.* In this step the purpose of the study is decided and a problem is formulated. This can be done by using an exploratory tool such as Pareto analysis, fish-bone diagrams or Gantt charts.

Step 2 *Get and present data.* Here data from the present method is collected and presented in an orderly form such as process charts.

Step 3 *Analyze data.* The data gathered in step two is analyzed by using for example time study, flow analysis or work sampling. The purpose with this analysis is to identify the operations which are unnecessary or can be improved.

Step 4 *Develop ideal method.* Develop the best solution for the identified operations from step 3 by considering different constraints such as productivity, ergonomics or cost.

Step 5 *Present and install method.* In this step the new method is presented for the managers and workers that are working with the operation to make sure that the changes will be successful.

Step 6 *Develop job analysis.* Ensure that the right personnel has the right training for the job.

Step 7 *Establish time standards.* Standardize the method in a fair way by using time studies, work sampling, standard data or a predetermined time system.

Step 8 *Follow up.* In the last step the new method is followed up by verifying the savings, making sure that the installation is correct and that the anticipated productivity and quality is realized. Then the methods procedure should be repeated to find further improvements.

Freivalds and Niebel (2009) states that step 6 and 7 are not strictly part of a method study, but they are needed for a production unit to be fully functioning.

A method of conducting the study was adapted from Freivalds and Niebel (2009). This developed method was also influenced by the authors' previous experiences. The method used is presented in figure 3.1 and shows in which order the steps were performed. Some of the steps were performed simultaneously.

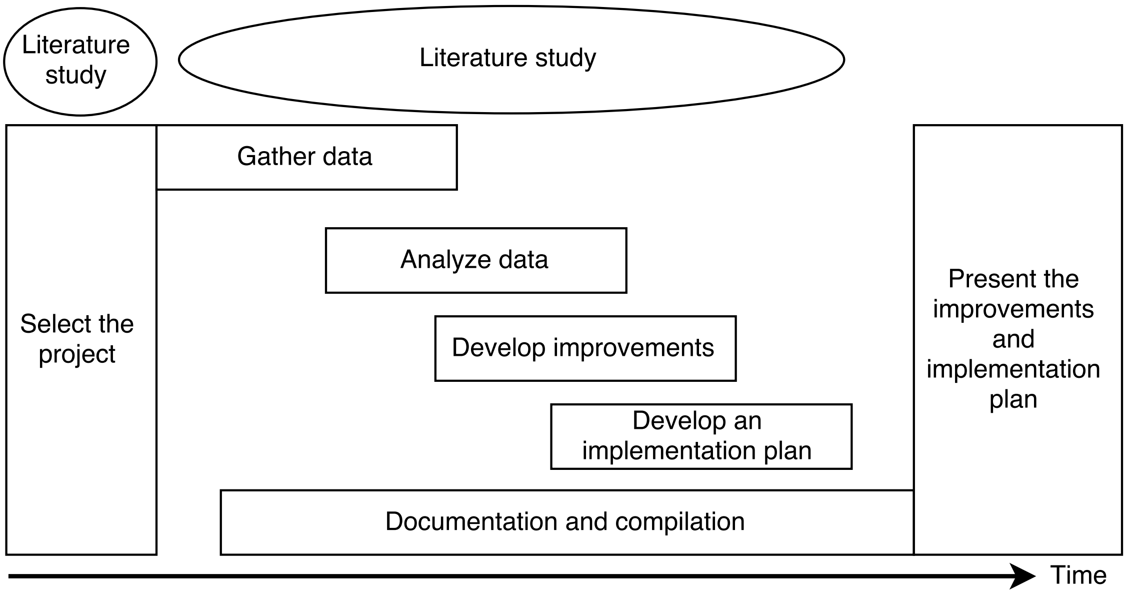


Figure 3.1: The steps in the developed method.

3.2 Step 1: Select the project

The project was initialized by the company reaching out for suitable students, looking to learn more about their production system. The goals for the project was developed alongside the company and the project supervisor. The work sampling method for gathering data was decided upon along with some initial limitations of the study, however following the pre-study further limitations was identified as the authors learned more about the production system. A literature study regarding work sampling was conducted to increase the authors' knowledge about the chosen method, as well as a study related to production systems.

The activities for the work sampling was decided upon and grouped together through brainstorming and discussion with the supervisor. These activities were tested during a pre-study through two sessions to gain further knowledge and improve them.

Brainstorming
Buggie (2003) defines brainstorming as a method of noncritical "group think" to generate new concepts and fresh ideas in order to help produce options for almost any task. According to Fortune (1992), brainstorming requires a good deal of self-discipline and should be used to generate ideas while maintaining a supportive and encouraging atmosphere for a small group to be creative. Van Valin (2014) defines five rules in order to excel at brainstorming:

1. Suspend judgment
2. Be curious, not critical
3. Think it, say it, write it
4. Quantity creates quality
5. Piggyback on ideas

The brainstorming technique can aid in for example identifying applications, developing strategies, uncovering market opportunities, coming up with new approaches and gaining competitive advantage in general (Buggie, 2003).

3.3 Step 2: Gather data

The second step of the method resulted in a current state description of the present situation at the time of the study. The focus of the data gathering was the utilization of the oven builders and the machines gathered through two separate work sampling studies as well as qualitative data gathered through interviews, meetings and spontaneous talks. The temperature in the production was also measured in the middle of the area using a digital thermometer, which was read randomly during the study.

3.3.1 Work sampling

Work sampling is a method to analyze work performed by taking a large number of observations at random times (Freivalds and Niebel, 2009). Zandin (2001, chapter 125) explains 8 steps of preparing for a work sampling study;

- Gain acceptance of work sampling by talking with those who are to be studied.
- Define the problem.
- Make an observation recording form for the job made specifically for the study.

- Select the frequency of observation depending on the nature of the operation, the physical limits and the total number of observations required.
- Determine time of trips on a random basis
- Estimate the number of observations that will be needed to achieve sufficient accuracy
- Evaluate methods to reduce the amount of biased readings
- Have a session with the observers and clearly define and discuss each element to be observed to promote consistency

The amount of samples needed is given by the formula shown in equation 3.1,

$$N = \frac{z^2 p(1-p)}{e^2} \tag{3.1}$$

where N is the amount of samples needed depending on the variables z, which is given by the confidence level, p, the probability of an occurrence of the least occurring activity, and e, the standard error (Zandin, 2001).
Studies of the utilization was performed in two parts, one regarding the oven builders and one regarding the machines. These studies had different challenges and goals and was therefore designed differently. All the data was handled through Excel, an example of this can be seen in appendix A.

Oven builder utilization
The study was performed until the result had reached a sufficient high level of confidence. This level was chosen, by guidance of the supervisor and literature, to be at least 95% confidence level at an acceptable relative error level of 10%. Each session lasted for 40 minutes with samples taken each 20 seconds and covered three randomly selected oven builders, chosen by the observer. Samples which were unclear were attributed to an activity through discussion between the observers. The sheet used for this study with a randomized order for which operator to measure is presented in appendix B. The work day was divided into 40 minute sessions, and through a randomization function the study sessions was selected among these. An example a weekly sampling schedule can be seen in appendix C.

Machine utilization
A general utilization study of the large machines was performed through sampling every 20 seconds for 30 minutes and noting if the machines were either;

- working
- being set-up
- being maintained
- not having an operator present.

This study was performed for a week when there was a gap in the oven builder utilization study and resulted in the need for a more detailed study of the most used machines. The more detailed machine utilization study was performed similarly, however it had more activities. This study was conducted until the results were accurate enough to be used as a basis for investment potential, in this case a relative error of 20% at a confidence level of at least 95%.

3.3.2 Qualitative data

The qualitative data for the study was gathered mainly through small talk with the employees of the company. A few non-recorded semi-structured interviews were conducted where the authors had prepared some topics of interests but no detailed questions. The authors also participated in the daily morning meetings to improve the comprehension of the current situation as well as the company culture.

3.4 Step 3: Analyze data

In order to understand the data gathered in step 2 the authors discussed and analyzed it during the data gathering. The similar less occuring activites used in the oven builder utilization study were grouped together to improve the credibility of the result. Once the study was concluded the authors had a brainstorming session to identify potential issues within the company while also compiling the data from the study. Both the quantitative and the qualitative data were used in this step to identify as many issues and potential improvements as possible. A fishbone diagram was used to illustrate and group the identified issues to get a clear picture of the causes for the current situation.

Fishbone diagram
The fishbone diagram, also called cause-and-effect diagram, is used to find the root cause of a problem (Bergman and Klefsjö, 2010). When a problem is detected the next step is to roughly describe the causes followed by a investigation of the details of these causes (Bergman and Klefsjö, 2010). This process is then repeated until the root causes are identified. According to Bergman and Klefsjö (2010) the fishbone diagram is an excellent foundation for problem solving and can be used both top-down and bottom-up. When using the bottom-up method post-its are often used to group the causes together to major causes which becomes the larger bones in the diagram (Bergman and Klefsjö, 2010).

3.5 Step 4: Develop improvements

Solutions and improvements for the causes identified in the previous step was brainstormed by the authors and further developed. A literature study was also conducted for the identified issues to further increase the authors' knowledge and gather inspiration for solutions. The improvement suggestions were evaluated in terms of potential productivity improvement in order to motivate them. When developing some improvements, several concepts were designed and evaluated. Some of these can be seen in appendix D.

3.6 Step 5: Develop an implementation plan

Once a list of improvements had been developed, a plan for implementing them was developed. The plan was based on a literature study of the area in order to successfully implement the solutions.

3.7 Validity & reliability

Validity for this study means that the data is gathered by empirically tested methods, while reliability means that the results are based on high-confidence data. This study relies on known methods such as work sampling, which gives high validity as the method is well known combined with good reliability as the normally distributed data has a given confidence level.

4
Current state

The current state chapter presents the authors' perception of the state of the company and it's production as it was during the time of the study.

4.1 Organization

Due to the size of the company the amount of office personnel was quite small. The CEO had the main knowledge about the design of the ovens and was together with one additional designer and the electrical designer responsible for the creation of the drawings for the projects. All projects were managed by one of the two project leaders which managed the customer contact and followed up if the progress coincided with the project planning. The programming and development of the control system for the ovens were made by one employee who also was responsible for the company's website and other IT activities. The supportive functions economics and purchasing was managed by two additional employees. The amount of blue-collar personnel at the company was regulated by extra personnel which could be hired to help out in the production when the permanent workers' capacity didn't cover the demanded capacity. The distribution of the employees at the company is summarized in table 4.1

Table 4.1: Overview of the employee distribution.

Office		Shop floor	
Project leaders	2	Oven builders	5-10
Mechanical designers	2	Fan builders	1-2
Electrical designer	1	Electricians	2-3
IT & PLC programming	1	Laser cutter operator	1
Economy	1	Small oven builders	1-2
Purchasing	1		
Summary	8	Summary	10-18

Every morning at 9.15 there was a meeting to check progress and see if any immediate purchases were required. Short term daily planning was based on these meetings, for example if a worker believed extra resources was needed to finish on time then this could be worked out. Apart from the morning meetings the oven builders and the white-collars had meetings on the shop floor and in the office to discuss problems and solutions that had appeared during the process. The employees in the office lacked clear roles and responsibility areas as many of these areas were divided among them.

4.2 Process overview

The company produced three to five ovens at the same time, depending on the sizes of the ovens and the length of the order book. During the study two chamber ovens, one smaller and one larger, and one conveyor oven was built and three other ovens were test run, packaged and transported out to customer. The general production process used at the company started with customer contact to get the specifications needed for the oven as they are customer adapted, followed by the creation of electrical and mechanical drawings. When the drawings were completed, the frame and other sub-parts such as doors, roof and the electrical cabinet were constructed, isolated and finally assembled to the main product. After construction and assembly of the product was finished, it was tested and adjusted. The product was then disassembled if needed, to be packaged and transported to the customer where it was re-assembled by an oven builder and tested again. One oven builder was in charge of the project, and sometimes assisted by others in some of the sub-tasks included in the building. A process chart with the steps of the oven building process is presented in figure 4.1.

Figure 4.1: Process chart of the company's general production process.

4.2.1 Order initiation

The first step of the process was customer contact, usually initiated when a potential customer inquired about the company's products. Once contact had been established, both parties agreed on a technical specification which served as the basis for product design, however product design didn't start until an order was confirmed. When the order was confirmed the company continued with product design, where drawings and bill of materials were created to support the oven builder. There were no assembly instructions as each oven builder had their own way of building ovens based on years of experience.

4.2.2 Frame construction

In the frame construction step of the process beams of the correct profile were cut into the required lengths. If the beams weren't long enough multiple beams were welded together to form a sufficiently long beam. Once the beams were the proper length they were welded together to form the basic shell of the oven. For some ovens the roof, floor and door(s) were built separately to be assembled to the end product later on in the process.

4.2.3 Insulation

In the insulation stage of the process of building an oven, the frame was insulated according to the drawings. Several layers of insulation material was assembled to the frame to minimize the risk of heat escaping the product during usage. This part of the process included opening boxes of insulation material, rolling the material out, cutting it into desired sizes if needed and finally assembling it.

4.2.4 Assembly

Following the insulation stage, the sub-parts were assembled to the main oven. This included the electrical parts as well as roof, door(s), floor, conveyors, robot and other things which may have been a part of the project and varied heavily from oven to oven depending on the customer needs.

4.2.5 Testing

Once everything was assembled, the oven was tested according to specifications and adjusted until it was performing as specified. Sometimes the customer also came and visited during this part of the process. When everything was working as specified, some parts of the products were disassembled if needed to easier transport the product.

4.2.6 Packaging & transportation

All parts of the product were packaged in this step of the process, to be ready for transport by trailer. This step required covering the oven in plastic, heating up the plastic to make it tight as well as placing and securing it on the trailer after which it was transported to the customer.

4.2.7 Installation

Once the product was at the customer it was installed at the desired place. This was sometimes done by the company's oven builders. When it was, the oven builder brought some tools and materials which may have been required to install and test the oven properly in order to leave the customer with a fully working industrial oven solution.

4.2.8 Supportive sub-processes

Along from the processes described previously, there were several other supporting processes which were performed regularly. One of these was the arrival of goods to the shop floor during the day, which was handled by the employees when they noticed the delivery person waiting for a signature. The receipt was then placed in a document holder next to the door where the goods arrive. Another such supportive process was the improvements and cleaning performed on Friday afternoons. The facility was cleaned on a shallow level, tools were put back in their place, parts of the floor were swept and sometimes improvement work was performed on the initiative of the workers.

4.3 Layout

The facility consisted of two halls, one primary area in which the ovens were built and one secondary area where other work was done. In both halls there were overhead cranes which were used when moving ungainly material or products. There were also a smaller room for the electric preassembly and areas for storing and maintaining equipment. On the second floor there was a small workstation for smaller products. The layout of the facility is presented in figure 4.2 with different areas letter-coded to better understand the details to follow in this chapter.

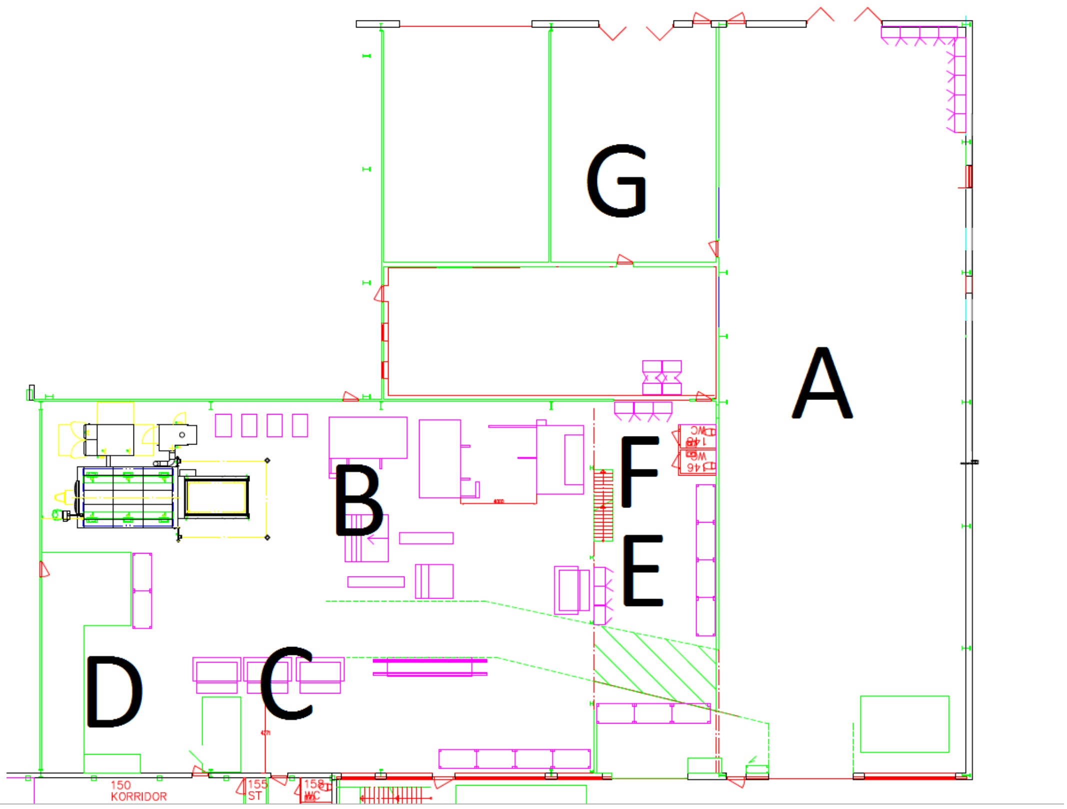


Figure 4.2: Layout of the facility, with letter coding for the different areas.

