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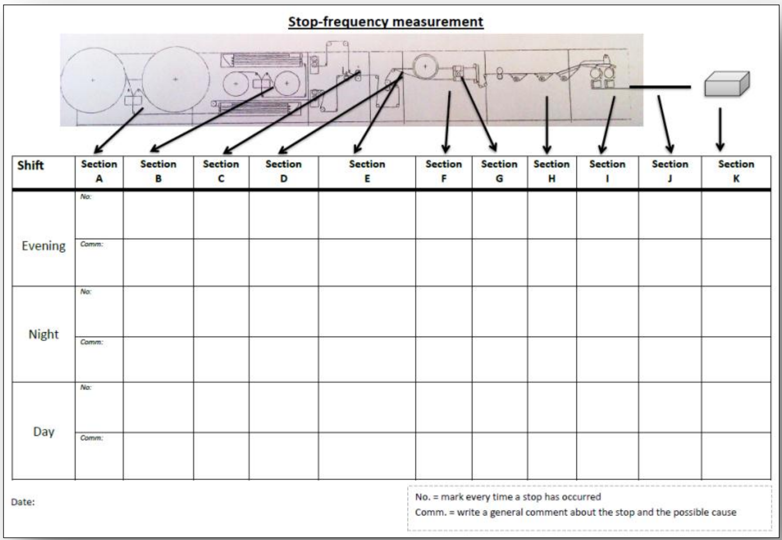

SUSTAINABLE EFFICIENCY IMPROVEMENT

– by Means of Engineering Methodologies

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Preface

This report is the result of Master's Thesis in Production Engineering supervised by the Department of Product and Production Development at Chalmers University of Technology and performed at a production site in Sweden.

We would like to thank the company for supplying us with all we needed and more, to perform the thesis work, such as information, support, working time, equipment and the opportunity to get an insight about an industrial company – which is valuable for our future careers. People at the company deserve a special thank for their support and help that we received in order to accomplish our project. We also hope that the company would find use of some of the findings and recommendations that we discovered, or at least get some inspiration for their future work.

We are also thankful towards our supervisor at Chalmers, Jonas Laring, PhD, for help and guidance during the thesis work.

____________________________ ____________________________

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Abstract

A study exploring a number of different ways of improving efficiency of an industrial production company was performed in a minor scale, at one production line. A number of different methods and approaches were used and the results were documented. Thereafter, recommendations for the future state implementations were given.

The report does not follow the conventional report-structure, but is instead based upon the PDCA (Plan-Do-Check-Act) cycle. By working according to this cycle, the discovered problems are solved in a way that is preferable to be used in a lean-oriented company.

The study focused on finding a way to measure efficiency, identifying problem areas, pointing out common stop-causes, developing new routines for further optimization of machine usage. Also, procedures for information exchange, optimized set-up, reduction of downtime and stop-frequency were implemented and evaluated.

Methods used in this study were work sampling study – performed during four shifts, stop study – conducted by the operators, but also interviews and observations.

OEE (Overall Equipment Efficiency) was used as a measurement to follow up changes in efficiency and availability throughout the project. One set-up activity on the machine was observed and analyzed, followed by recommendations given according to the SMED (Single Minute Exchange of Die) principle. Tree diagram, matrix diagram, VSM (Value Stream Mapping) and benchmarking were other methods that were used in order to develop solutions to achieve an improvement.

The root causes of the stops were identified with tree diagrams and countermeasures were developed. The use of matrix diagram allowed suggested solutions to be prioritized according to their importance to improve efficiency and work environment.

VSM of the current state showed that only about 0.08% of the production lead time was value adding. However, it should be taken into consideration that due to technical specifications, the produced products requires some time to “be settled” and consequently the longer lead time is desired to some extent.

Benchmarking gave inspiration to many useful ideas, but most of them were applicable only in large scale, due to required higher overhead costs, and therefore not implemented in the project.

Finally, some of the recommendations that were given to the company are:

- Hiring a process engineer, who would teach personnel and coordinate the improvement work
- Better communication between the operators of different shifts and machines
- Implement and follow out the work with continuous improvements
- Continuous OEE follow-ups and visualization of production goals and also
- Visual control aids for avoiding mistakes during set up
Keywords: continues improvement, Kaizen, LEAN, 5S, OEE, PDCA, TPM

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Abbreviations and glossary

5S	Sorting, straightening, systematic cleaning, standardizing, and sustaining. A way of organizing a workplace
OEE	Overall Equipment Efficiency: tool for monitoring the efficiency of manufacturing processes in a facility
PDCA Cycle	Plan-Do-Check-Act Cycle: A systematic approach for continuous improvement
SMED	Single Minute Exchange of Die, A method to analyze and enhance the setup activities
WIP goods	Materials and components that have begun their transformation to finished goods

1 Introduction

This master thesis report is formed to imitate an industrial report, by firstly introducing the problem and then following the PDCA cycle (Plan-Do-Check-Act) to solve it.

1.1 Background

The background of the project is the company's raised need to make the production even more effective in order to meet the growing demand of their products. Since, as it is stated in delimitation paragraph, the thesis work is only covering a limited area of the factory, and the results could be used as a pilot study before a large scale introduction of new work methods.

1.2 Company introduction

This master's thesis is conducted at a company (from this point referred to as "the Company") producing paper products from incoming raw material, that is processed and modified within the premises. The degree of automation is relatively high at the studied part of the company, meaning that the operator mostly supervises the process and also feeds the line with raw- and packaging material.

1.3 Problem definition

Although the machine is running in a three shift schedule, the availability is relatively low, and the improvement potential is high, as well as the possibility of reducing the time for set-ups between products.