4.3.1 Oven building area (A)

In area A the ovens were built, tested and finally packaged and loaded on the transportation trucks. The area was open and featured delivery gates in both ends (see figure 4.3. There were no fixed working positions in this area. All deliveries were received through the delivery gate at the front of the factory (bottom of figure 4.2) and then placed just inside the gate until the operator needing the material received it. It was also inside this gate where all smaller goods waiting for delivery were placed until the transportation arrived. In the right corner next to the front delivery gate the company's own oven was placed, which was used for heat treatment for customers. It is illustrated by a green box in the bottom right corner in figure 4.2.

Figure 4.3: Photo of the oven building area.

On the left wall there were two tool boards and one tool bench where common tools were stored, as well as some lockers in which tools, safety gear such as gloves and respirators and other smaller materials were stored. There were also two larger working tables which could be moved with the overhead crane.

4.3.2 Machine area (B)

In the machine area, which is shown in figure 4.4, all raw material was cut and bent to the desired size and shape. The machines at the company could be divided into three different groups, the laser cutter, the larger machines and the small machines. The current layout of the machine area is shown in figure 4.5.

Figure 4.4: Photo of the machine area.

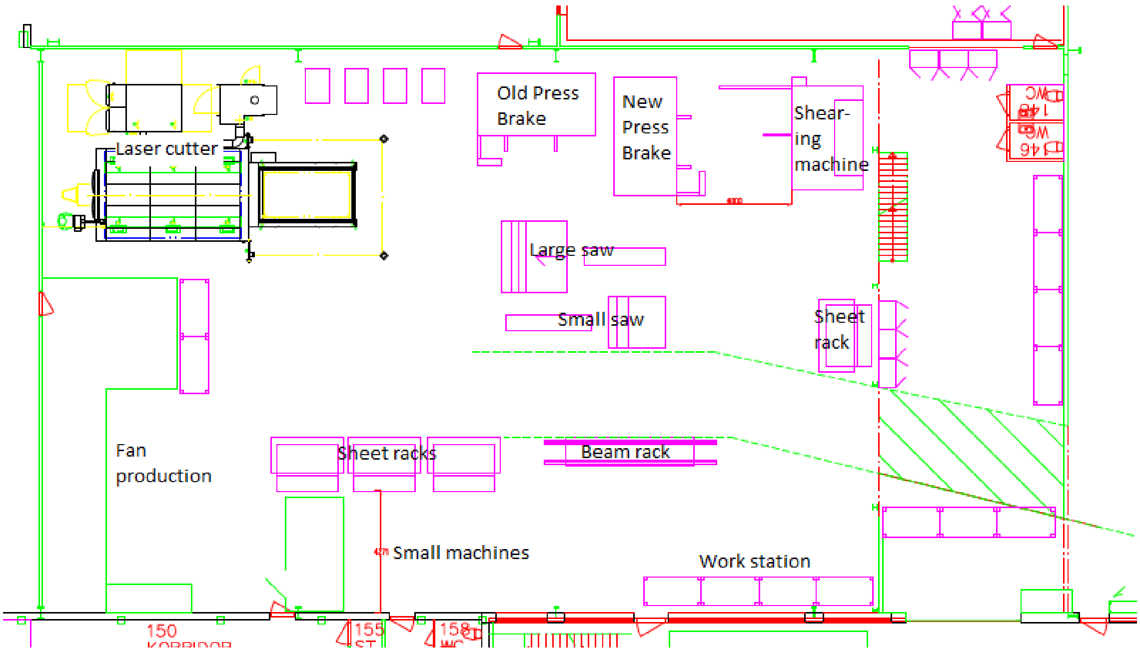


Figure 4.5: Layout of the machine area.

The laser cutter was mainly used to cut sheet metal with more complex shapes like holes and other cutouts. It was operated by one full-time operator and the programming was done by one office employee. All raw material was received from the sheet racks in area C and transported to the machine with a forklift and then loaded into the machine using an overhead crane with a vacuum lift tool.

The larger machine group consisted of two press brakes, one newer and one older, one shearing machine and two saws, one larger and one smaller. All these machines were operated by all shop floor employees when parts were needed for a product or sub-part.

The press brakes were used to bend the sheet metal into the desired shape according to the drawings. Both machines required on-line programming and tool changes to achieve the right bend, both of which were done by the operator. For larger parts, the operator needed to lift the part up during the pressing process to protect the sheet metal which often required two operators.

The shearing machine cut sheet metal into the right length and width but could only cut straight cuts. The operator programmed the machine to adjust the counter-hold to achieve the right size of the part and then placed the metal sheet in the machine and pressed a button or pedal to shear the part. When cutting big sheets of metal the operator used the overhead crane to load the material into the shearing machine.

The two saws were used to cut beams, pipes and axes to the right length. When getting larger pipes from the top level of the beam rack the operator used the overhead crane to load the material into one of the saws.

Behind the raw material storage there were a group of smaller seldom used machines. This group included a rolling machine, two corner cutting machines, a small press and a small press brake.

4.3.3 Storage areas

At the company the raw material was stored in area C while small components such as screws and nuts were stored in area F (figure 4.2).

Raw material (C)
In this area the sheet metal, beams, pipes and axes were stored in material racks. The beams, pipes and axes were stored in one long beam rack close to the saws, and the sheet metal was stored in four sheet racks. Three of these were placed close to the laser cutter, while the fourth one was placed close to the shearing machine.

Small components (F)
On the first floor in area F the small components were stored. In this storage area the nuts were placed in one shelf where the different types of nuts were sorted into different levels of the shelf. There was one shelf for each type of screw, and each shelf had bins for different sizes of screws. There were also a lot of other small

components such as for example hanging loops stored in this area, either in shelves or on the floor. In the middle of this storage area there was a small working table which was full of packaged components.

4.3.4 Other areas

Fan production (D)
All the fans for the ovens were produced in-house in area D. The fans were often built by one operator who used the machines in the machine area (B) and had most of the tools and special components stored at the working area (D). When the fans were finished the operator transported them to the oven building area (A) by a special cart and assembled them on the oven.

Area for storing and maintaining tools for heat treatment at customers (E1)
One operator performed heat treatment either at customer's facilities or in-house. The area E on the first floor was used for storing the equipment needed for these heat treatments and it was also in this area where the operator performed the maintenance of the equipment required for this work.

Small products production area (E2)
On the second floor in area E one operator manufactured and assembled smaller products, like rod ovens and mobile heat treatment equipment, as well as heat elements. The components which only were used for these products were stored in this area while metal parts produced in the machine area were lifted up to the second floor using a forklift.

Electronics assembly area (G)
In area G the electricians assembled the control cabinets and other electrical components for the ovens. The components used to assemble these products were stored in this area. The electricians in this area were the same as the ones that installed the electrical parts on the ovens in the oven building area.

4.4 Planning & Material handling

This sub-chapter presents the current state of the planning and material handling functions at the company.

4.4.1 Planning

The planning process at the company could be divided into three parts to give a better understanding;

- The production planning part, which considered how many projects and orders were handled at the same time in order to roughly plan how much capacity was needed or if more orders could be accepted.

- The project planning part, which was based on finishing the product on time, was used to create a plan of when each sub-part and sub-process needed to be started and finished in order for the product to be finished on time. An example of a product plan used at the company is given in figure 4.6.

- The resource planning part, which consisted of what each worker should do on a day-by-day basis to accomplish the goals established in the product planning part was done weekly. An example of a resource plan used at the company is shown in figure 4.7.

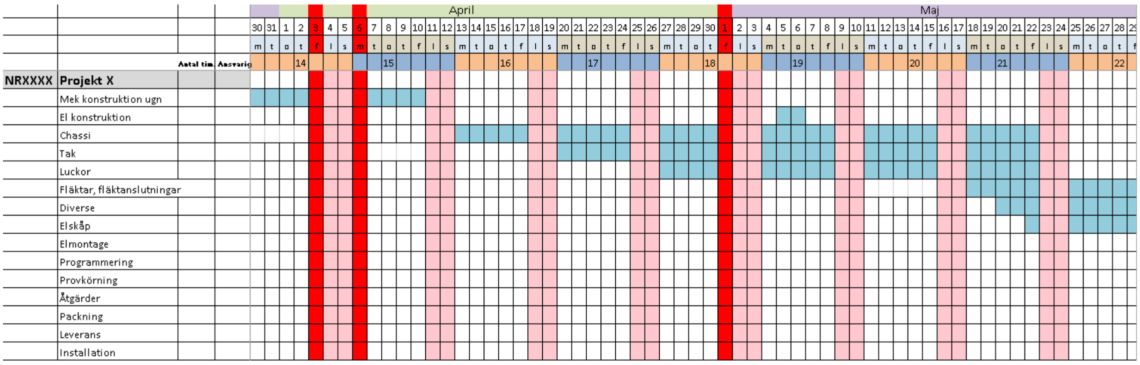


Figure 4.6: Example of the project planning. The blue squares represent when a task is performed.

	Monday	Tuesday	Wednesday	Thursday	Friday
Worker 1	Product A	Product A	Product A		
Worker 2	Product A	Product A	Sub-part E	Sub-part E	Product A
Worker 3	Sub-part B	Sub-part B	Sub-part B	Product A	Product A
Worker 4	Sub-part C	Company A	Company A	Sub-part C	Sub-part C
Worker 5	Product B	Product B	Product B	Product B	Product B
Worker 6	Sub-part A	Sub-part A	Sub-part F	Sub-Part D	Product B
Worker 7		Sub-part D	Sub-part D	Sub-part D	Sub-part C
	Not available		Work-related trip		

Figure 4.7: Example of the resource planning.

4.4.2 Material handling

Material
To build ovens, construct tools and perform laser cutting operations for customers as well as in-house work the company needed different sheet metals, pipes, axes and beams. The company stored around 50 different sheet metals, some standard beams, a few special beams and a lot of different pipes and axes in the facility.

Procurement process
The employees responsible for material purchasing started by contacting suppliers to compare prices and other important factors such as delivery time. Once the supplier with the best deal was identified the order was placed. This could be done either by the employee responsible for purchasing or one of the designers.
To determine when it was time to order new standard material the operator at the laser cutting machine together with the employee working with the purchasing function performed inventory every Friday in order to determine if the supply would last the following week. The other materials were not inventoried, however the workers were expected to report when there was little or no material left so a new order could be placed.

5

Current state analysis

The following chapter presents the analysis of the findings presented in the previous chapter. It starts off by presenting the results from the oven builder utilization study, which serve as a basis for the analysis of the different areas brought up.

5.1 Oven builder utilization

An explanation of the various activities used in the oven builder utilization study is presented in table 5.1, where all value-added activities include re-work as re-work could not be identified without interrupting the worker.

Table 5.1: Description and categorization of the oven builder activities.

	Activity	Description
Value added	Working on main product	All work in building the oven that needs to be done on the product.
	Working on sub-parts	Oven building work which could be performed outside of the product.
	Using press brake/saw/shearing machine	All work using these machines. Including set-up.
Supportive	Fetching material	Getting material for the value adding activites, i.e. screws and insulation material.
	Performing maintenance and fetching tool	The process of getting tools for the value adding activites, such as a grinder, and the maintenance of these.
	Moving a product or part of a product	The process of moving larger items with the help of an overhead crane.
	Talking/discussing	When workers are talking or discussing in order to find a solution.
	Performing uncategorized supportive actions	Such as packaging and receiving goods.
Non-value added	Taking personal time	I.e. using the toilet or talking on the phone.
	Cleaning and moving material out of the way	Cleaning the floor after isolating or moving things that are in the way.
	Waiting for a machine job to finish and other idling	Other idling includes waiting for a coworker to perform synconized work.

The utilization of the oven builders is illustrated in figure 5.1. All results from this study has a confidence level of at least 95% at a relative error of ± 10% and are based on the 17927 gathered samples. For example, this means that if an activity was performed 5% of the time, the true number is within 5±0.5% with at least 95% certaincy. Working on sub-parts and working on the main product were the two most frequently occurring activities, being 22.30% and 21.66% respectively, followed by taking personal time at 14.21% and discussing or talking about solutions or other work related things at 12.77%.

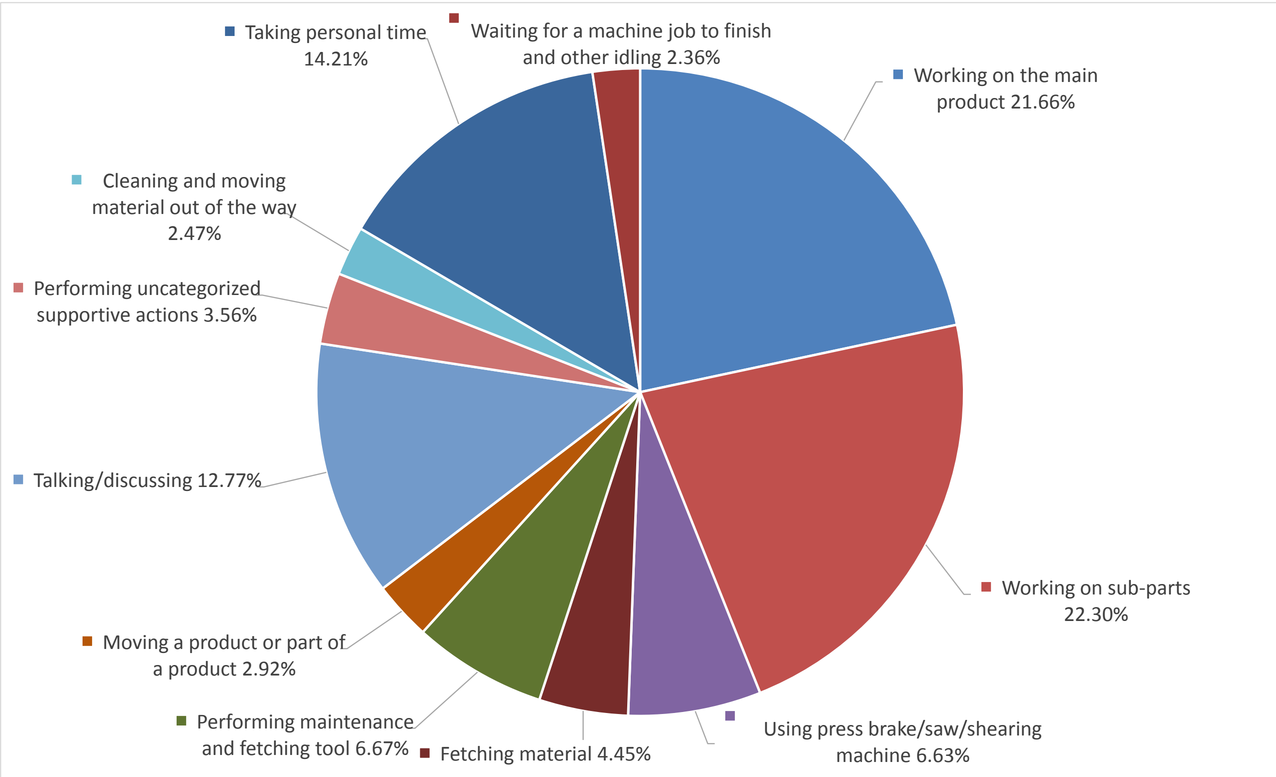


Figure 5.1: Detailed utilization of the oven builders.

The utilization of the oven builders varied depending both on the time of the day (figure 5.2) and the day of the week (figure 5.3). Dividing the data like this shows that the oven builders were performing less and less value added work as the day went on, possibly due to being interrupted more and more and losing focus. It also shows that Mondays were the least productive day of the week. This could be due to the weekly planning performed by the office employees on Monday mornings, which caused the oven builders to merely pass time as they didn't yet know what to do.

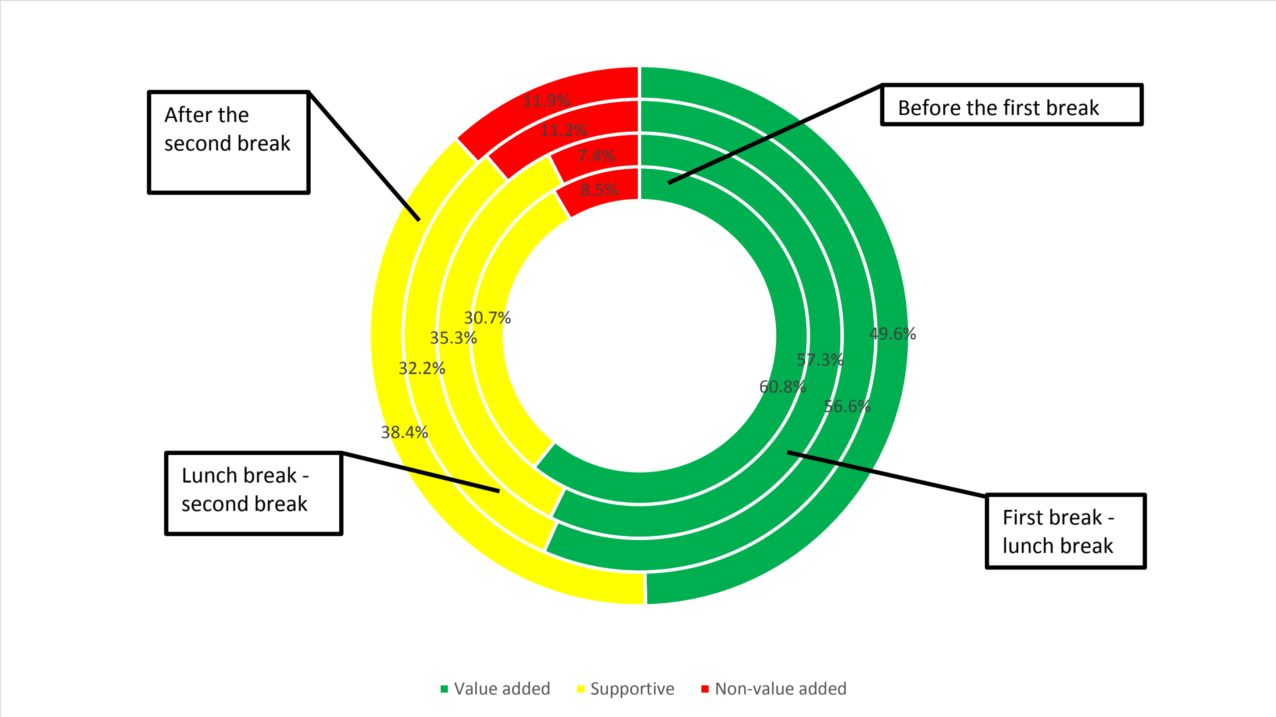


Figure 5.2: The utilization of the oven builders divided into different time of the day. Breaks are not included in this graph.

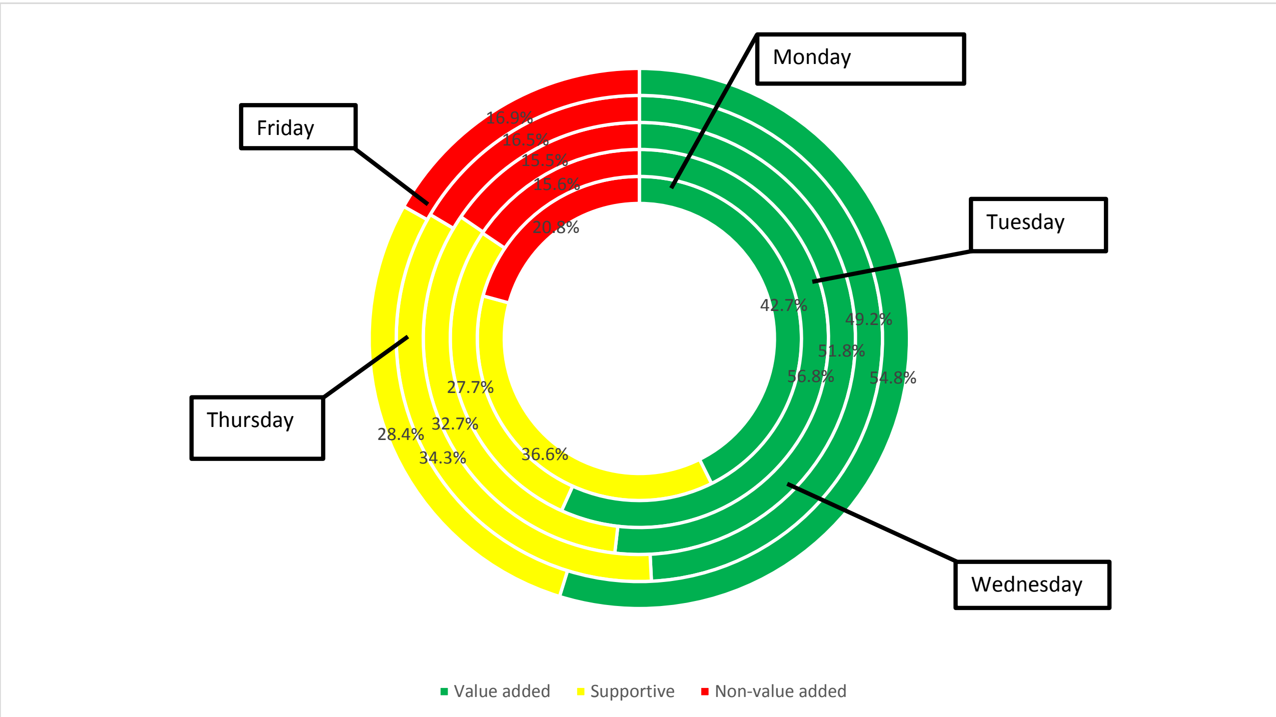


Figure 5.3: The utilization of the oven builders divided into days of the week.

5.2 Organization

The organization at the company was unclear, mostly due to the lack of responsibility areas for the employees. The project leader role was clear but it was difficult to know who was responsible for supportive functions, such as raw material replenishment, as many of these functions were performed by several people. This led to inefficiency as well as a lack of improvements since there was no sense of responsibility for each supportive function.

The morning meetings was a nice way to check progress and allocate resources short-term while still keeping track of medium-term goals. The part of the meeting related to immediate purchases could be slightly problematic, as it was based on an employee's understanding of the situation and not that of the person responsible for the area. However this part of the meeting had its benefits as it allowed for coordination of smaller purchases and reduced the amount of trips to and from stores.

The mentality of the organization was to have a lot of different things to do and solve issues as they arise. Cleaning was performed before a major customer visit as shown in figure 5.4, however little interest was shown in keeping the facility clean and tidy outside of this visit and after the insulation process when there were lots of dust particles.

(a) Before customer visit.

(b) During customer visit.

Figure 5.4: Example of cleaning for customer visit.

The dialogues between the shop floor employees and the office employees really helped improve the connection between them and was a smart way to keep them working together. However some of it was related to the issues regarding incorrect or unfinished drawings. Having an office employee interrupt the oven builder was detrimental to productivity, however this was unavoidable due to the need of solving issues as they arise.

Some of the operators no longer brought up improvement proposals as these proposals had been ignored for too long. This related to several things, among them that the office employees had many other things to focus on and that the improvement process wasn't taken seriously. While it is easy to bring up issues, solutions and suggestions, it is harder to take the time to actually implement these and create the environment needed for continuous improvement to thrive. Without the sense of being taken seriously, it is reasonable that the oven builders no longer consider bringing up improvement proposals as it feels like wasted time and a source of disappointment. In general, there was a will to make changes and improvements throughout the organization but no time to actually perform them.

Another activity that reflected the culture of the company was the amount of personal time the workers took during the day, which accounted for 14.21% of the available time. This activity included the two 15 minute breaks the oven builders had each day as well as any personal time outside of this. If there were no personal time outside of the allotted 30 minutes per day, the share would be around 6.25%. It is not unreasonable to assume that workers need to use the toilet outside of the breaks and that there could be important phone calls during the day, and combined with the fact that the morning meetings sometimes were late this number was not that much higher than reasonable. The last bit could be related to the social nature of group work, as working together solving problems could lead to employees talk about non-work related things at times as a form of mini-break.

Identified issues:

- No employee was responsible for the supporting functions
- Lack of feedback on improvement proposals from the employees

5.3 Production processes

Producing three to five large industrial ovens at the same time put a lot of strain on the office. As the amount of supportive personnel was limited, each project could only receive a limited amount of support. Hence, each project might only have had one or two office personnel available to aid the oven builder. This was one of the reasons for the lack of focus on any one project on the shop floor, for the unnecessary product movements due to variation in deadlines and shipping dates and the severe area changes over time. For example, a large project was started in one part of the oven building area, only to be moved later due to a new project being started in an adjacent area, taking up the space needed for the first project. Moving a large industrial oven across the factory was not an easy task and affects the entire facility as it becomes a group effort, thus minimizing these would be preferable. These kinds of issues related to considering many aspects due to running several projects at once caused inefficiency throughout the entire organization.

As can be seen in figure 5.1 the oven builders spent 21.66% and 22.30% working on the main parts and on the sub-parts respectively. It is important to note that this time also includes pure re-work, performed only because something went wrong in an earlier stage and that the work itself was un-optimized. There was also more time spent on these things than necessary due to a lack of knowledge sharing combined with a high variety of activities. For example, the bending of heating elements was a process which was done a few times a month but since there was no work standard the employees must find their own way of doing it. This led to a long ramp-up time each time the process was started as the employee either tried to remember how it was done last time, a few months ago, or figured out a new way of doing it.

Another issue related to the office was that drawings at times were incorrect or not finished when they were needed. As a result, the bill of materials was faulty and the oven builder had to spend time trying to figure out how the product was supposed to be built based on previous knowledge. This could also be a result of the company's intention of running several projects at once with a limited office workforce. Since the company relied mostly on one person for drawings, this person would have a lot of responsibility and become the key to the entire process. Any changes to the order from the customer affected all other projects as well as resources which must be taken from somewhere else to solve the issue at hand.

The most frequently occurring supportive activity during the study was the talking/discussing activity which was performed 12.77% of the time. As this activity includes discussions on how to solve a problem as well as the interpretation of drawings and specifications, it can be related to the incorrect or unfinished drawings since the workers didn't always know what to do nor how it should be done. It also includes the morning meetings and whenever an oven builder was interrupted by an office employee as this was assumed to be related to the project. The oven builders often carried a notepad on which drawings were created and calculations were made in order to support the work and keep track of measurements, which also is an effect of the poor drawings. Due to the process, some of these activities was necessary due to the non-standardized work, but some could be categorized as waste, such as drawing due to a poor drawing and re-calculating measurements for the same reason.

Once the basis for the project was completed, the oven builders spent time using the saw to saw the beams into the proper dimensions needed to begin building the frame. The oven builder also used the press brake to press the sheet metal parts for the oven as well as the shearing machine to cut the sheet metal parts that are not cut in the laser cutter. The time the oven builders spent working on the machines was 6.63% of the working time, in which all the set-up and maintenance of the machine is included. This part of the process involved no operations which required a skilled oven builder other than the part of correcting whatever errors there may have been in the drawings and bill of materials or understanding the specification. The incorrect bill of materials also caused the oven builders to spend time interpret the drawings and thinking of solutions.

Changes to the drawings and specifications sometimes occured after the relevant part had been assembled, such as for example the addition of a hatch. This caused unnecessary rework for both the office employee and the oven builder as new drawings were needed which delayed the project. It also caused frustration, as something which was considered done needed to be altered, and could have been avoided altogether unless it was based on an order alteration from the customer. Alterations could also require more material than initially expected, which in turn could lead to shortages, frustration and delays.

The process of packaging and transporting larger products often required more than one worker, however after having covered the product in the plastic film only one worker could heat up the plastic as there only was one tool available for this process. As a result of this, the packaging process took much longer than needed for larger products as the heating part of the process can be very time-consuming.

The supportive sub-process of receiving goods sometimes interrupted a worker in the midst of a process, which sometimes forced co-workers to wait as some work was supposed to be done in parallel. This was wasteful and possibly a source of frustration due to inefficiency. Since the document holder for receipts was full, there could be a lack of interest in taking care of these, related to issues in the organization.

The oven builders also spent time performing uncategorized supportive actions, which made up 3.56% of the oven builders available time during the study. This activity consisted mostly of packaging products and receiving goods from couriers. While packaging products was a necessary supportive activity to deliver a clean product to the customer safely, having an oven builder stop working to confirm the reception of goods isn't necessarily the best solution as this might lead to another operator waiting or a temporary loss of focus.

While the time allotted for cleaning and improvement on Friday afternoons was a good idea, there was a lack of predetermined locations for all tools and other material which made the cleaning process ineffective. In some places there were notes for who was responsible for each area, but this didn't seem to be followed gravely, possibly related to some of the issues in the organization. There usually was a lot of dust from grinders and welds on the floor which needed to be cleaned as well, however this was not done very often which led to a worse work environment. It was possible that the dust also affected the quality of some floor-level welds, however this issue was not mentioned during the study at all.

Waiting for a machine job to finish and other idling was an activity which made up for 2.36% of the oven builders average day. As this activity included waiting for another operator to finish their work due to balancing issues, it could be extremely difficult to eliminate due to the difference in working pace and lack of work standards. The reason for why workers were waiting for a machine job to finish was sometimes that the waiting time wasn't long enough to warrant any other activity but in some occasions it was related to the mentality of the oven builders.

Identified issues:

- Too many projects were carried out simultaneously
- Incorrect or unfinished drawings
- Incorrect bill of materials
- Relied on one employee for design
- Rework due to order changes
- Receiving goods interrupted the oven builders
- No standardized work methods

5.4 Layout

The company believed that there wasn't enough space in the facility to be able to expand and produce more ovens. The reason for this was a lack of free floor space in the facility during periods of many simultaneous orders, which in turn was caused by the disarrangement of material, tools and products combined with poor planning.

One reason for the disarrangement of the tools and materials was that no-one was responsible for maintaining order in the facility, as this responsibility was divided between all the workers. There had been a system in which the workers had their own area for which the worker was responsible for maintaining order and cleanliness through the weekly cleaning sessions. However this system failed when the company had an increase in orders as there was no time for cleaning. The company had one utility-man who cleaned and sorted tools and materials when the other oven builders didn't require assistance.

Identified issues:

- No-one was responsible for maintaining the order in the facility

5.4.1 Oven building area (A)

The disarrangement and the amount of free space varied a lot depending on how many and how large products were produced at the same time. When the study started there was quite large amount of free space because the big chamber oven project was just started in this area, while both the boogie and the door was produced in the other facility. There was also a conveyor oven that was in progress, and half way through the study the construction of another smaller chamber oven was started. At the same time as the smaller chamber oven's frame was finished, both the door and the boogie for the big chamber oven was delivered to the facility. At this time, before the roof was mounted on the top of the frame of the big chamber oven, there was very little free space in the oven building area. This was caused by poor planning which didn't take the work space into consideration. The number of products in progress also affected the amount of different materials placed in this area, as more products in different stages required different materials and therefore more pallets which could increase the disarrangement in the area.

There were three small machines in the oven building area; one column drill machine located in the middle of the area next to the right wall, one small saw placed on a pallet which was moved around as needed and a grinder which also was placed on a pallet and moved around. These movable machines did not have a set place to be stored when they weren't used and were therefore placed where there was available space at the moment. This resulted in the need of moving these machines more than necessary due to for example being placed too close to another product or to be able to transport other material to the workplaces. This problem also occured with the welds that were used by the oven builders. When an oven builder was finished with the weld, it was placed where it last was used until it was needed again. The lack of set places for the moveable machines, welds and other material stored in the oven building area resulted in that the oven builders spent 2.47% of the time on cleaning and moving material out of the way. Cleaning was at times necessary, such as when trying to get rid of the leftover dust and small particles from the insulation stage in order to improve the work environment. Another problem was that there were too few electric sockets and compressed air outlets in the oven building area, combined with most of them being placed on the right wall. This resulted in the workers sometimes having to wait for another worker to finish a job so the socket becomes available, or finding and connecting a long extension cord to an available socket somewhere much further away. This not only took time away from production but also increased the risk of tripping accidents.

Most of the smaller hand tools were stored in this area on tool boards, in lockers or in the personal tool carts the oven builders had. The tool boards were poorly organized as they lacked specific positions for each tool, but the lockers had signs with photos explaining the contents of each locker. The personal tool carts were managed by the oven builder that used it and therefore the order among the tools was different depending on which oven builder was responsible for the tool cart. There were no standardized tool cart layout. There was a problem with tools not being returned to the right place which caused the workers to spend 6.67% of the time looking for them and performing maintenance. The maintenance part of this activity however was only a very small part, a vast majority of the time spent on this activity related to the finding and plugging in of the tools. Another problem that could arise when extra personnel was hired was the lack of extra tools which caused the ordinary workers to share the tools from their tool cart with the extra personnel. It was also common that the extra personnel forgot to return the tools which led to a lack of tools for the ordinary oven builders and further disorder.

All the arriving and departing goods were stored in the oven building area which decreased the amount of free space even more. The reason for the chosen storage area was probably because there was no set place for these goods and therefore it was placed close to where the workers loaded and unloaded the transportation trucks. There was a small shelf just inside the door for smaller arriving and departing goods, however this shelf was not used due to being full of other materials.

The working condition in this area varied with the tasks performed by the operators. As there were a lot of welding, grinding, isolating and painting, the work environment at the company could be explained as dusty and noisy with welding arcs in several un-shielded locations combined with the smell of thinner in the air. Due to the poor ventilation in the facility, the delivery gates were opened to vent out fumes and dust. There was also a problem with sparks from the welds and the grinders which was solved by portable screens that were used to shield off the workstations and to keep other products clean. Another issue with the working environment was the temperature in the facility. It varied a lot (see figure 5.5) depending on the openings of the delivery gates, either to vent out fumes or to load and unload transportation trucks, the number of running ovens and the outside temperature. This issue didn't seem to bother the workers, as more clothes were put on when it was colder and the gates were opened when it was warmer.

Identified issues:

- Lack of storage area for the movable machines
- Lack of storage area for the welds
- Not enough electric sockets and compressed air outlets
- Unorganized tool boards
- Tools were not returned to the right place
- Lack of extra tools
- No storage area for incoming and outgoing goods

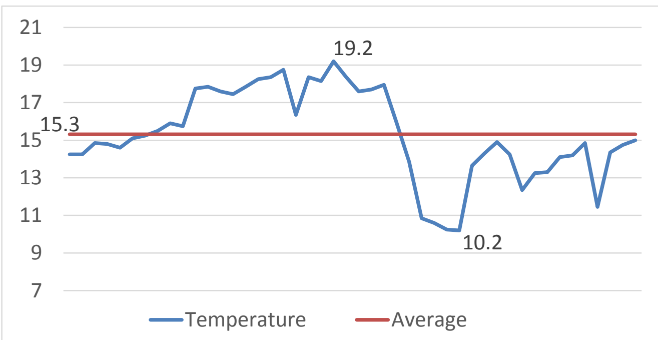


Figure 5.5: Temperature in the oven building area in °C.