1.4 Purpose

- To suggest methods for further improvement work with availability and set-up time reduction
- To suggest methods to increase efficiency of the production line

1.5 Goal

- To establish a reliable way of measuring efficiency and improvements
- To point out the most common stop-causes, and also to give suggestions that can decrease or eliminate these stops.
- Improve or create new routines for further, optimized, machine usage, but also for information exchange, optimized set-up procedures, stop time and stop-frequency reduction.
- To design an implementation plan and eventually suggest solutions for further implementation within the rest of the company.

1.6 Delimitations

The project is concentrated to one production line within the company. No major adjustments of the current physical layout are possible to implement.

2 Theoretical framework

Theory for clarifying methods used in the project is presented below.

2.1 Plan-Do-Check-Act (PDCA) Cycle

A problem solving approach called the PDCA Cycle or the Deming Cycle, which this study is based upon, is a cornerstone in continuous improvement within Lean Production. The ideas about PDCA Cycle were spread by the American quality engineer W. Edward Deming to the Japanese industry, which later was adopted by Toyota and incorporated into their Toyota Production System (TPS) and Lean Production (Section 2.2). The PDCA Cycle is used within many organizations working with Lean methodologies. While PDCA Cycle is commonly used for more detailed work processes, it can even be extended to be used on all levels from projects to company and between companies. Another corresponsive problem solving approach to PDCA Cycle is DMAIC: Define, Measure, Analyze, Improve and Control process. While PDCA Cycle is originally used within Lean Production projects and organizations, DMAIC is mainly used in Six Sigma and Lean Six Sigma projects. The main difference between these two is that DMAIC can be more effective when the focus is to reduce and control the variations of the processes. (Liker, 2004; Salah, Rahim, & Carretero, 2010)

The PDCA Cycle consists of four phases which refer to the steps in the systematic improvement work. By following these over and over again, the performance level within the organization is continuously improving (Figure 1). Each improvement step must be standardized, just so that knowledge and performance levels will sustain. (Liker, 2004)

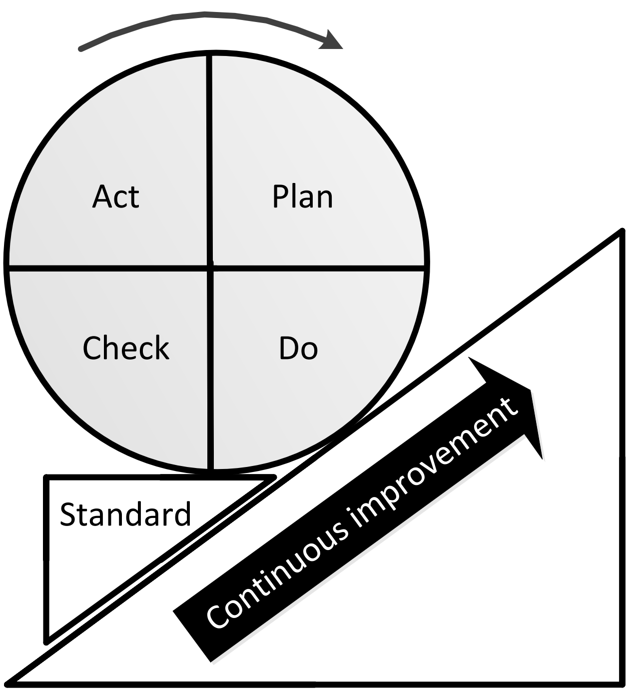


Figure 1: The PDCA Cycle as a mean to maintain the continuous improvement.

Closer explanation of the PDCA Cycle:

Plan – This phase incorporates the definition of the problem. A thorough analysis of the current state issues is conducted in order to identify the root causes. Appropriate solutions are then formulated and evaluated to identify the most profitable solutions available.

Do – The decided solutions are implemented one by one. At this phase, the people implementing the solutions will have to support the concerned people to make sure that the solutions are fully understood and followed.

Check – The achieved state after the implementation of the improvements are then analyzed in order to verify the solutions. If the results are negative, the improvement work will have to start over again at the plan phase. If not, the tested solutions will continue to the act phase.

Act – Once the improvement cycle has reached this step, the solutions are prepared for final implementation by standardization and possibly spread to other parts within the organization. To maintain the continuous improvement work, the key to success is to repeat the cycle in infinity to reach an even higher level.

Just as Liker (2004) points out, it took decades for Toyota to become the learning enterprise it is today. Probably it would take years for other companies to evolve their culture to become a learning organization. This project will strive to introduce continuous improvements mindsets among the employees by suggesting them to follow the authors' way to improve the processes within the company.

2.2 Lean Production

Lean Production is a philosophy which is applicable in various kinds of organizations. The philosophy of Lean Production shall influence the daily work throughout the entire company. The ideas of Lean Production originate from the Toyota Production System (TPS) and today are used by many manufacturers around the world, including those in Sweden. The basic idea of Lean Production is to create more value to the customer, while using fewer resources. (Liker, 2004)

Getting rid of non-value adding activities is vital in Lean Production. The focus is to identify and eliminate waste in production, which is explained further in the section below. To be successful in improving the processes in a company, all the decisions should be made according to a long-term vision which is aligned with the company core values. The management of the company needs to be committed in the continuous improvement work by showing their interest in the daily work and be a good example to the employees. The following sections will elaborate the core concepts of Lean Production, which are all applicable in this improvement project. (Liker, 2004)

2.3 Waste reduction

There are eight categories for waste in manufacturing processes and these are shortly described below (Liker, 2004):

Waiting **–** Time that workers spend on waiting for the next processing step, tool or supply part. Other causes for waiting can be stock run-out, processing delays or machine downtime.

Overproduction – Production of goods that have no real customer demand. This causes storage and transportation waste and leads to overstaffing.