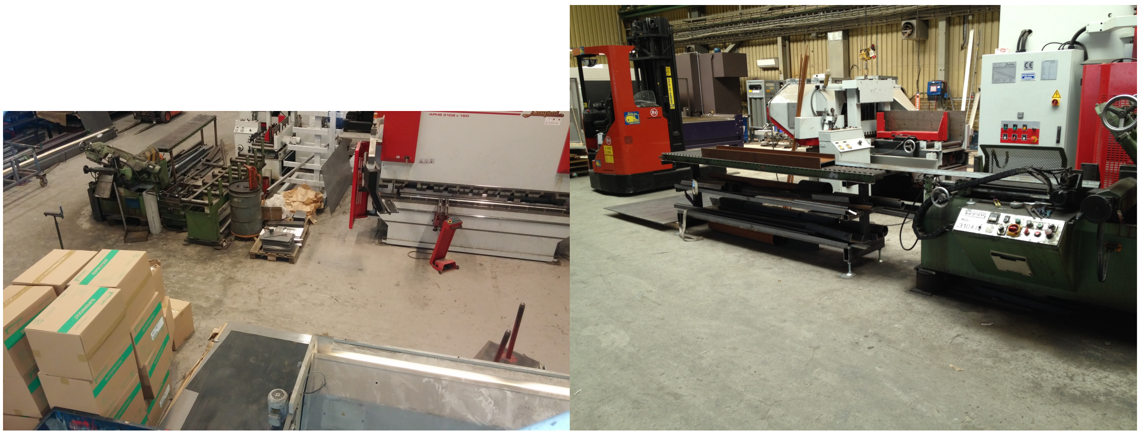
5.4.2 Machine area (B)

During the study the machine area was the area in which the disarrangement was reduced the most. The workers built a material rack for the smaller parts of sheet metal which leaned against the wall previously (figure 5.6a), which improved the working area and showed that the workers want to improve. The material rack, as shown in figure 5.6b, was placed close to the shearing machine where the scrap container used to stand and the container for scrap material was moved a bit further away from the machine. This made the loading process somewhat shorter while the process of throwing away scrap material became somewhat longer. The workers also built shelves for the leftover parts from the saws which used to lie underneath the small saw (figure 5.7), which also showed that there is a will to improve.

(a) Metal sheets around the machines.

(b) The new material rack for smaller parts of sheet metal.

Figure 5.6: The effect of the material rack.



(a) Beams underneath the saw.

(b) The new shelves underneath the saw.

Figure 5.7: The effect of the shelves underneath the saw.

One issue with the layout in the machine area was the lack of space around the machines which led to difficulties producing the biggest parts without obstructing the work nearby. This issue was seen in the area between the shearing machine and the new press brake (see figure 5.8) but could also possibly occur around the saws when sawing the longest beams, as these can extend into nearby areas. Another issue that also affected the space around the machines was that this area also was used for storage of raw material, which was placed here due to lack of better storage areas in the facility. There were also semi-finished parts and products waiting for the next process stored on the floor in this area. These semi-finished parts and products were often placed very close to or in between the machines in order to make them easy to access when they were to be used.

Figure 5.8: Lack of space between the new press brake and the shearing machine.

All types of machines present at the facility were needed to be able to produce the ovens completely in-house and maintain the flexibility in the production. The process flow chart for the machine area is presented in figure 5.9. However, more than one machine of each type might not have been necessary. As can be seen in table 5.2 all machines had a low utilization, as the machines were idle for a majority of the time since there was no operator present. The old press brake and the large saw was only used when the new press brake or the small saw was occupied by another operator, which implied that it wasn't necessary to have two saws and two press brakes as long as two operators didn't need to use the machine at the same time. All results related to the machine utilization study has a confidence level of at least 95% at a relative error of ± 20%. The activities used in the detailed machine utilization study are described in 5.3.

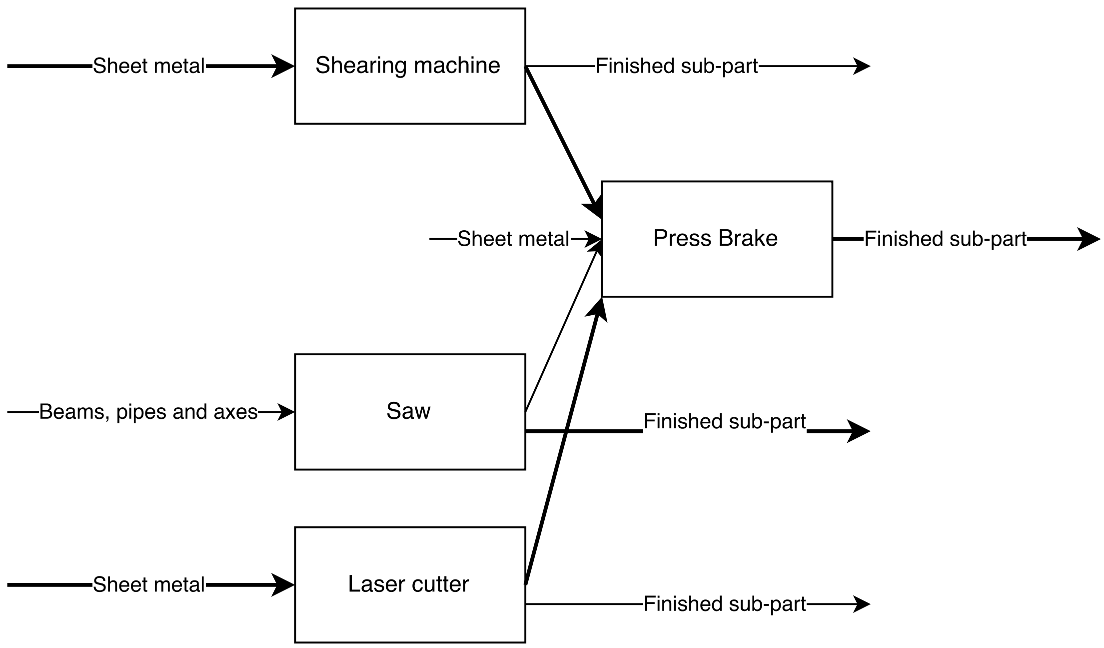


Figure 5.9: The production flow in the machine area. The thick lines represent the most common path for the parts produced following each machine, while the thin lines represent the less common path.

Table 5.2: The general utilization of the machines studied.

Machine	Working	Setup	Maintenance	No operator
New Press Brake	10.3%	18.3%	0.0%	71.4%
Old Press Brake	10.1%	6.1%	0.0%	83.8%
Shearing Machine	1.7%	7.3%	0.5%	90.4%
Small Saw	9.7%	10.9%	0.1%	79.3%
Large Saw	1.5%	0.7 %	0.0%	97.7%

Table 5.3: Description of the activities used for the detailed studies on the new press brake and the small saw.

Activity	New press brake	Small saw
Working	When the press brake is pressing material	When the small saw is cutting material.
Being loaded	When the machine is being loaded and unloaded.	
Being set up	Programming of the machine's software.	Setup cutting angle and usage och activation buttons.
Waiting due to tool switch	The process of changing tools to get the right bend.	
Waiting due to foreman	When a person from the office is hindering the operator from workin with the machine.	
Waiting due to drawings	When the operator is observing drawings to find out how to use the machine.	
Waiting due to pre-measure	Measurement performed before loading and working.	
Waiting due to control-measure	Measurement performed after working to control the outcome.	
Waiting due to looking for tool	When the operator is performing a rool switch but can't locate the proper tool.	
Waiting due to discussion	Operators discussing solutions and thus occupying but not actively using the machine.	
Waiting due to misc	Operators occupying but not using the machine for other activites such as manual bending or preparng material	Saw not working.

The material flow for the most utilized machines, the laser cutter, the shearing machine, the small saw and the new press brake was quite cluttered as can be seen in figure 5.10, which also includes the transportation of material to the first process as well as from the last process into the oven building area.

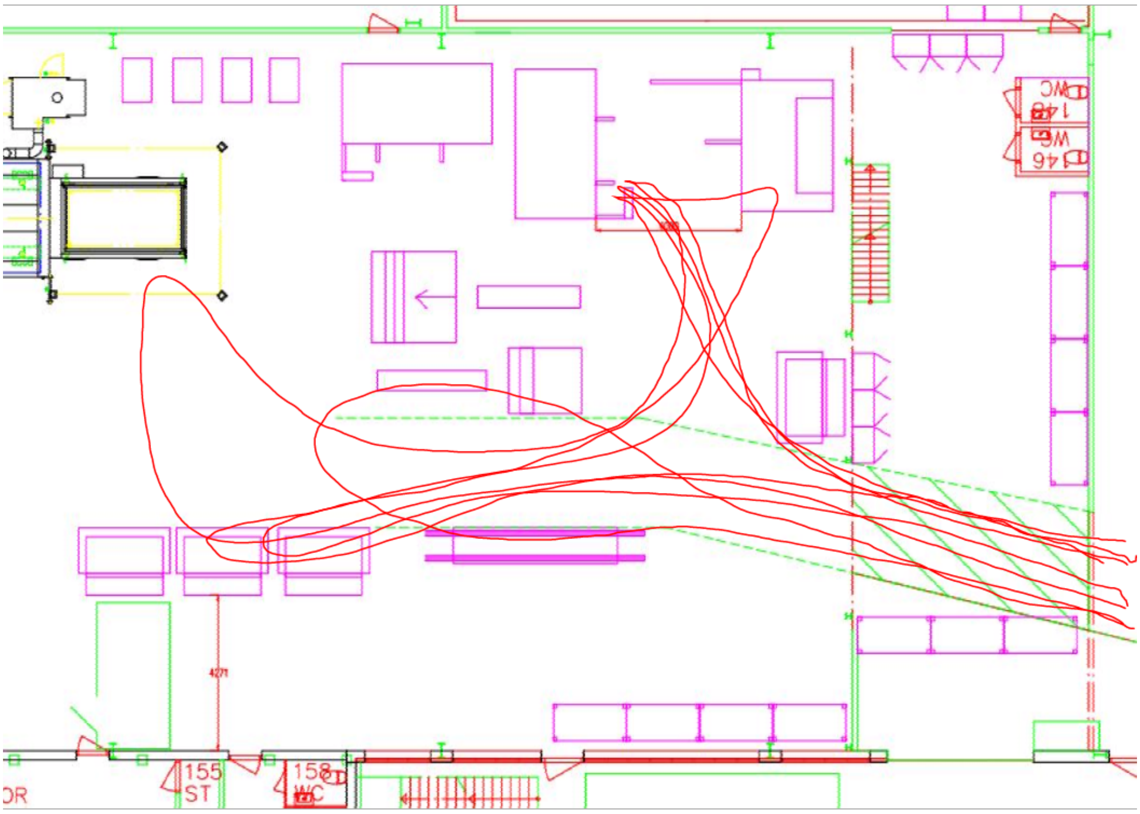


Figure 5.10: The material flow in the machine area.

Utilization of the new press brake

The new press brake was the machine with the highest utilization and the highest percentage of operator present at the machine. One reason for this was that many of the parts from the laser cutter and the shearing machine needed to be processed in this machine. The machine worked 26.7% of the time there was an operator present as can be seen in figure 5.11, which is the actual value-adding process. This low percentage could depend on that the time it took to make one bend was very short in comparison to the time it took to load material in and out of the machine. As can be seen in figure 5.11 there was a lot of time spent on loading and unloading material from the machine. One reason for this was the lack of working space in front of the machine which forces the operators to place large material and finished parts further away from the machine than desired. Another reason was that the operator placed the material further away than necessary. These problems had the biggest impact when large batches were produced, such as when the cover plates were bent.

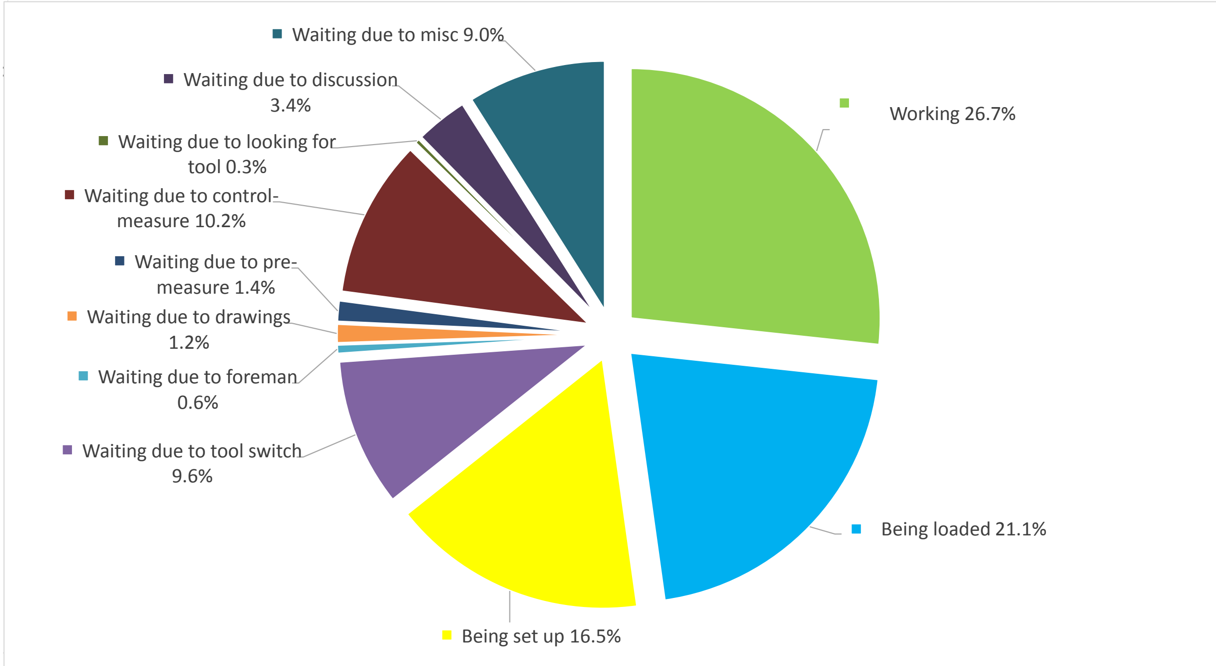


Figure 5.11: The utilization of the new press brake when an operator is present.

The set-up time varied depending on which operator performed it due to a difference in skill levels. The operators that used the machine most were the fastest at performing the set-up. The percentage of the time the new press brake was being set up in relation to the time there was an operator present was 16.5%, which can be seen in figure 5.11. The amount of set-up in relation to working time was much dependent on the batch size, as when only one part is produced the set-up might have taken more time than the actual working, but when a large batch was processed the set-up time was small in proportion to the working time. The reasoning around the set-up can also be applied to when the machine was waiting due to control-measurement which was conducted 10.2% of the time when an operator was present. When an operator had a problem with the set-up there was a need to control-measure a lot more and when the control-measures didn't coincide with the drawings there was a need for more set-up. One other reason for the quite large amount of machine waiting due to being set up and control-measure was that the accuracy of the machine in some cases wasn't good enough and therefore needed more set-up and control measures to compensate. Another problem with the new press brake was that it spontaneously turned itself off during work which forced the operator to turn it on and reload the program in order to continue working.

The new press press brake was waiting due to tool switch 9.6% of the time an operator was present. Both the top tool and the bottom tool was switched by loosening and tightening through screwing. The bottom tool could be lifted out and switched, while the top tool was removed and put in place by sliding it in a rail to the side of the machine. This process could be frustrating for the operator as it involved a lot of steps, sometimes only to make a few bends. The 0.3% of time the new press brake was waiting due to looking for tool while there was an operator present was negligible, as the tools were stored in a well ordered shelf close to the machine.

The categories for when the machine was waiting due to pre-measure, foreman, discussion and drawings was mostly associated with the operator not having the sufficient information to be able to produce the part. The pre-measure could also be caused by an uncertainty if the part had the right dimensions according to the drawing, as well as on which side should be bent. All the activities in the category machine waiting due to misc could be moved outside the press brake as the operator didn't need the machine to perform these tasks.

Utilization of the small saw

An operator was present at the small saw 20.7% of the time, as can be seen in table 5.2, and the small saw was the machine with the highest utilization when an operator was present of the two studied machines with 59.9% of value adding time (see figure 5.12). The value added time depended on what type of material was cut and the cutting speed which was adjusted by the operator. The speed was determined by the operator's knowledge about how fast it was possible to cut different profiles and pipes without destroying the symmetry. It should also be noted that during the value adding time the operator usually didn't need to be present at the machine.