Overprocessing **–** Producing goods that have higher quality than necessary is waste. There may be processes steps performed which are not required.

Excess inventory **–** Excess inventory is found as raw material, Work-In-Process (WIP) and finished goods. Inventory that is over dimensioned will cause a longer lead-time than necessary. It will also hide real problems in the production flow, such as machine downtime, changeover times, cassations and late deliveries. The stock-levels need to be adjusted to fit the requirements of the processes and industry.

Unnecessary transport **–** Transportation between processes is considered as waste if it is carried out in an inefficient way. Letting the goods travel without involving human work will reduce this waste.

Defects – Produced goods which are defective is waste. These goods will require repair or be thrown away as scrap. Besides, it will require additional production time as replacement.

Unnecessary movement **–** Waste within this category are movements performed by workers that will not provide any value to the customer. Examples of these are: reaching for, searching for, walking and stacking goods.

Unused creativity – Not making use of the ideas from the production staff will become a waste. Involving the production staff in the improvement work, will improve the total efficiency of the workplace.

These wastes are the starting-points to identify the improvement potential in a production environment. In this project, some of the described wastes are identified and countermeasures are suggested to eliminate these.

2.4 Standardized work

In order to be able to improve the productivity, the processes must be stabilized and work should be standardized. Otherwise, new improvements will not be measurable and sustain over time. Liker (The Toyota Way, p.140) use the following notion to address the importance of standardized work: “Standardized tasks are the foundation for continuous improvement and employee empowerment”.

Standardized work is a quite broad concept, and it often comprises the work sequence, takt time and defined stock-level (Liker, 2004). The standardized work is not just necessarily applied on worker-jobs, but also on leader and manager-jobs (Emiliani, 2008). Spear &

Bowen (1999) states that even the communication between employees can be standardized in Lean Production. They argue that standard contains a framework for how the employees are involved and it also defines the response time to deviations in the production processes. Standards should also define the division of responsibilities between suppliers and customers.

Working according to standards will ensure that variations are reduced, which mean better and more conformable quality of produced goods. Freivalds (2008) argues that the work standard is vital for the validation of efficiency improvements. A work standard can shorten the introduction time to new employees, besides the risk for new employees to do mistakes is reduced. Having the work places standardized in a more thorough way will enable the possibility of introducing work rotation. Liker (2004) claims that new standards should have gained approval among the employees that performs the daily work, and preferably been developed by themselves doing during the work.

Standardized work is not that easy to apply in practice, due to negative preconceived thoughts among the employees. Still, there is a fear among employees working at the shop floor that their jobs are threatened as the productivity increase. The top management will have to convince the workers that productivity improvements will not lead to lay-offs, but rather be exploited to produce in higher quantities and to a lower cost. (Liker, 2004)

2.5 **Continuous improvement - Kaizen**

Kaizen, from Japanese kai - "to take apart" and zen - "to make good”, is a philosophy of continuous improvement where the workers who do the actual work are also participating in improving activities within the factory. It is done due to the reason that they have the best knowledge about the process and also because they are often the ones who are getting the most advantage from the improvements. (Karen & Osterling, 2007)

The improvements are implemented gradually, with small changes applied at a time, which will sum up to a larger economic improvement at the end (Productivity Press Development Team, 2002). The improvements can be done by identifying and solving problems, documenting and improving processes (Karen & Osterling, 2007)

Kaizen is claimed to be one of the cornerstones of Lean production (Liker, 2004), and it is considered to be a method that takes the human dignity into consideration and care of the needs of the workers. (Karen & Osterling, 2007)

One way to work with improvement is conducting Kaizen Events, which are often performed during a short period of time. These events aim at fast achievements and dramatic improvements of a workplace. (Karen & Osterling, 2007)

2.6 **Total Productive Maintenance (TPM)**

In Lean Production, the philosophy is to shut down a machine if it does not operate according to the standard, produces defective goods or there is not a customer need. A general low inventory at the factory level will starve other downstream processes quite soon after an intermediate machine is down. The importance is therefore to work in a systematic way to prevent unplanned stops. (Liker, 2004)

In Lean Production, there are numerous types of wastes associated with bad equipment reliability, such as:

- Excess inventory to manage loss in throughput, which causes overproduction.
- The need of spare parts for the machine creates excess inventory.
- Downtime at the machine creates waiting.
- At machine failures, mechanics or electricians will do unnecessary movements in order to gather spare parts and return to the machine and fix it.
- Defects are created before the failure of the machine is recognized, but also during the run-up period after the repair.
- Unused creativity by not involving all employees in the maintaining activities.

If there are many unplanned stops at a machine, causing low dependability, then an improvement program called Total Productive Maintenance (TPM) can be effective to implement (Liker, 2004). TPM is a philosophy which follows principles and practices to improve the maintenance of production equipment. The implementation of TPM should involve all employees from workers to senior management; however it is primarily focused on the operators. In order to assist a smooth implementation of TPM, the use of the 5S methodology can assist in creating a clean work environment. Another important point when working with TPM is the commitment from the management. Visual control, described in section 2.7 will also help employees to know the status of the machine and why it fails. (King, 2009)

The operational mode of TPM functions as autonomous maintenance, where changes are made by the maintenance group to improve the reliability of the machine. A measureable goal with TPM is to improve the OEE, by maintaining stable and robust machine equipment. (King, 2009)

Wireham (2004) suggests five basic goals in TPM:

1. Improving equipment effectiveness
2. Improving maintenance efficiency and effectiveness
3. Early equipment management and maintenance prevention
4. Training to improve the skills of all people involved
5. Involve operators in routine maintenance

The first point is the most important one, as the other points support the goal to improve the equipment effectiveness. The implementation of TPM will have to be adapted to the type of industry (such as assembly or process industries). The application of TPM is even more beneficial within process industries, because there the degree of machine productivity is more important than the labor productivity. (King, 2009)

2.7 Visual control

Visual control systems are communication devices or methods which can be used to tell the workers how to perform tasks and give feedback about how they are performing. It can also show where different working tools should be placed (5S) when not used and give information about the status for WIP goods. (Liker, 2004)

There are some other examples how visual control can be applied:

- Painted shop-floor pallet-locations with scrap, WIP and finished goods etcetera.
- Lights to help the employees to be aware of issues.
- Whiteboards at the shop-floor to convey information about problems and production results.
- Illustrative diagrams to show production goals and daily follow-ups of results.
- Quick guidelines and pictures to visualize the work procedures in a clear way.

The idea with visual control methods is to increase the efficiency of the production line by making the process steps more visual to employees. Liker (2004) mentions some other benefits by applying visual control: it reduces defects and mistakes; helps meeting deadlines, facilitates communication, improves safety, lowers costs and gives more autonomy to the employees. It can also be effective when implementing new work procedures and teach new employees. Implementing visual control creates an atmosphere where everyone knows what is expected from all employees and by having things scripted as visual control will save time due to verbal communication deficiencies. (Liker, 2004; Bulsuk, 2011)

2.8 Setup reduction

Historically, the traditional manufacturing strategy was to produce goods in large batches in order to avoid unnecessary changeovers. This is particularly true if the setups are time-consuming and causes substantial amounts of defective goods during the run-up period. However, there are drawbacks with large batch production, such as inability to discover quality defects immediately after a process and overproduction of goods that are currently not demanded by the customer (internal and external). (King, 2009)

A method to analyze and enhance the setup activities was developed by the Toyota consultant Shigeo Shingo during the 60s and 70s. The methodology is known as Single Minute Exchange of Die (SMED), accomplished to optimize setups at Toyota that took hours to perform before, down to just a few minutes some years later. (Liker, 2004)

The fundamental ideas with the SMED methodology (as illustrated in Figure 2) are:

1. Recognize tasks that can be performed as external tasks. Examples of tasks that can be performed as external are retrieving new material and cleaning up between product variants.
2. The second step is to move those setup tasks which are possible to conduct while the machine is running, to be performed before or after the setup stop.

3. Optimize the internal setup by modifying the equipment to simplify the setup activities. Implement visual control to guide the employees in doing the right things efficiently is important as well.
4. If it is possible, internal setup activities should be conducted in parallel to further reduce the setup time. This will be enabled by cooperating several employees to do the setup activities together.

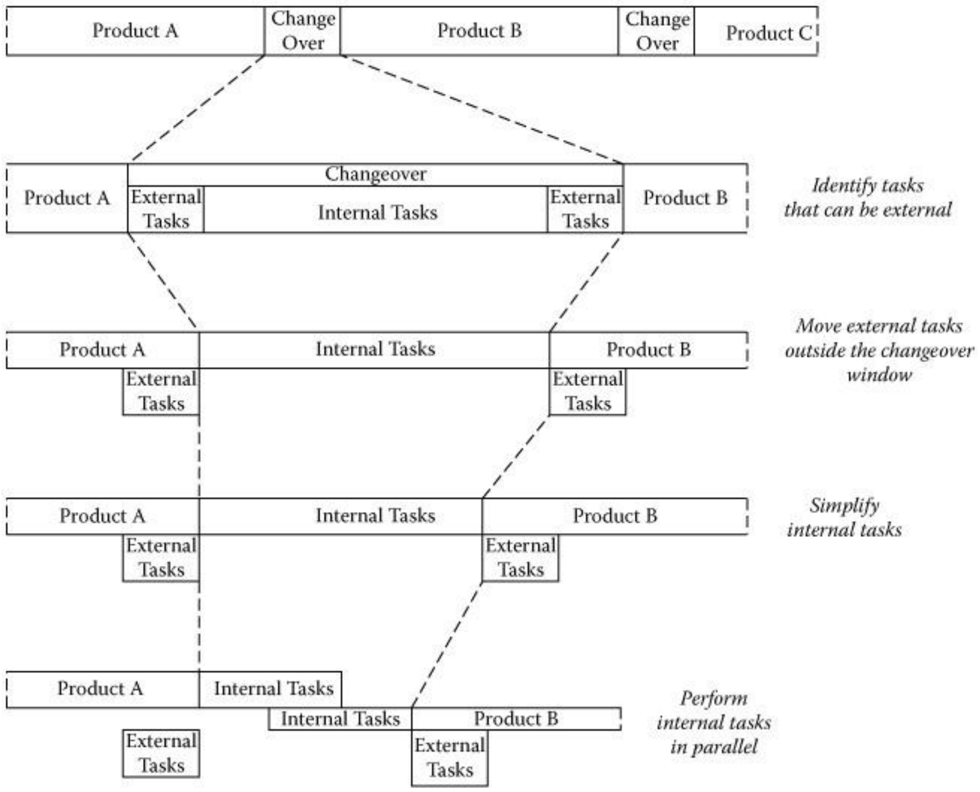


Figure 2: The principle of the SMED improvement steps. (King, 2009)

Depending on the industry and manufacturing processes, SMED can be applied in different ways. For processes which demand manual tasks as well as adjustments during run-up after a setup, will also require technological improvements to lower the setup time and run-up losses. Such improvements can be adaptive machine settings which adjusts the machine after the properties of the raw material. (King, 2009)

MacIntosh, et al. (2001) addresses the contrast that exists between a setup reduction and improving the OEE in industries. This is due to that availability serves as an objective in OEE and setups are consequently considered as loss. The choices are either to increase the productivity and OEE by reducing setup frequency and setup time, or to increase the manufacturing flexibility by exploiting the reduced setup time. They have established that this contrast will be diminished as the setup time is minimized.