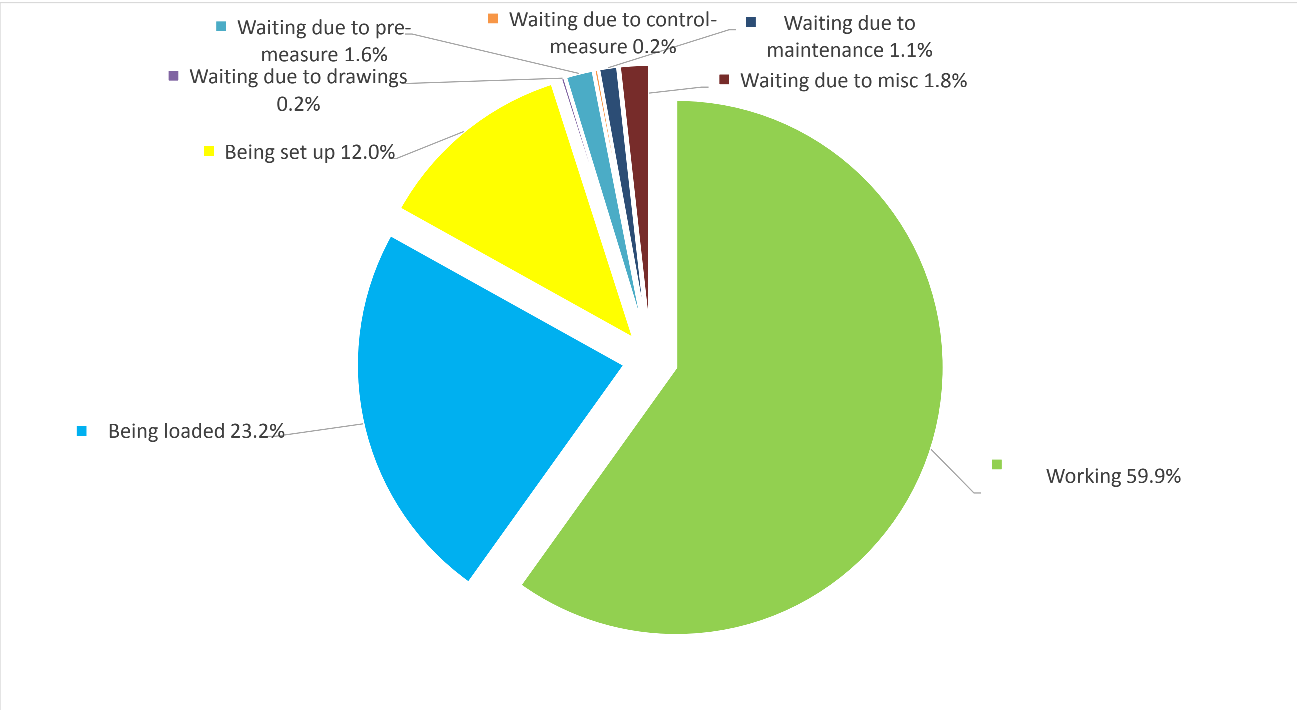


Figure 5.12: The utilization of the small saw when an operator is present.

As can be seen in figure 5.12, the machine was being loaded almost a quarter (23.2%) of the time there was an operator present. One reason that it took this much time was that the operator needed to manually place the part in the right place to achieve the right length on the finished product. Since the machine had a manual loading and feeding process the loading time was not reduced when producing larger batches, as was the case for the press brake.

The manual loading was the reason for the low amount of machine waiting due to control-measures as the operator already had measured the part in the loading process. This was also the reason why there was so little machine waiting due to pre-measure at the saw. The operators rarely read the drawings while working at the saw, probably due to the simplicity of the products produced and only cutting in straight cuts. Maintenance of the saw consisted of cleaning the cooling liquid from metal chips and it was a necessary process to prevent machine breakdown. In the event which resulted in the machine waiting due to misc category, the saw didn't start and the electricians at the company came to try to solve the problem. It turned out that another operator had unplugged the power cable to use a weld instead due to a lack of available electric sockets.

The group of small machines were seldom used but were an important asset when producing all parts in-house. Some of the work done by these machines could be done by hand with other tools but was done much faster by the machine. It also allowed the company to quickly and easily produce one-off tools instead of custom ordering them, further enhancing the flexibility.

Identified issues:

- Lack of working space around the machines
- The area around the machines was also used as material storage
- More machines than necessary
- Operators placed the material further away than necessary
- The accuracy of the new press brake wasn't good enough in some cases
- The new press brake shut itself down during work
- Time consuming tool switch for the new press brake
- The operators lacked sufficient information to perform some tasks

5.4.3 Storage areas

Raw material (C)
The biggest problem identified with the storage of the raw material was the lack of set places for the different materials. The sheet metal was placed in racks but due to the weight restriction in the racks it wasn't possible to order the sheets in such a way that the most used sheets were placed in the most accessible positions. In the beam rack where the beams, pipes and axes were stored, one side of the rack was used for black steel while the other was used for stainless steel. This system

was not enough to make it easy for the workers to find the right raw material as the workers still needed to spend time looking for the right material, which took 4.45% of the oven builders' available time. This included trying to find the right material, control-measuring its dimensions, and moving it to the wanted place. While fetching material was a required supportive activity, some of the moments the oven builders were required to do were non-value adding, such as searching for the right material and control-measuring the dimensions. The beam rack was not big enough to store all the beams which results in beams lying on the floor next to the rack. These beams were a potential tripping hazard, especially when the workers were fetching material from the beam rack.

The insulation material used in the ovens were usually not stored in this area and as stated previously it was often stored elsewhere in the facility where there was some free space. Raw material was sometimes stored outside on the front or back of the facility, due to a lack of storage areas inside the facility.

Identified issues:

- Lack of set places for the different materials
- The beam rack was not big enough to store all the beams

Small components (F)
The company had many different types of screws, nuts and other small components in storage and large quantities of some of the types. One explanation for having these large quantities of one of the screws was that the company had bought another company which had a huge storage of these screws that the company barely uses. Due to the high price of this particular screw the company didn't want to scrap them, instead the company tried to use them. The high amount of different components and the large quantities of some of them created a need for more shelves which resulted in a very narrow hallway between the oven building area and the machine area, further enhancing the impression that there was a lack of space.

On the working table in the middle of this area there were a lot of boxes with components which weren't yet sorted into the shelves. This was probably a result of lack of time and that no-one felt responsible for this area as there was storage area available on the shelves in this area.

Another disadvantage of having this many small components in the storage and components that weren't sorted in into the shelves was that it became harder to find the right part and to keep track of which components that needed to be bought or not. This became a vicious circle which might lead to more mispurchases which in turn would further increase the inventory.

Identified issues:

- Not enough time to sort the boxes with components into the shelves
- No-one was responsible for the area

5.4.4 Other areas

These areas were not included in the study, as it focused on the oven builders, but had an effect on the work for the oven building process. Area E1 for example was a passage which some of the workers used to get to the machine area (see figure 4.2) and when this area was unarranged, it causes the workers to take a detour.

5.5 Planning & material handling

This sub-chapter presents the analysis of the planning and material handling at the company, while connecting analyzed issues to results of the oven builder utilization study.

5.5.1 Planning

The current method of planning could require a lot of space, as the roof, floor and doors of the product were finished before they were needed. It also forced unnecessary moves, as some other products needed to be moved around to create sufficient work space. The staircase type of planning exemplified in Figure 4.6 was necessary as somewhat few resources were dedicated to each project, meaning that a lot of things needed to be done by few oven builders hence requiring this type of planning.

The division of the planning process into production planning, product planning and resource planning allowed the company to ensure that long-term and short-term planning worked together. Since many projects were run simultaneously as described in chapter 4.2, a lot of strain was placed on the planner which could lead to sub-optimization. The production planning process was optimistic as many projects were run at the same time, which further enhanced the impression of a lack of work space. The product planning as explained earlier required a lot of space due to the low amount of resource allocation per product and also contributed to the aforementioned impression. Planning made in the resource planning gave the impression of being very fluid and seemed to be highly accepted within the company as the workers accepted changes to the daily tasks with short notice without question. This part of the planning was also very clear as it was visually shown for every employee via a print-out Gantt chart similar to figure 4.7 on the whiteboard in the break room. The extra personnel available as presented in chapter 4.1 was a smart way to gain flexibility without adding too much cost when it wasn't needed. Too much temporary employees however could be a part of the reason for the lack of improvement work and the disorderly state of the facility presented in chapter 5.2 and chapter 5.4.

Machines were not planned for in the same way that other resources at the company. There were no planning for when the machines should be utilized for which project nor any allocation of times for various projects. This led to some waiting times and frustration from the oven builders as several projects sometimes needed to occupy the same machine simultaneously.

The planning process also failed to account for the space available in the oven building area, as it was too simple in order to fully comprehend how much space each project needed to occupy for various amounts of time. This was also a contributing factor towards unnecessary movement which made up 2.92% of the time. The movements were labeled as supportive in general, however certain moments were non-value adding such as the repositioning of products or parts of products due to making room for another one.

Identified issues:

- Sub-parts were finished before they are needed
- No planning for the machines
- The planning process didn't account for available space in the oven building area
- Unnecessary product moves

5.5.2 Material handling

As explained in chapter 4.4.2 there were a lot of different materials in stock. Many of these were rarely used and was a result of employees ordering too much or ordering the wrong material. Since the products were customer-adapted, the materials required for their production varied and as the product design process didn't really consider which materials were in stock at the moment, the chance of the excess materials mentioned previously being used was low. Sometimes ordering in exact dimensions was expensive, thus ordering standard dimensions might be a better decision economically but it resulted in some spare material, which may never be used again. Combined with the analysis from chapter 5.3 regarding the faulty bill of materials, it became difficult for the company to understand just how much of the materials purchased were used for each project. Since there was no follow up as to how much material each project used, this cycle keeps on repeating itself which resulted in the current situation with lots of material of different qualities and dimensions in stock.

Progress had been made to begin standardization of material choice, such as the removal of two metal sheet thicknesses and replacing it with the one in between. This exhibited signs of making the material handling more efficient through standardization, however much work was left to be done as there were around 50 different sheet metals in stock. One reason for having sheet metals in storage was that the orders for the contract production could have very short delivery times and if the material wasn't available at the facility the company would lose the order.

Regarding the ordering process, there was a lack of re-ordering points for standard materials. As the ordering of this was based on an assessment made once a week without considering how much was expected to be used until the next assessment, this process had potential of being better. The ordering of non-standard material was handled poorly, as it was re-ordered when there was no more in stock if an employee notified the office. However similarly to that of standard materials the expected usage of these materials wasn't really considered. Who was responsible for placing the orders was also an issue, as the responsibility areas were unclear as explained in chapter 5.2 and several employees had the ability to place orders of raw materials. This could have led to sub-optimization of the order placement, if for example two separate orders were placed for the same supplier, thus not minimizing the cost of delivery. This issue also led to that employees at times had to travel to a supplier and purchase material due to the lack of a proper ordering and inventory management function within the company.

The price on steel products could vary a lot depending on the availability at the supplier and on the market price. The company used some special qualities, which were for example heat resistant, which weren't always kept in storage at the suppliers which in turn directly influenced the price. When the company procured the raw material needed it was often much cheaper to buy in larger quantities and therefore the standard metal sheets and beams were often bought in larger quantities than immediately required. The cost of purchasing a small part of a pipe was sometimes almost as expensive as purchasing the full-length pipe due to the extra work required at the supplier's end, thus raw material was generally purchased in full lengths unless it was assumed never to be used again. The delivery time varied a lot between different materials, for standard sheet metal it could be as low as 2 days while the special qualities could take up to 12 weeks. If the delivery of sheet metal was very urgent the company used a supplier close to the facility but the prices were almost twice of those at the regular supplier. Therefore this supplier was only used when there is an urgent demand of raw materials. When there was an urgent lack of smaller materials or safety equipment, one of the employees traveled to a local supplier to solve the situation.

Since the company used many suppliers, there were both benefits and drawbacks to analyze. The biggest benefit was that the company became less reliant on one supplier, however the ability to work closely with a supplier diminished with the use of several. This could also have contributed to the issue described in the beginning of this sub-chapter regarding the amount of material in stock, as not having the supplier relationship required to get the right amount of material at the right time in itself caused either more stock or shortages.

Identified issues:

- Lack of re-ordering points for standard material
- Several employees had the ability to place orders of raw materials
- The employees had ordered too much or the wrong material
- No-one was responsible for there being enough material

5.6 Improvement potential

As revealed in this analysis, there was great potential in increasing the utilization of the oven workers and thus increasing the company's capacity in general to reach the goals established. Grouping of the causes into three main categories yielded the cause-and-effect diagram presented in figure 5.13. A more detailed view the issues related to each category is shown in the following figures; the organization (figure 5.14), the layout (figure 5.15) and the planning function (figure 5.16).

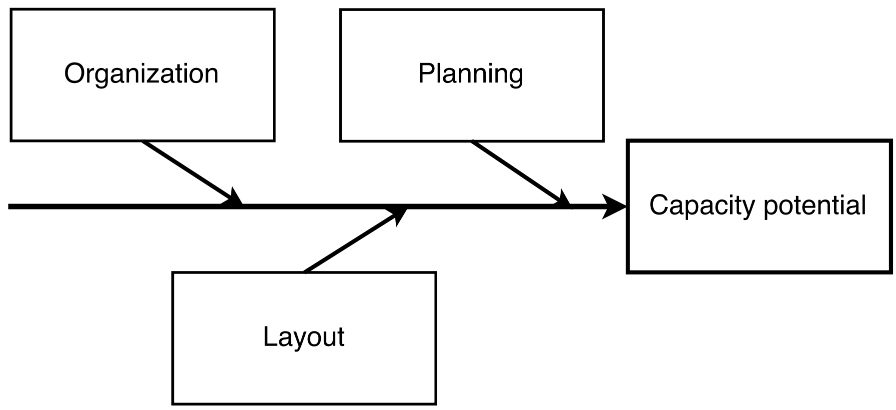


Figure 5.13: A cause-and-effect diagram of the current situation showing the three main groups of issues.

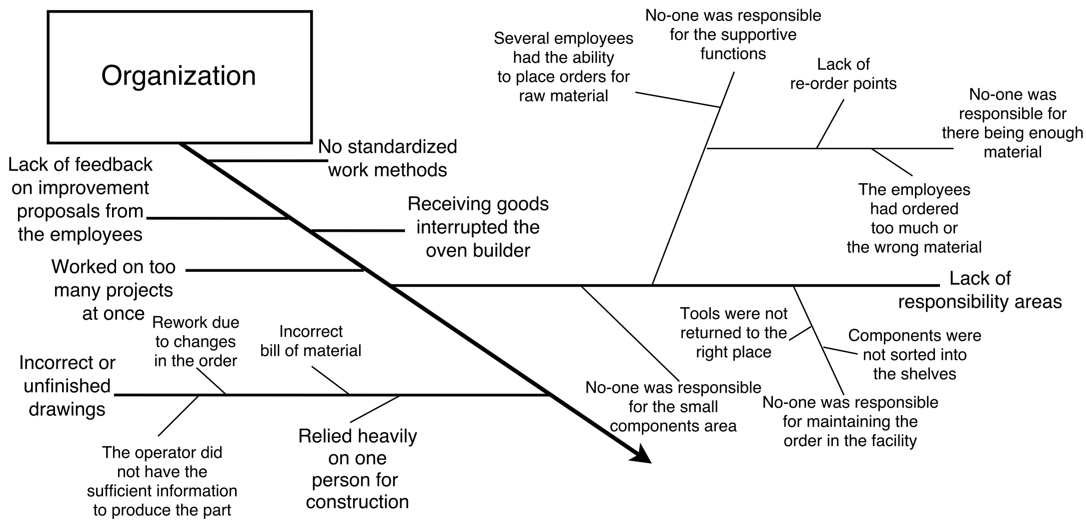


Figure 5.14: Issues related to the organization.

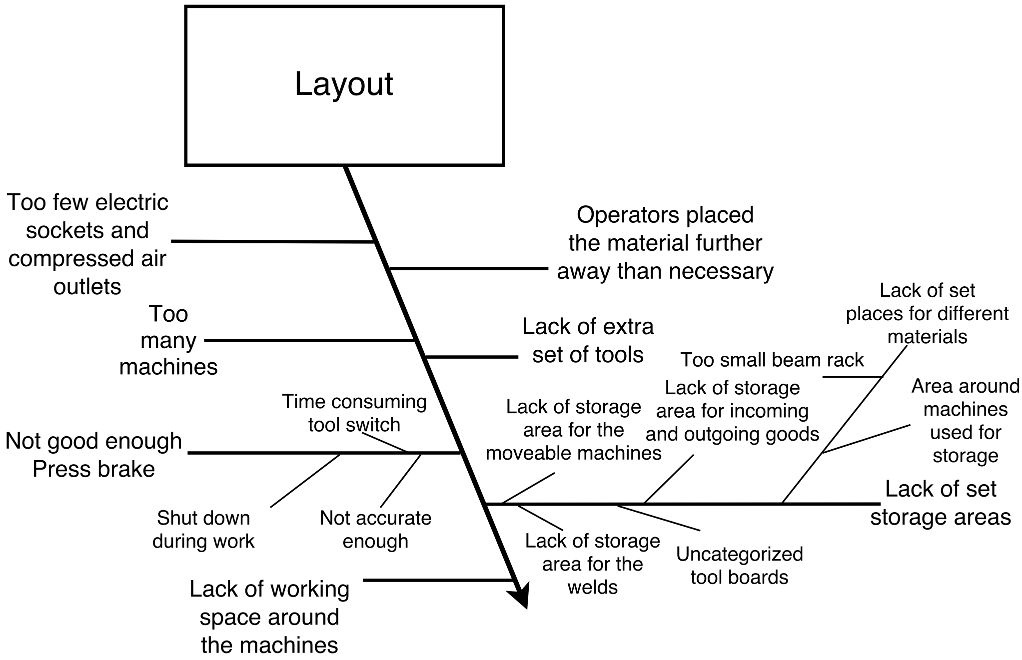


Figure 5.15: Issues related to the layout.

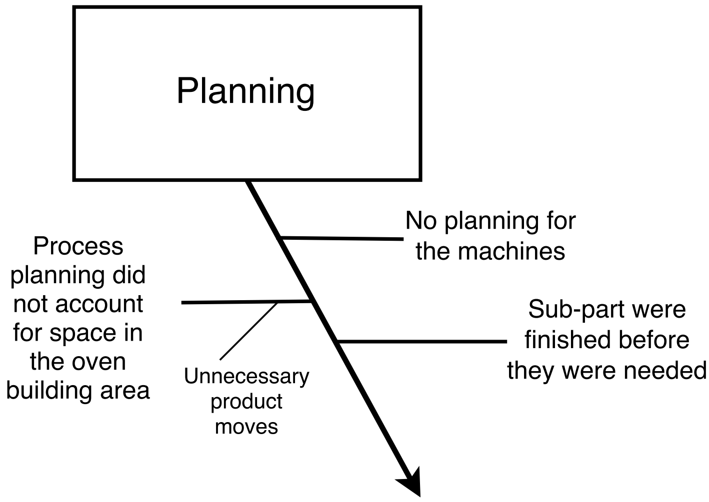


Figure 5.16: Issues related to the planning function.