2.9 Reduction of stops

The dependability of a machine is of main concern in the productivity improvement process. Reduction in number of stops for a machine can lead to better availability, quality and production planning. The focus should be aimed to reduce the number of stops and prevent the same stop from reoccurring. Instead of improving the repair time of the stops, the best potential for productivity improvement is finding the root cause of the stoppages and then put in countermeasures to improve the dependability of the machine. (Barkland, 2010)

Today it is more common that companies measure the OEE of the processes. What is interesting is that by using less time and resources, counting the stops can be just as good if it is used properly in the improvement work. The stop counting can entail that the root causes are identified, because it is the only way the stops can be prevented from appearing again. (Barkland, 2010). This knowledge about reducing the number of stops is fundamental in this project's problem solving.

3 Methods

This section will present the methods used in this project. Under each method chapter, the method description is followed by a description of how the method was implemented. By doing this, method theory and implementation are linked together to improve understanding of the report.

3.1 Work sampling study

A method for determining the proportion of time for different activities is called work sampling study. The method was first used 1927 in the British textile industry. Work sampling studies can be performed both on production equipment and workers. The outcome from a work sampling study can for example be used for determining the utilization of machines and operators, allowances and different time standards. (Freivalds, 2008)

When conducting a work sampling study the analyst also gets a good overall view of the work content at the workplace. In this matter, work sampling is a better method than time studies. The result retrieved from a work sampling study lays a foundation for continuous improvement. (Carl, 2010)

The first thing to do in a work sampling study is to define what to measure (e.g. the downtime of a machine or operator activities). Thereafter, a detailed planning of the study is made, constructing a sample form, collecting data and analyzing the results. The activities that are logged in the study can be divided into value adding and non-value adding work. These main categories can thereafter be divided into sub activities (e.g. for manual work the sub activity can be; operator idle). (Freivalds, 2008). In this project, the fraction for different downtime activities was of highest interest.

3.1.1 Planning of the work sampling study

The planning of the study is essential for what conclusions can be drawn from the study. There are formulas for determining the number of observations needed to get a certain established statistical result. (Freivalds, 2008). Equation 1 shows the formula used in this project.

Equation 1 - Work sampling

$$N = \frac{z^2 \times \hat{p}(1-\hat{p})}{e^2} = \frac{3.84 \times 0.25(1-0.25)}{(0.1 \times 0.25)^2} = 1152\ observations$$

The $\hat{p}$ in Equation 1 is the estimated downtime for the machine. That number was calculated by using historical records of the downtime for the machine. The confidence interval was chosen at a level of 95 % and the relative error was fixed to 10 %, which are normal levels when performing work sampling studies. The calculated number of observations serves as a goal to reach; if an insufficient number of observations are recorded, the results from the work sampling study will not be reliable. (Freivalds, 2008)

The frequency of the observations is determined by the available time, numbers of analysts and how many shifts that needs to be observed (Freivalds, 2008). In this work sampling study it was decided that observations should be collected during four different work shifts, eight hours each. Due to limitations of working time, only day and afternoon shifts were studied. For each shift 288 samples were recorded in a premade work sampling form.

A work sampling form was designed before the collection of data was made. The design of the form is unique for every work sampling study, provided that the activities and the random observation times are always different in each case. (Freivalds, 2008). Because the work sampling study was concerning the machine only, the activities defined were either running or stopped. If the machine was down when observed, the location of stop cause was noted. This allowed pointing out of sections with highest occurrence of stops. Activities other than stops in sections were cleaning or unmanning of the machine. The layout of the work sampling form is seen in Figure 3.

Date: **2010-xx-xx** Shift: **Day**

Stop location / cause:

Random time				Running	Cleaning	Material shortage	Unmanned	Section A	Section B	Section C	Section D	Section E	Section F	Section G	Section H	Section I	Section J	Section K
13:34:55	14:12:00	15:03:52	15:40:42															
13:36:41	14:14:36	15:03:57	15:43:06															
13:39:07	14:17:38	15:05:51	15:43:53															
13:39:22	14:19:46	15:06:41	15:44:45															
13:39:45	14:19:53	15:08:43	15:46:41															
13:39:54	14:20:57	15:08:50	15:48:37															
13:40:11	14:25:26	15:08:51	15:51:07															
13:40:15	14:26:44	15:12:28	15:54:27															
13:45:16	14:27:28	15:17:35	15:54:49															
13:45:43	14:30:48	15:17:52	15:55:21															
13:47:20	14:34:44	15:17:52	15:56:26															
13:47:53	14:35:08	15:18:27	15:58:07															
13:47:55	14:35:34	15:18:40	16:00:19															
13:47:59	14:36:19	15:21:36	16:00:44															
13:48:44	14:36:48	15:24:40	16:04:20															
13:52:39	14:36:59	15:24:51	16:04:59															
13:56:13	14:37:46	15:27:37	16:07:19															
13:56:50	14:38:00	15:28:14	16:07:19															
13:58:10	14:39:02	15:28:35	16:07:40															
14:00:44	14:39:28	15:30:06	16:08:36															
14:02:30	14:41:10	15:30:08	16:11:52															
14:04:33	14:44:11	15:30:25	16:12:03															
14:07:17	14:47:45	15:31:15	16:13:29															
14:07:49	14:47:51	15:31:45	16:13:45															
14:07:53	14:50:26	15:34:07	16:14:32															
14:08:15	14:58:19	15:34:14	16:19:57															
14:08:45	14:58:38	15:38:25	16:21:43															
14:09:22	15:01:29	15:40:19	16:23:37															

Figure 3: Example of work sampling form with randomly generated times.