6
Improvements

The following chapter presents the proposed improvements. It starts off each subsection by presenting and motivating actions, followed by presenting the expected effects of the actions.

6.1 Organization

Responsibility areas
There should be clear responsibility areas throughout the organization, as many things currently were being handled poorly. The lack of clear responsibility areas was jointly responsible for a poor efficiency throughout the company in areas such as purchasing, which in turn caused losses in productivity. Clearly assigned responsibility areas would improve the handling of standard material re-ordering through purchasing responsibility. It would also open up possibilities for the upper management to put demands on the handling and development of all functions within the company to further increase the efficiency. Assigning responsibility to the right person would also ensure that improvement suggestions from the oven builders are taken seriously.

Another such responsibility area which should be assigned is the shop floor. A shop manager should be responsible for this area, and also take care of the goods reception process, the maintenance and location of tools and other sub-functions related to the shop floor. Considering the size of the company, it is most suited to use an experienced employee for this role that can aid the other employees in their work when needed. The shop manager should also be responsible for the development of the shop floor to ensure that it is able to support the company fully, and be the link between the shop floor and the office. This would help the long term development of the company as it would increase the alignment of the manufacturing and the other business functions if taken seriously.

Actions:

- Define, assign and make responsibilities such as purchasing clear throughout the company.
- Assign a shop manager, responsible for shop floor development, ensuring that the shop is maintained properly as well as shop floor-related sub-functions

such as goods reception and the maintenance and location of tools.

The effect of these actions on an organizational level are function effectivization, the improved ability to follow up and learn over time as well as improved long-term development of the company as it would be easier to work with continuous improvements. With regards to the production capacity, these actions would reduce the amount of time the workers need to spend on supportive actions such as the maintenance of tools, searching for tools, cleaning and packaging as the shop manager would reduce the need for these actions. The shop manager would ensure that the tools are in their place and reduce the amount of clutter created by the oven builders as this manager would be able to ensure that everything is in its place.

Process improvements
Fewer ovens should be produced simultaneously, using more resources simultaneously for a shorter period of time. Having multiple oven builders per oven would reduce the amount of space needed as well as the work in process. It would also give the oven builders more support in terms of having co-workers to discuss solutions with. Producing fewer ovens at the same time would improve the company's focus and make it clear whether sub-parts will be finished on time, which in turn would make resource planning easier.

Drawings should be finished to the extent which is possible with regards to customer changes before production of the oven is started. All products should be well prepared in order to make the production process as efficient as possible. Part of the inefficiencies in the production process were tied to the quality of the preparations such as drawings and planning, and should be reduced and avoided as much as possible through improved preparations.

Actions:

- Build fewer ovens much faster using more resources.
- Focus more on drawings and other preparations.

These actions would reduce the lead time in production, allowing for quicker delivery dates as well as reducing the facility-related overhead costs tied to each product. There would also be an impact on the time the oven builders needs to spend in order to understand the drawings and figure out solutions, as there would be more than one worker performing the task and the drawings would be of a higher quality. It would also be easier to understand how the load on the office is, as it would be clear what isn't finished on time which would allow for long-term improvements in terms of hiring for the right positions. Better preparations in general would also reduce the amount of work hours required to produce an oven, while building fewer ovens at a time faster would reduce the amount of space required to produce the same amount of ovens.

Resources

There should be an employee responsible for the production of kits to supply the oven builders with materials. This employee should be trained in all of the major machines, including the laser cutter, and work in tandem with the laser cutter operator. To further increase the amount of time the oven builders can spend on building ovens, reducing or removing any other activities is essential. This action would also separate the machine area flow from the oven building area flow.

Action:

- Assign an employee responsible for producing sub-parts in the machine area.

The sensitivity for variations and the risk of having starved oven builders would be reduced through this action, thus also giving a reduced risk of stalled production. The oven builders would be required to spend no time using the machines, severely reduced time walking between the machine area and the oven building area empty-handed and much less time fetching materials as all that needs to be done is fetch a kit. There would also be less time spent understanding the drawing as no times would be spent on calculations and figuring out how to produce the parts that are needed.

6.2 Layout

Oven building area
Due to the varying size of the products there were no fixed working areas for the ovens, however the implementation of a layout planning system would ensure that the ovens were placed in a strategic way. The problems with disorder in this area should be addressed and every tool and other piece of equipment needs to have its own place. There was also a need for a fixed assembly table on which small sub-assemblies could be performed and a pallet rack for storing the material and tools that were very seldom used. To find the best solution for the layout with fixed places for all equipment a workshop with the workers should be held since the workers were the ones that knows the process best as well as which tools that were used most. To further increase the order in the oven building area the personal tools on the tool cart should be colored to make it easier for the shop manager to find the oven builder responsible for tools in the wrong place. This would increase the ability to follow up if the disarrangement problem is caused by everyone or just a few of the oven builders.

After the initial work sampling study was performed the company invested in more compressed air outlets in the oven building area which solved the problems of oven builders waiting on each other due to lack of outlets. The same should be done for the electrical sockets which sometimes were a constraint when building or testing the ovens.

Actions:

- Hold a workshop to determine the fixed places for all equipment

- Mark the tools and carts with color to pair them together
- Invest in more electrical sockets

These actions would result in a reduced amount of time spent looking for tools due to fixed storage places and better order. The increase of electrical sockets would reduce the time the oven builders are waiting for each other to finish jobs that require electricity. The reduced amount of time required for these supportive and non-value adding activities would increase the amount of time available to perform value adding activities.

Machine area

The layout of the machine area should support the organizational action previously presented where the flow is divided. To make the machine area flow and oven building flow as independent as possible from each other a finished sub-part storage should be placed at the end of the flow in the machine area. Another small middle storage should be placed before the press brake in order to allow the operators to batch work together in order to reduce the amount of start-ups and setups and make the process as efficient as possible. The new material flow is presented in figure 6.1.

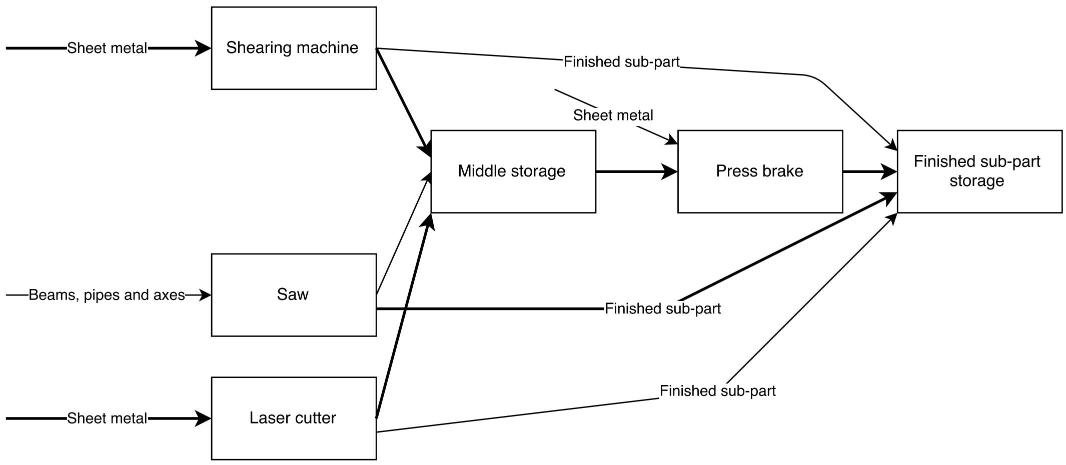


Figure 6.1: The improved production flow.

The layout should focus on the flow between machines and allow for comfortable working space. It should utilize pallet racks for semi-finished goods and finished goods to avoid parts being stored in the work areas. It should also be easy for the oven builders to fetch parts without disrupting the other work in the area. The two machine operators should also be able to work without disrupting each other.

The capacity required at the press brake and the saw was less than full time at one machine, hence the improved layout was based on utilizing one press brake and one saw instead of two of each. The company had invested in a new sheet metal rack which could store more sheet metal per square meter, therefore one sheet metal rack could be discarded. The layout designed on this basis and its material flow is shown in figure 6.2.

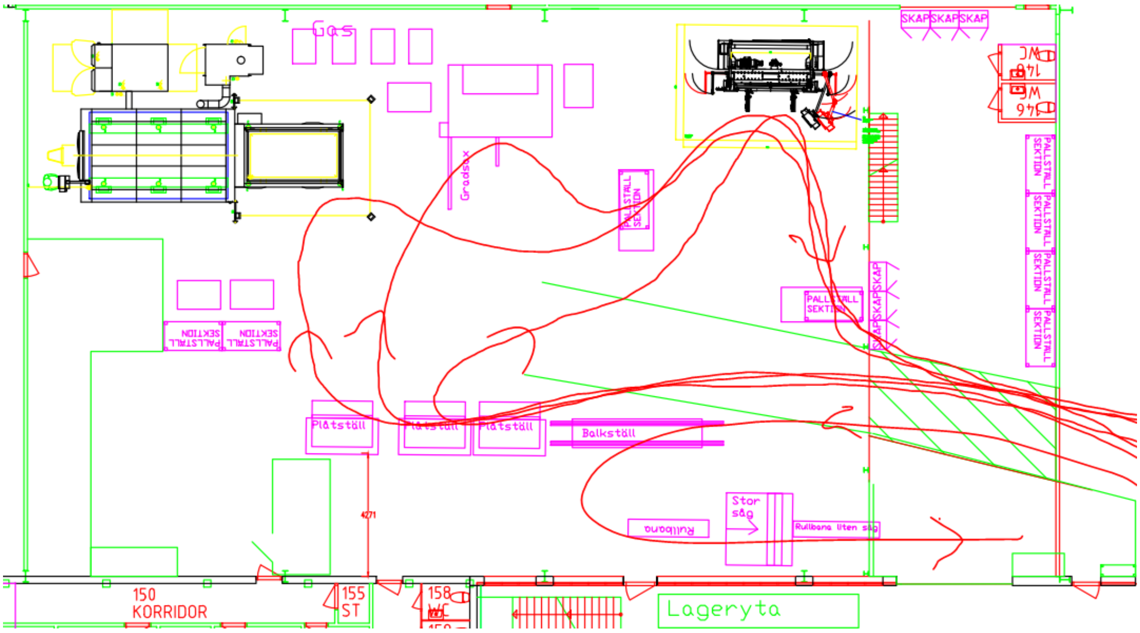


Figure 6.2: The improved layout and resulting material flow in the machine area. The red lines represent the main material flow.

Action:

- Rearrange the area according to figure 6.2.

The U-shaped material flow layout as shown in figure 6.2 would give a visually clear flow which would help identify problem areas. The layout would provide easy access for the oven builders, so that the process of fetching kits is quick. This would reduce the amount of time the oven builders needs to spend fetching material. Having all finished parts in a pallet rack would also reduce the amount of time the oven builders needs to spend searching for material. The layout would reduce the amount of parts and materials stored in the working areas as there will be a storage place for the parts between operations. This would reduce the distance between the machine, the raw material and the semi-finished parts.

6.3 Planning

Project planning
To reduce the production lead time for the ovens a parallel planning should replace the existing sequential planning in the project planning. The goal of using parallel planning is to eliminate the time in which the main product or sub-parts are waiting for each other. This means that sub-parts should be finished as close as possible to the time it should be assembled on the main product. If the products are finished in advance, the utilization of the building space in the oven building area is unnecessary low due to storing finished products. Another advantage of parallel planning is that it would reduce the amount of active projects at a time, which should help the company to focus more on a specific project.

When using parallel planning the starting point would be the delivery date of the product and then planning backwards in the production process. Parallel planning requires that the planner has good knowledge about how long time it takes to perform each step in the process and that no big interruptions occurs. In the case of the production of a chamber oven the first step would be to determine when the testing and packaging should start based on the delivery date. Then the start time for assembling the electrical components should be decided so that it is completed when the testing should begin. This process is then repeated for all sub-parts of the oven, an example of this is shown in figure 6.3. The company should continue to use the Gantt-chart to visualize the plan and make it easy to understand for all involved personnel.

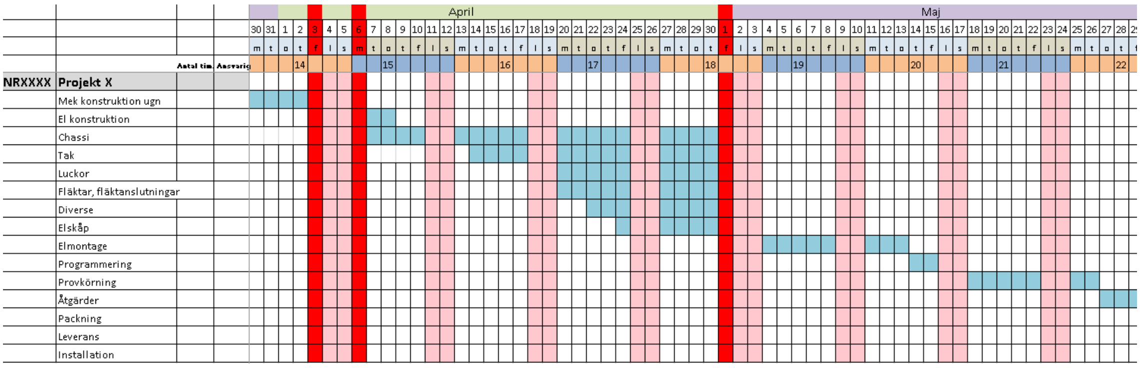


Figure 6.3: Example of an improved parallel planning.

Action:

- Increase the usage of parallel planning
- Build the plan backwards, start with the delivery date and work towards the production start

These actions would result in shorter production lead times, which would increase the factory's capacity, as well as fewer active project simultaneously which should improve the company's focus on each project.

Layout planning

In today's planning process the available space in the oven building area are not included which resulted in unnecessary moves of products and too many ovens produced at the same time. To solve these problems the planner should use the space as a constraint when accepting an order and setting a delivery date. This should be done by using the drawing of the oven building area and and determining the position of the different parts of the product as shown i figure 6.4. The size of the working space is determined by the technical specification. The planning should also include for how long time the product or sub-part will acquire the specific area. The choice of position should be based on the entire production process to reduce unnecessary moves, for example sub-parts should be produced as close to the main product as possible and there should be sufficient space for the trailer when a product is loaded for transport without moving other ovens around. It is also important to ensure that there is enough working space around the products and if there is a need of using special equipment, like the larger fixed crane, it must also be taken into consideration when performing the layout planning.

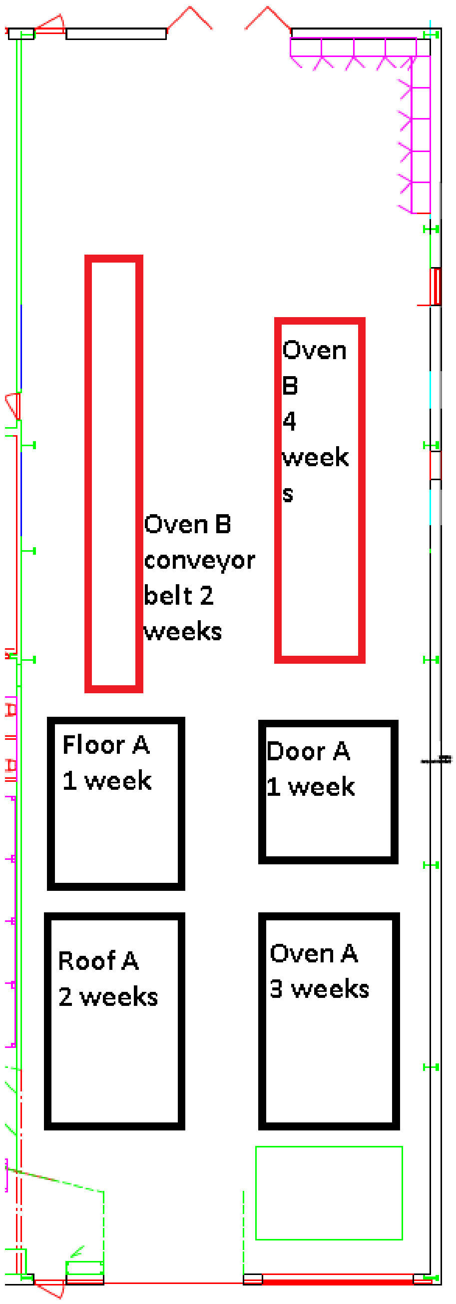


Figure 6.4: Example of a layout planning.

Action:

- Implement a layout planning for the oven building area
- Include the layout planning in the production planning

The effect of these changes would be a reduced amount of unnecessary movements of products and sub-parts, which results in less time spent on unnecessary activities and would free up more time to build ovens which would increase the output. There would also be a tool to avoid crowding the oven building area which would lead to a more open working environment in which it becomes easier to find tools and materials.

Machine planning
Due to the division of the production flow into one flow for the machine area and one for the oven building area there would a need for a new planning function for the machine utilization. There would be a internal customer relation between the machine area and the oven builders, which would result in that the delivery times from the machine area should be the same as the time the material is needed in the oven building process. The production orders from the oven building area should then be sorted so that orders in the same machine are batched together to reduce the amount of times the operator needs to do the start-up at the machine. The most important constraint for the machine planning however are the delivery dates, as it would be very important that the oven builders don't get starved for material since it would stop the work on the oven. The planner should also consider which operations that requires two operators, for example large parts in the press brake. These parts should be produced at the same time as the laser cutter works on a long program as it minimizes losses in the machining area. The machine planning will also be a good foundation for the material handling system because the planning shows how much material that is required to fulfill the orders for the narrow future.