3.1.2 Carrying out observations

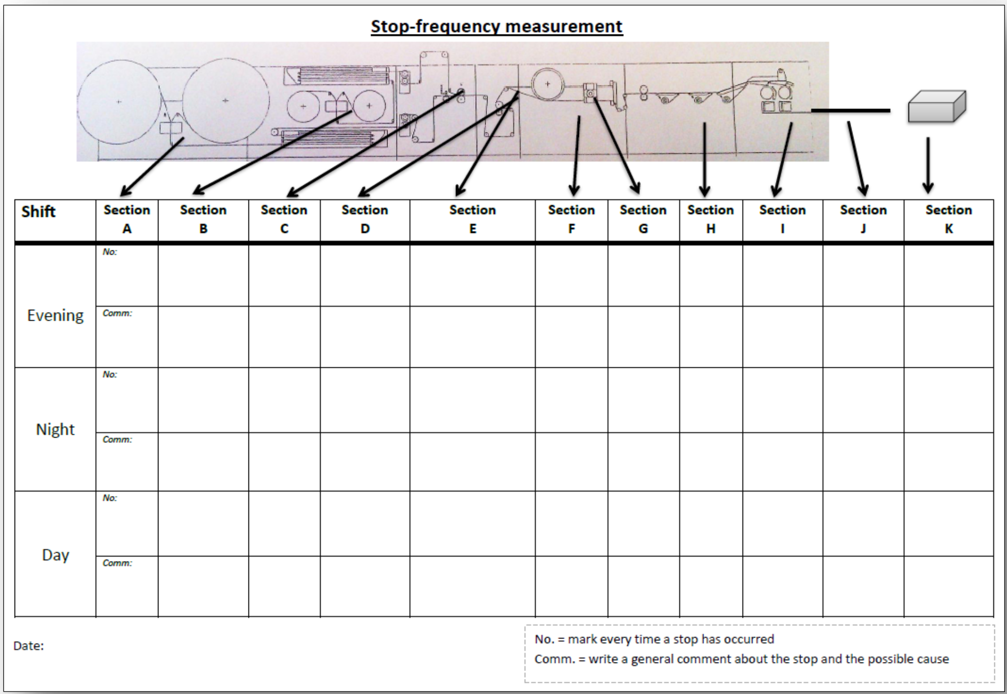
The occasions for observations were retrieved from a random number generator, written in an Excel document and adopted with the work sampling form before the observations were done. Freivalds (2008) also emphasize that the analyst should have a fixed position when taking the observations and that the reason is marked if e.g. the machine or operator is idle. In that way, the information retrieved from the work sampling study can be used to improve the productivity of the job.

3.1.3 Interpreting results from the work sampling study

The results from the work sampling study will determine the distribution of the total scheduled production time. The actual time for an activity is calculated by dividing the total observations for the activity with the total number of observations. The causes for productivity losses can then be ranked in a Pareto diagram, in order to determine the largest causes. (Freivalds, 2008) By using the outcome of the work sampling study, the potential for different improvements can then be evaluated (Carl, 2010).

3.2 Stop study

A method to identify the stop frequency and where the stops occurred was used in the project. The procedure of the study involves counting the number of stops and optionally the place where they occurred and possible root cause (Barkland, 2010). By just collecting these two parameters, the procedure of the study is made simple and therefore enables the operators to self-log these events in a stop-sample form. A stop-sample form (Figure 4) was developed, where operators could fill in the number of stops and the place where they occurred. This type of data collection induces the operators to be committed in the continuous improvement work, by making them aware of the stoppages. The data collection for the stop study lasted for two weeks for every work shift. The stop study served as complement to the work sampling study, by giving information of the frequency of the stops rather than just knowing the cumulative downtime for different stops.



Stop-frequency measurement

Shift	Section A	Section B	Section C	Section D	Section E	Section F	Section G	Section H	Section I	Section J	Section K
Evening	No:										
	Comm:										
Night	No:										
	Comm:										
Day	No:										
	Comm:										

Date:

No. = mark every time a stop has occurred
Comm. = write a general comment about the stop and the possible cause

Figure 4: The stop-sample form divided in machine sections.

3.3 OEE

OEE, Overall Equipment Efficiency is a tool of monitoring the efficiency of manufacturing processes in a facility. It is a simple but efficient tool, based on the three factors: availability, performance and quality that multiplied together give a number between 0 and 100% (Equation 2) that can be used to detect effects of improvements within the factory.

Equation 2 - OEE calculation

$$OEE = Availability\ (\%)\ x\ Performance\ (\%)\ x\ Quality\ (\%)$$

Figure 5 shows a schematic picture of how OEE is calculated. Based on the numbers in the figure, the OEE is calculated to 64% (86% x 76% x 98% = 64%), which is to be considered as an average figure for a manufacturing company (OEE Pocket Guide, 2011). If a company has the OEE rate of 85% then it is considered to be of world class. (The Fast Guide to OEE, 2008)

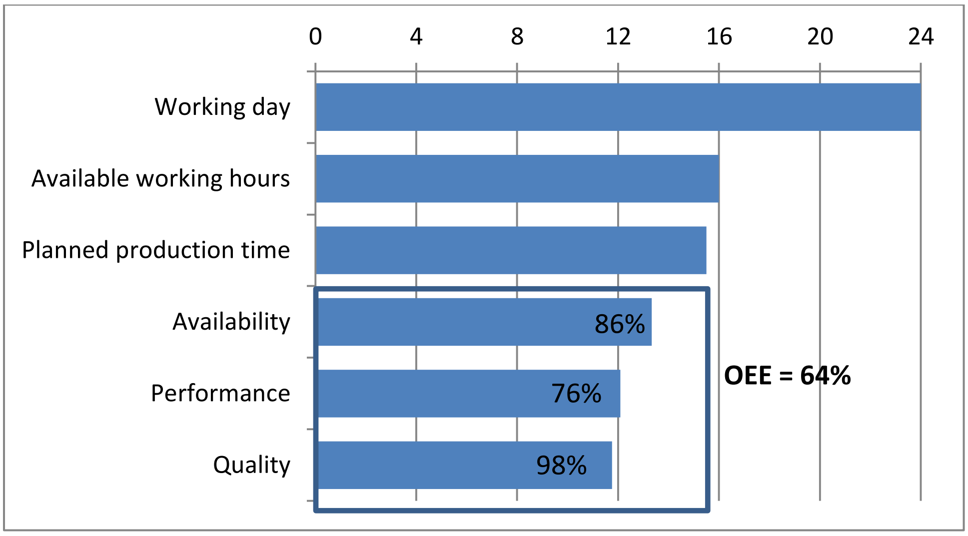


Figure 5: Example of OEE calculation (adopted from (Andersson, 2010)).

According to Jonson and Lesshammar (1999), OEE is an ideal tool for noticing changes in productivity efficiency when some improvement measures have been taken, due to internal improvement work, where the OEE numbers are used as supportive figures. Therefore it should not be used for comparing different companies with each other.

One disadvantage with OEE is that it only measures efficiency and does not take other aspects, such as of economics, environment or the workers' social health factors (such as work satisfaction) into consideration. This means that a process with higher number might be efficient, but less profitable than a process with a lower OEE number.

Another difficulty is establishment of a way of data collection, for instance, automatic data collection is more accurate than manual, so the risk of personnel trying to affect the data into more positive figures than they really are, is higher when data is collected manually. (Jonson and Lesshammar, 1999)

The three OEE factors are calculated as following:

Equation 3- Availability

$$Availability = \frac{Planned\ Production\ Time - Stop\ Time}{Planned\ Production\ Time}$$

Equation 4 - Performance

$$Performance = \frac{Ideal\ Cycle\ Time * Nr\ of\ Produced\ Items}{Planned\ Production\ Time - Stop\ Time}$$

Equation 5 - Quality

$$Quality = \frac{Produced\ Amount - Waste}{Produced\ Amount}$$

There are some factors, commonly known as the Six Big Losses that effect the calculation of the OEE number. The correlation between OEE-factors and the Six Big Losses is shown in Table 1 (adapted from (OEE Pocket Guide, 2011)).

Table 1 - Six Big Losses

OEE factor	Type of OEE loss	Six Big Losses category	Example
Availability	Down time loss	Breakdowns	Tooling & equipment failures Unplanned maintenance
		Setup and Adjustment	Setup/changeover Material or operator shortages Warm-Up Time
Performance	Speed loss	Small stops	Obstructed Flow Component Jams Sensor Blocked Cleaning/Checking
		Reduced speed	Rough Running Under Nameplate Capacity Equipment Wear Operator Inefficiency
Quality	Quality loss	Startup rejects	Scrap Rework In Process Damage Incorrect Assembly
		Production rejects	

By working with reduction and elimination of the occurrence and frequency of the stops, it is possible to improve the efficiency of the manufacturing. Automatic data collection is a good way of information gathering, providing a reliable source that could help when making decisions in the improvement processes. (OEE Pocket Guide, 2011). The performed OEE analysis is described thoroughly in section 4.2.5.

3.4 Tree diagram

One of the problem solving tools used in the project is called tree diagram. The purpose of the tool is to find the root causes of the problem identified. A similar method is the "five why", which begins by first asking why the problem occurred, and then ask why again repeatedly, until the root cause of the problem is identified. Thereafter, suitable solutions can be suggested to solve the root cause problem. At each level, countermeasures can be suggested, but it is just at the deepest countermeasure level that will avoid the problem from occurring again. (Liker, 2004; Bergman & Klefsjö, 2008)

Before the root cause analysis could be started, the problems must be properly defined by observations, or as it called Genshi Genbutsu - "going to where the problems are". The problems identified are then used with a Pareto analysis, to rank them after frequency etcetera. (Liker, 2004)

In this project, the tree diagram was used in a similar way as the five why method. By using the tree diagram, several root causes of one problem could be mapped into the same diagram. After all root causes have been identified, countermeasures can be suggested in the diagram (see the principle in Figure 6).

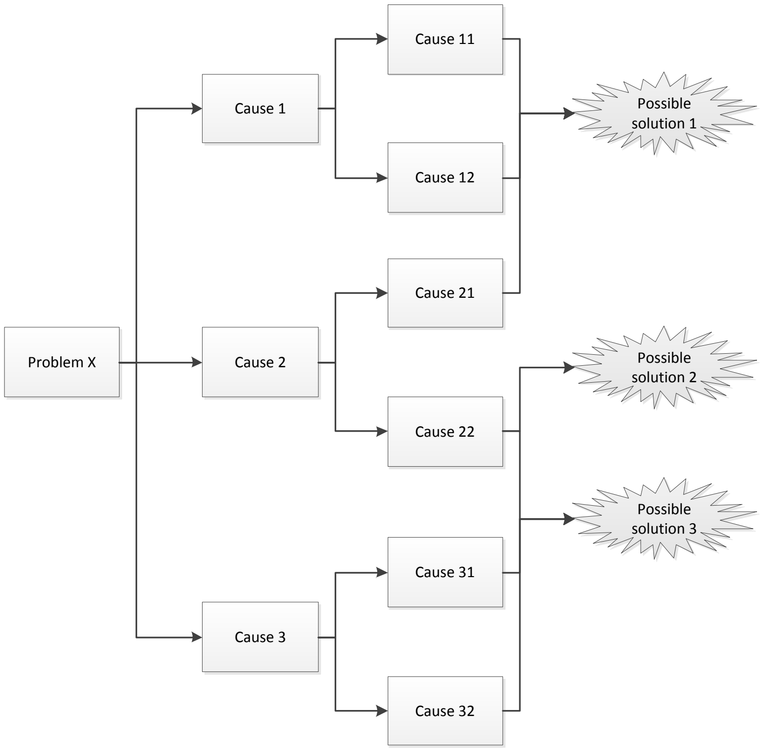


Figure 6: The principle of a tree diagram.