Action:

- Implement a planning function for machine area
- Use the machine planning as a basis for material procurement

A machine plan would result in the oven builders getting the material needed in right time to avoid interruptions in the production in the oven building area. It would also make the material procurement process easier which would allow the company to reduce the safety stock and free up capital.

6.4 Expected outcome

The expected effects of the actions on the respective categories of oven builder utilization is shown in table 6.1. For example, if there were to be a shop floor manager, the cleaning activity should be reduced as the shop floor manager would help improve cleaning standards as well as maintaining the standards. The shop floor manager should also help with some of the supportive actions such as the reception of goods. Other activities such as the usage of the press brake, saws and the shearing machines could be completely removed, but sometimes the operators might still need to quickly produce a part and as such there still might be a need to use these machines.

Table 6.1: Expected outcome of the actions in hours per day based on an eigth hour workday.

Activity	Current time	Expected time	Change	Reasoning
Using press brake/-saw/shearing machine	0.53	0.05	-90%	Shouldn't be done at all ideally
Fetching material	0.36	0.14	-60%	Only needs to fetch filled bins from machine area
Performing maintenance and fetching tool	0.51	0.26	-50%	Everything is in its place, colorized personal carts, shop manager
Cleaning	0.15	0.08	-50%	Shop manager take care of some
Walking empty-handed between areas	0.03	0.00	-95%	No empty transports needed but still might need to discuss with operator
Moving a product or part of a product	0.23	0.12	-50%	Better planning reduces the needs for moves
Talking/Discussing	1.02	0.41	-60%	Better drawings and less need for discussing, no machine calculations
Performing uncategorized supprotive actions	0.25	0.13	-50%	Shop manager take care of some
Waiting for a machine	0.01	0.00	-90%	Shouldn't be done at all ideally
Moving material out of the way	0.04	0.00	-90%	Not needed ideally as everything should have its own place
Taking personal time	1.14	1.14	0%	The amount of personal time is not expected to change
Waiting for machine job and other idling	0.18	0.09	-50%	Less need to wait, more focus on the shop floor
Summary	**4.45**	**2.41**	**-46%**	

Figure 6.5 shows the expected utilization of the oven builders after implementation of the expected effects. The differences between the current state and the expected future state following the implementation of all the actions based on an eight hour long workday is that each oven builder can spend 4.88 hours instead of 3.52 hours working on the oven or related sub-parts, an increase with 38.75%.

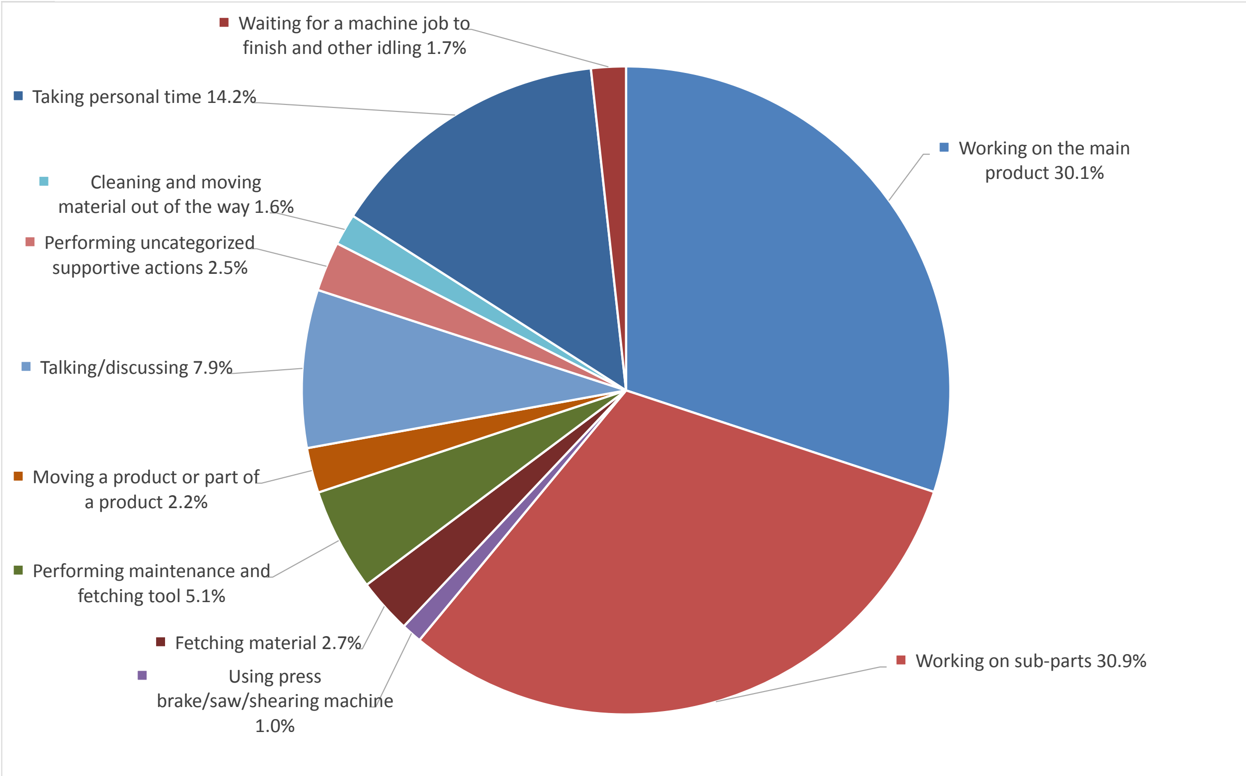
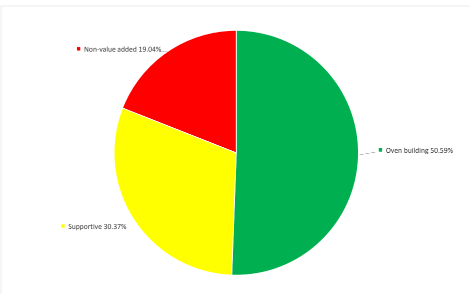
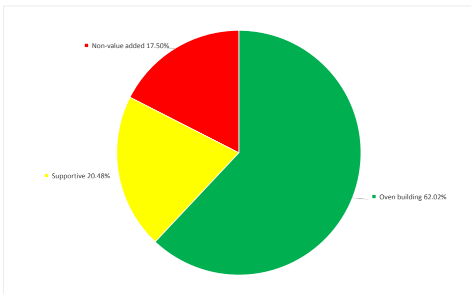


Figure 6.5: Expected future utilization of the oven builders.

Figure 6.6 shows the current state of the oven builder utilization divided into the three main categories as resulted from the study (figure 6.6a), compared with the expected utilization of the oven builders following the actions (figure 6.6b). The value added part of the oven builder utilization is expected to increase by 22.6%.



(a) Current utilization.



(b) Expected utilization.

Figure 6.6: Current and expected future utilization of the oven builders.

7
Implementation

This chapter presents an implementation plan as developed by the authors with the purpose of aiding the company in successfully implementing the solutions and improving long-term.

A plan for implementing the actions was developed for the company to follow in order to succesfully implement all actions. The plan was based on Kotter's (1996) eight steps for succesful change combined with the following three steps (Miltenburg, 2005):

1. Set course projects.
2. Shoot and aim projects.
3. Main projects.

For this company, this means starting with an initiation of the change process, followed by changes to the production area and the office area simultaneously and continuing with changes to the machine area. The last step of this implementation plan is to create a culture and environment where continuous improvement can thrive.

7.1 Initialization

The top management should start this improvement implementation by discussing how the company should be in the future, what the company culture should be like and what the main goals for the company are. When the top management has reached a conclusion to these questions the result should be presented for the rest of the employees to make sure that all employees at the company knows and understands the end goal of the change process ahead. This presentation can preferably be combined with a team building activity to strengthen the cohesion at the company.

The next step is to implement an easy improvement which has a guaranteed positive effect on the company. In this case the investment in more electrical sockets is a quick fix which would result in reduced frustration for the oven builders due to the reduced time spent on waiting for an available socket. This was a well-known problem in the production area at the company and could therefore be seen by the oven builders as the top management showing interest. Following the first quick fix an improvement to a problem considered important by all employees should be implemented. At this stage the company should divide the improvement work in two categories, improvement in the production area and improvements at the office. These two categories should be implemented simultaneously since they affect each other.

7.2 Production area

The first improvement that should to be done at the shop floor is the assignment of a shop manager, to start the work on creating a well-organized and clean working environment. The shop manager would also give feedback during the change process, both to the oven builders and the top management. To achieve the best starting point for the shop manager a workshop should be held to find fixed places for the equipment and material stored in the oven building area.

This workshop should be held by the shop manager with support from one of the top managers to show the oven builders that the top managers and the shop manager are working in the same direction. By using a workshop the managers shows interest in all employees opinion which would improve the continuous improvement work in the future. The first step in the workshop is to define the goals of the workshop. In this case the main goal is to reduce the disarrangement in the oven building area and to reduce the time the oven builders spend on looking for tools or move material around. Therefore the workshop participants needs to determine fixed places for all equipment and material in the oven building area. The next step is to invite the relevant employees, the shop manager, one top manager and the oven builders, and find a suitable location in which the workshop won't get disturbed. Before the workshop the shop manager needs to prepare a foundation for the discussions which should contain a list of all equipment and material that needs to be stored in the area as well as a print-out of the drawing of the facility without any moveable equipment or shelves and print-outs of the equipment in the same scale as the drawing to make suggestions visible. During the workshop the participants should move around the printed equipment on the drawing and discuss pros and cons for the different solutions. It is also important to document the different solutions in case there is a need to compare one of the previous solutions with the current.

Once the workshop has reached a solution the oven builders and the shop manager should start the work of implementing the solution. The implementation should take place when there are as few ovens in production as possible and the oven builders should not be working on the ovens during the implementation. This would help the oven builders and the shop manager to focus on finishing the implementation in a thorough way, without disruptions from the production. During this implementation all the tools that are kept in the tool carts should be color-marked, one color for each cart. This would help the shop manager to keep the order in the area long-term, hence it is easier to find the employee responsible for the disarrangement with color-marked tools.

The last step in the implementation is to sustain the new order in the oven building area, which becomes the shop manager's responsibility. It is also important that the top managers gives feedback to the employees to motivate them to improve the order even further.

7.3 Office area

The first improvement which should be done in the office is the designation and assignation of responsibility areas. This could be done through a workshop, where all members of the office meet and brainstorm all areas which exist in the company, group them up and assign the responsibilities to those most suited. It could also be done by top management if the consensus is that it will be accepted that way. This improvement should yield slight immediate results, but is mainly a long-term solution as it enables other improvements, while aiding the process of following up how functions are being handled.

Following this improvement fewer products should be made simultaneously using more resources, as the shorter lead time will be noticeable right away, combined with better drawings. The quality of the drawings has been an issue during the entire study, and any improvements made in this area would yield significant effect and spread a positive feeling throughout the shop floor as the oven builders would feel that their concerns are taken more seriously. These changes work well in tandem, however it requires more effort from the office and could be limited by the current capacity. These improvements are also expected to become more efficient as time goes on due to the continuous improvement of work methods which spawns from the knowledge gained of performing tasks.

Parallel layout planning should be implemented once the previous steps are working, as it is a comparatively more complex solution. It requires knowledge of how much space is needed around the products and sub-parts as well as what kind of movements must be performed and in which order. This implementation will likely not be perfect in its initial implementation, as the time required for sub-processes currently consist mostly of qualified guesses, hence it is important to follow up and learn from the experiences with it to further improve it as more projects have been completed.

7.4 Machine area

The first improvement which should be implemented for the machine area is to rearrange it according to figure 6.2. This would make work performed in the area more efficient and show that management is invested in the change process. Following the rearrangement, a machine operator should be assigned or hired which over time should become better at utilizing the machines than the current users. This change would free up much time for the oven builders and works well with the improvement regarding better preparations as presented in chapter 6.1. It would also improve the focus on building ovens on the shop floor and help find improvement areas as the flow will be divided. Once this has been implemented, machine utilization and raw material procurement can be planned in greater detail, as it will be possible to combine data from the machine utilization planning with inventory data and procurement details such as delivery times and economic order quantities. This would significantly improve the procurement function as there should be much less need for excess inventory and a lower risk of mispurchases.

7.5 Future

When the previously described steps of the implementation phase are completed, it is important for the company to continue improving. To achieve this the company needs to become a learning organization, which follows up all changes, good and bad, and learn from them. Experience gained needs to systematically be seized so it can be utilized in future improvement work, so the same mistake doesn't occur again. The company also needs succession planning and knowledge management, as a lot of knowledge lies within individuals rather than the organization which puts the company at risk of losing it. It is also important to keep improving the company culture to keep improving throughout the organization while aligning with the long-term goals. The future of the factory and organization as well as its culture should be supportive to the long-term goals of the company to avoid contradictory actions.

7.6 Implementation plan

The implementation plan presented in figure 7.1 summarizes the steps described in chapter in the order they should be performed. The last step of this plan is iterative, as the change process is never-ending.

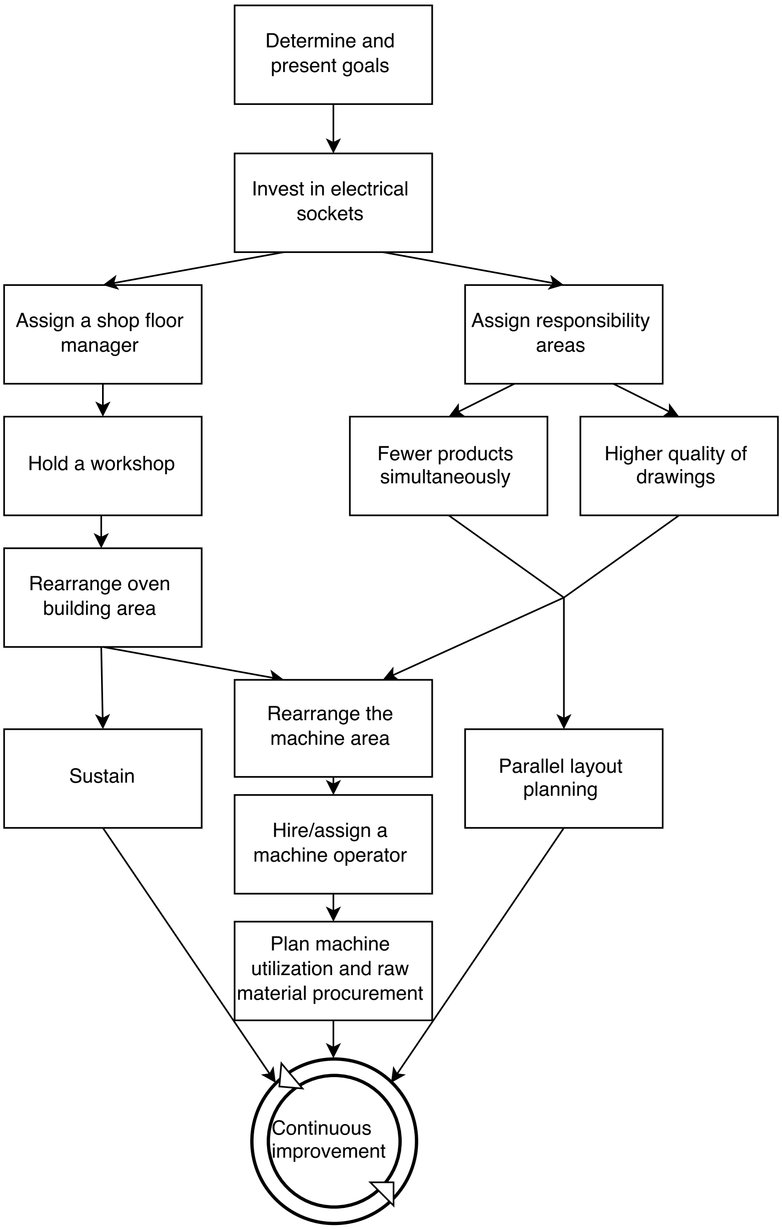


Figure 7.1: The implementation plan.

8

Discussion

The discussion chapter presents a discussion about the methodology, the findings and analysis of the current state, the improvements and implementation plan as well as the response given from the company.

Methodology

The methodology used in this thesis was followed as planned without major complications. The methods and tools used served the authors well in capturing the current state of the whole company. However adapting the methods engineering concept to this study was difficult at first, as neither author had any experience of this concept nor the work sampling method. The concept was compared to how previous projects had been carried out by the authors which lead to the realization that it was quite similar. After some minor alterations, the methods engineering concept worked well for the project, however some steps weren't feasible to apply due to the limitations of the project.

The biggest difficulty during the study was performing a work sampling study. Initially there were lots of things to consider, as activities weren't clearly defined and the authors had issues quickly getting a grasp of what the oven builders were doing at the sampling moment. It might have been better for the study if the authors had more experience performing work sampling as it probably would have made the start of the study smoother. The authors could also have benefitted from further testing of the activities to further improve them. This was however achieved when finalizing the work sampling study when similar activities were grouped together. A possible source of bias in this study is that the authors weren't able to fully randomize which oven builders to study each session. Since not all oven builders were present every day, this choice was conducted by the authors once possessing knowledge of which oven builders were present and what the oven builders were doing. Later during the workday the authors chose subjects before entering the production facility.

Current state

During the entire data gathering part of this thesis, the authors saw signs of the Hawthorne effect at the company. Several improvements which had been neglected for a long time were performed such as building racks for leftover materials for both beams and sheet metal as well as investing in more compressed air outlets. In general, the employees at the company seemed more willing to improve and new improvement suggestions were brought up as some of the old ones were dealt with. The authors believe this is due to the management apparent interest in the production and working conditions as displayed by the initiation of this thesis. This effect didn't clearly show up in the work sampling study, as the changes didn't directly affect the utilization, however the company culture and working environment was subjectively improved as the study went on.

As the company had good efficiency but lacked some in effectievness, the authors' choice of excluding the workers' performance rates in the study worked out well. Especially since the biggest opportunities were identified outside of individual worker performance.

The company faced issues dealing with suppliers as they are a comparatively small player on the market. For example, they can't find good deals for customized shapes and sizes which forces them to buy standard size materials even though otherwise would have been preferred. They also sometimes need to buy more material than needed to get a good deal in terms of shipping, which results in excess inventory and in turn reduces the available space. Working closely with supplier could help them improve on this situation, for example by having a storage at a supplier. Currently this type of cooperation is difficult to achieve, as the company sometimes require very quick deliveries of material to secure an order. This forces the company to procure more expensive material just to get it quickly enough from a local supplier.

A recurring theme during the work sampling study was that when the oven builders were doing more time consuming activities, such as isolating a large oven, work was performed with more intensity over a greater period of time as there were no natural interruptions, such as fetching a new tool. This shows that the company culture is to work hard but that all the small interruptions which normally occurs are detrimental to productivity. Based on the authors observations of this very focused work, the assumption that productivity would improve if the amount of interruptions are reduced is expected to hold true.

Improvements and implementation
In order to decide how much each studied oven builder activity would be affected by the actions proposed, the authors discussed what the actual effect would be. Hence the expected outcomes of the improvements are based exclusively on the authors' perception and best estimates. The estimates were on the lower end so that the changes to the oven builder utilization is expected to at least match the presented estimates.

One thing which might have enhanced the results of the study and given a better basis for the machine area improvements, especially the machine planning action, is including a detailed study of the utilization of the laser cutter. With this data added to the study, the machine resources could have been balanced between the proposed two operators. However, the laser cutter was excluded from the machine studies as the focus of the main study, the oven builders, don't operate it. The areas excluded from the study are also affected by the improvements suggested and should also be considered to avoid sub-optimization. Therefore it might have been good to have studied these more, however the authors understand the connections between the excluded and included areas and have tried to avoid sub-optimization through this knowledge. For example, consideration of the fan production was included since the worker in this area also uses the machines in the machine area.

All improvements are based on a sustainable foundation, and are meant to improve or at least sustain all three parts of sustainability. The social part is expected to be improved as the solutions are based on a long term perspective where the work environment should be improved, while maintaining the social nature of the work itself. The implementation plan should also aid the social sustainability, as managing the change process well could improve the worker's openness to change. As the main goal with the improvements was to improve the capacity and productivity of the company in the short as well as long term, the economic sustainability should improve. The last part of sustainability, the environmental part, is only slightly affected by the changes. A shorter lead time would mean less overhead-related environmental impact per product, however the usage of raw material remain the main component of this impact. A deeper study of the work methods and everything surrounding the raw material could have a major impact on the company's total environmental impact.

Feedback from the company

The company responded very positively to the presentation of the results, improvements and implementation suggestions. First a presentation of machine utilization study was held as the company were evaluating investment of a new press brake. That presentation was an eye-opener as the company didn't know much quantitatively of these machines before. After that presentation, the company decided to invest in a new press brake and a new saw, possibly due to realizing the potential of having two machine operators running the machines and not needing two saws and press brakes. However it is important to note that we didn't see any need for new machines, this decision was taken by the company either way. It was also following the eye-opening quantitative data that the company realized the potential of the authors work, as well as starting to realize issues other than the lack of space.

The second presentation was an analysis and improvements of the machine area layout. It was based on the flow of material combined with the authors improvement ideas. The company grasped the concept of material flow quickly after this presentation, and together with the rest of the employees some smaller alterations to the proposed layout were made and implemented. The authors consider this a great solution, as the employees of the company were included in the decision of the new machine area layout along with the top management. It's also noticeable that this alteration was based on the new material flow, showing that there was thought put into the solution. This attitude shows that the company is ready and willing to change and further increases the success rate of the proposed improvements.

The third and final presentation at the company consisted of the oven builder utilization analysis, improvement suggestions as well as an implementation plan. According to the company the authors had succeeded in catching the state of the company on paper, which further validates the results of the work sampling study. The improvement suggestions were met with no critique, and the implementation plan was very welcomed. According to the company the implementation plan gave them good guidance to actually succeed, and might have valued it more than the actual improvement suggestions. This gave the authors the impression that the implementation plan was important and will be followed.

9
Conclusion

The main conclusion to be drawn from this thesis is that the company's capacity can be improved sufficiently to meet the company's goal. To find potential capacity improvements, a work sampling study was conducted on the oven builders to understand and describe the current state of the company. It was found that the oven builders spent about 51% of the working day on value added activities, about 30% on supportive activities and the remaining roughly 19% on non-value added activities. Combining this result with the goal of increasing the turnover, the authors focused on reducing the supportive and non-value adding activities through a series of improvements. An implementation plan for these improvements was developed in order for the company to successfully implement them, as the effect of each improvement action is affected by the success of the implementation.

The authors found that through following the implementation plan, the oven builders can spend 38.75% more time on building ovens than currently. This allows the company to exceeds the goal of increasing the turnover by 20% in three years by far.

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A

Data handling

The first image in this appendix shows how the data was managed from the oven builder utilization work sampling study. The first column contains the different activities (111, 112 and so on), the following columns were numbered per session which was where the data was input.

Session	48	49	50	51	52	53	54	55
Week	2	2	2	2	2	2	2	2
Day	Tuesday	Tuesday	Tuesday	Tuesday	Tuesday	Tuesday	Tuesday	Tuesday
Time	700	730	810	810	850	850	930	1010
111			48	34	7		26	33
112	44	67	15	11	12	24	30	46
113								2
12		8	13	15			12	6
13					2			
14								
21	2	1						
22	5	7	1	12	6	3	11	6
23	22	12	9	11	1	5	2	4
24	2	4	6				1	
25								
26	1			1				
27	8	11	21	30	19	17	23	15
28								
31		7						
32								
33								
34								
35	1	3	7	6	67	68	3	7
36	2				6	3	12	1

The second image displays the same as the first one, but for the machine setup study. The numbered columns each represent a measuring session.

New Bender

Session	1	2	3	4	5	6
Working	15	38	7			9
Being loaded	7	7	6			9
Being set up	3	7	3			10
Waiting due to tool switch						
Waiting due to foreman						
Waiting due to drawings						
Waiting due to pre-measure						
Waiting due to control-measure						1
Waiting due to looking for tool						
Waiting due to maintenance						
Waiting due to discussion						10
Waiting due to misc	1	1				
No operator	64	37	74	90	90	51
Total	**90**	**90**	**90**	**90**	**90**	**90**

Small Saw

Session	1	2	3	4	5	6
Working	3		1	11		17
Being loaded	2		1	3	3	6
Being set up	1			1		13
Waiting due to tool switch						
Waiting due to foreman						
Waiting due to drawings						1
Waiting due to pre-measure					1	6
Waiting due to control-measure						
Waiting due to looking for tool						
Waiting due to maintenance						
Waiting due to discussion						
Waiting due to misc						
No operator	84	90	88	75	86	47
Total	**90**	**90**	**90**	**90**	**90**	**90**

The final image in this appendix displays how the data was managed for the machine utilization study. Each row represents a session where the data was input depending on machine and activity.

	New Bender				Old Bender				Shear			
Session	**Workin**	**Set-u**	**Mainte**	**No oper**	**Workin**	**Set-up**	**Mainten**	**No oper**	**Worki**	**Set-u**	**Mainter**	**No ope**
%	12%	6%	10%	72%	27%	0%	11%	62%	3%	4%	13%	80%
Session 27		1	14	75				90	4	8	29	49
Session 28				90				90				90
Session 29	4	8	10	68				90	2	4	11	73
Session 30				103	56		15	32	1	1	15	86
Session 31	13	20	15	42	57		21	12	3	3	14	70
Session 32	4	12	10	64	45	5	20	20				90
Session 33	31	1	12	46	55		34	1	6	7	12	65
Session 34				90				90	2	4	4	80
Session 35	27	15	19	29				90	4	1	17	68
Session 36				90	55		17	18	9	7	8	66
Session 37	40	2	21	27				90	4	1	17	68

B
Sheet for work sampling

This appendix shows one of the randomized sheets used when gathering the samples. Columns A and C contain random number between one and three, which represent a random oven builder.

Session number:
Time:
Performed by:

	A	B	C	D	E	F	G	H	I	J
1	1		1		111					
2	3		1		112					
3	2		2		113					
4	3		1		12					
5	3		3		13					
6	3		1		14					
7	1		2		21					
8	3		2		22					
9	2		3		23					
10	2		1		24					
11	2		1		25					
12	2		1		26					
13	1		3		27					
14	3		1		28					
15	3		3		31					
16	2		2		32					
17	3		2		33					
18	2		1		34					
19	1		2		35					
20	1		1		Notes:					
21	1		1							
22	1		2							
23	3		1							
24	2		2							
25	3		1							
26	2		3							
27	1		2							
28	3		2							
29	3		2							
30	1		3							
31	3		2							
32	3		2							
33	1		2							
34	2		2							
35	1		1							
36	3		2							
37	3		1							
38	3		1							
39	3		2							
40	3		1							
41	3		2							
42	2		1							
43	2		3							
44	3		1							
45	1		1							
46	3		3							
47	2		3							
48	1		3							
49	2		3							
50	3		2							
51	2		3							
52	3		1							
53	2		2							
54	1		2							
55	3		2							
56	1		2							
57	3		2							
58	3		2							
59	3		2							
60	3		1							

C

Schedule for work sampling

	07.00-07.30		07.30-08.10		08.10-08.50		08.50-09.30		09.30-10.10		10.10-10.50		10.50-11.30	
	Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel
Monday	1		2		3		4		5		6		7	
Tuesday	13		14		15		16		17		18		19	
Wednesda	25		26		27		28		29		30		31	
Thursday	37		38		39		40		41		42		43	
Friday	49		50		51		52		53		54		55	

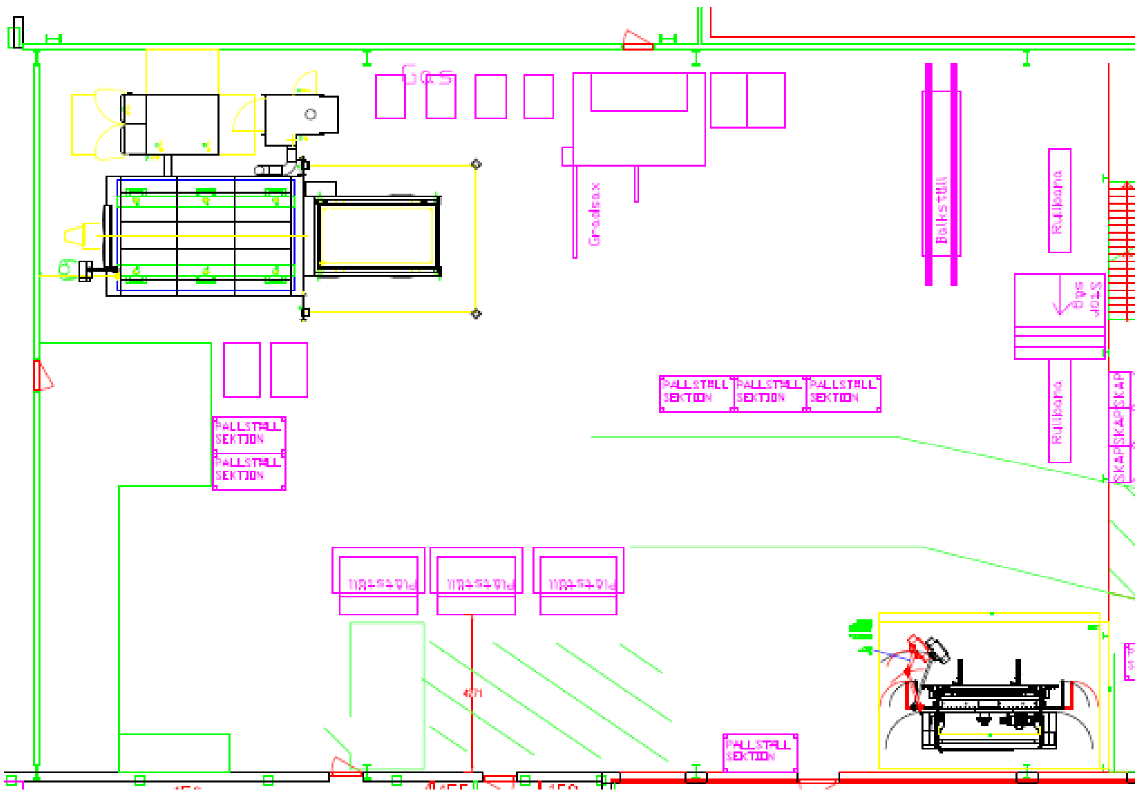
	11.30-12.00		12.00-12.40		12.40-13.20		13.20-14.00		14.00-14.40		14.40-15.20	
	Lunch		Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel	Anna	Daniel
Monday			8		9		10		11		12	
Tuesday			20		21		22		23		24	
Wednesda			32		33		34		35		36	
Thursday			44		45		46		47		48	
Friday			56		57		58		59		60	

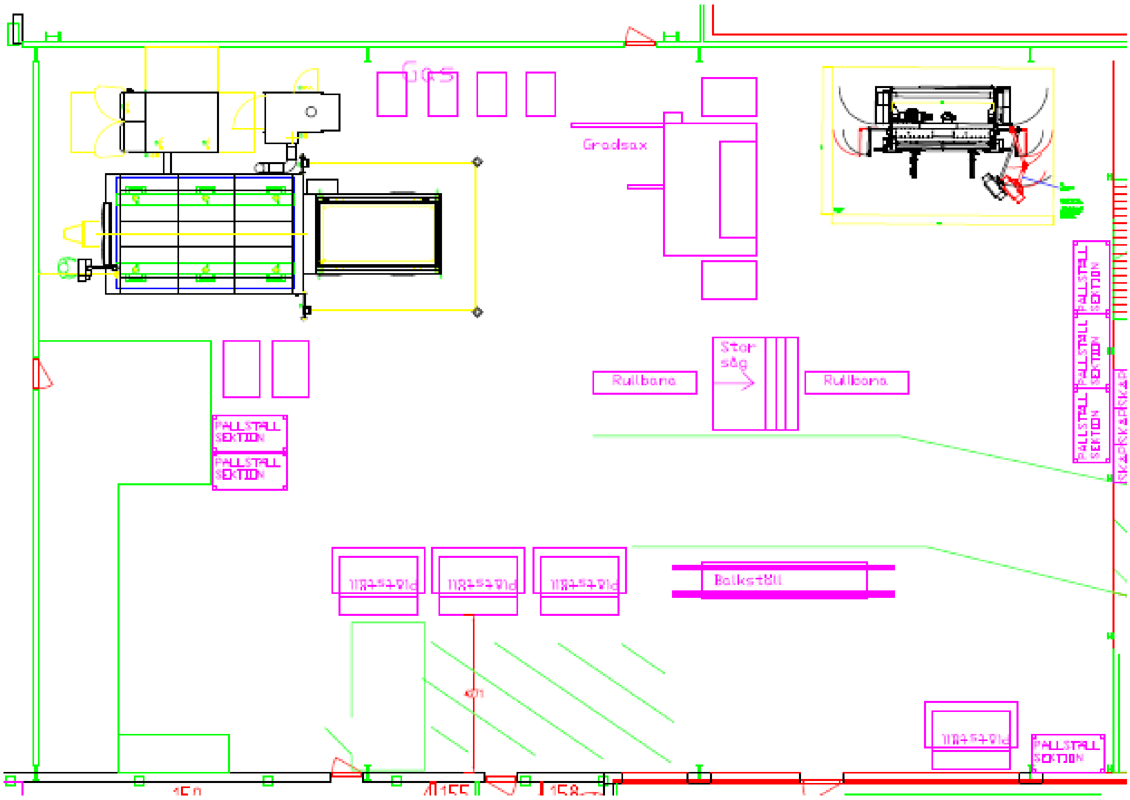
Other activities
Work sampling Anna
Work sampling Daniel
Machine utilization study

D

Layout solutions

In this appendix five of the proposed machine area layout improvements are presented. This is to show that the authors used a process of creating several potential layouts and comparing them in order to find the best one. For example, in the first image the press brake is far away from the laser cutter, but very close to the oven building area which would lead to a short distance to the oven building area. The second image presents a solution where the distance between the machines are shorter, but the flow wasn't very efficient.





All solutions were compared in a matrix as shown in the following image.

	Using and loading				
	Press brake	Saw	Cutting machine	Material handling	
1	+	0	+	+	OK
2	+	0	+	+	OK
3	+	-	+	+	NO
4	+	0	+	+	OK
5	+	0	0	+	NO
6	+	0	+	+	OK
7	+	0	0	+	NO
8	+	0	+	+	OK
9	+	0	+	+	OK
Phase 2					
Relative 1	0	0	0	0	OK
2	-	0	+	0	OK
4	-	0	+	-	NO
6	0	0	0	-	NO
8	0	0	0	+	OK
9	0	0	+	+	OK
Combination of 8 and 9 considered best solution.					

The following images show some of the solutions which were analyzed in the same way in order to find good and bad things about them to find a better solution.