3.5 Matrix diagram

The matrix diagram was one of the most important tools used in the project in order to determinate the most promising solutions. This method was chosen due to the fact that it could combine a large amount of data in the same place, so that connections between different factors could be illustrated.

A matrix diagram is designed by listing different problems on one axis and solutions on the other, as it can be seen in Table 2. The problems are chosen among those discovered by the use of stop studies (described in section 4.1) and then weighted according to their importance for the company.

The relevant solutions are suggested by using methods such as tree diagram (section 3.4) and they are also weighted according to their relevance of solving the problem. The numbers are multiplied with each other and the final score is obtained. The score shows the problems and the order of priority in which they should be handled. (Bergman & Klefsjö, 2008)

Table 2 - Matrix diagram

Solutions / Problems	Weight	Solution 1	Solution 2	…	Solution n
Problem 1					
Problem 2					
…					
Problem m					
Total score:					

Relative value of measure: ● Very efficient ◍ Efficient ○ Moderately efficient

3.6 VSM

Value stream mapping is a widely used tool to visualize flow of material and information within an organization. By mapping the current state, it becomes considerably easier to point out areas, where improvement could be made, and waste reduced. Parameters that are usually studied are: cycle times, down times, information flows, material transportations and inventory levels. Usually a "current state map" is produced, followed by an improved version, called "future state map".

When the current state map is produced, with information stretched from raw material supplier until the customer, then future state map could be made, showing the ideal conditions of parameters for the studied organization. (Value Stream Mapping - Waste Visualisation).

As a help in producing the future state map, following questions should be answered (Rother & Shook, 2003):

1. What is the takt time?
    - Synchronize the production with the sales
2. Will you build to finished goods supermarket from which the customer pulls, or directly to shipping?
3. Where can we produce in a continuous flow?
    - Develop a continuous flow where it is possible.
    - Flows without buffers between the processes
4. Where will you need to use supermarket pull systems for regulating the flow?
    - Control production of upstream processes

• Processes that serve many products
• Processes located remote, e.g. suppliers
• Processes with long lead times, e.g. heat treatment

5. At what single point in the production chain (the “pacemaker process”) will you schedule production?
6. How do we level the production mix at the pacemaker process?
7. What increment of work will you consistently release and take away pacemaker process?
8. Which process improvements will be necessary for the value stream to flow as your future state design specifies?

3.7 Interviews

In a general perspective there are two research methodologies. The quantitative methodology refers to collecting numerical data which is then analyzed and evaluated using statistical methods. The outcome from applying quantitative methodology is identification of patterns concerning a problem definition. The qualitative methodology is however used for answering and solving complex issues. This methodology can be applied by performing interviews that have qualitative characteristics. (Sörqvist, 2004)

Qualitative interviews can be classified into three different categories: structured, semi-structured and unstructured. At a structured interview, the interviewee answers freely or after different answering alternatives. In a semi-structured interview the interviewer gives both open and closed questions, with the possibility of giving additional attendant questions to the interviewee. An unstructured interview is suitable when the interviewer has a vague idea of what areas are interesting to get more information about. The interviewer gives open questions and the interviewee can talk quite freely about what he or she thinks is important. The disadvantage with unstructured interviews is that they are harder to put together and compare. (Bohgard, 2008)

The production employees at the factory were interviewed at several occasions during the project. The interviewing persons were technicians, electricians, operators, quality manager and production manager. There was also an interview with a project manager at another factory within the company, to serve as benchmarking with the studied factory. All interviews had the unstructured characteristics, due to that qualitative information was required as a complement to the quantitative information retrieved from the other studies performed at the factory (work sampling study, stop study and OEE). Information that was requested in the interviews concerned mainly machine functionality, working procedures, communication between production staff and improvement suggestions.

4 Current state (plan)

This chapter discusses identification and definitions of the main problems, ways to acquire and analyze data, determine root causes of the problems and evaluation of possible solutions.

Note: In this and following chapter, machine sections are mentioned, but not shown in figures due to confidentiality reasons.

4.1 Results

A number of studies were performed at the company in order to recognize the current state of the production, in regard to stop times, production efficiency, production flow and the workers' opinion about their working tasks.

4.1.1 Work sampling study

The work sampling study was performed as described in section 3.1. The number of samples collected was however somewhat fewer than what was originally planned, due to limited available time by the authors. The collected samples were reduced from 1152 to 1025. The absolute error of the work sampling study was consequently recalculated as shown in

Equation 6:

Equation 6 - Absolute error calculation

$$Absolute\ error = e = \sqrt{\frac{z^2 \times \hat{p}(1-\hat{p})}{N}} = \sqrt{\frac{3.84 \times 0.25(1-0.25)}{1025}} = 2.7\ \%$$

The stop causes could be (1) unmanned, (2) cleaning or (3) machine failure in one of the sections seen in Figure 7. The result of the work sampling study shows that the total downtime of the machine was 20.7% ± 2.7%, which is within the 95% confidence interval, and which is lower than what was noted after each work shift.

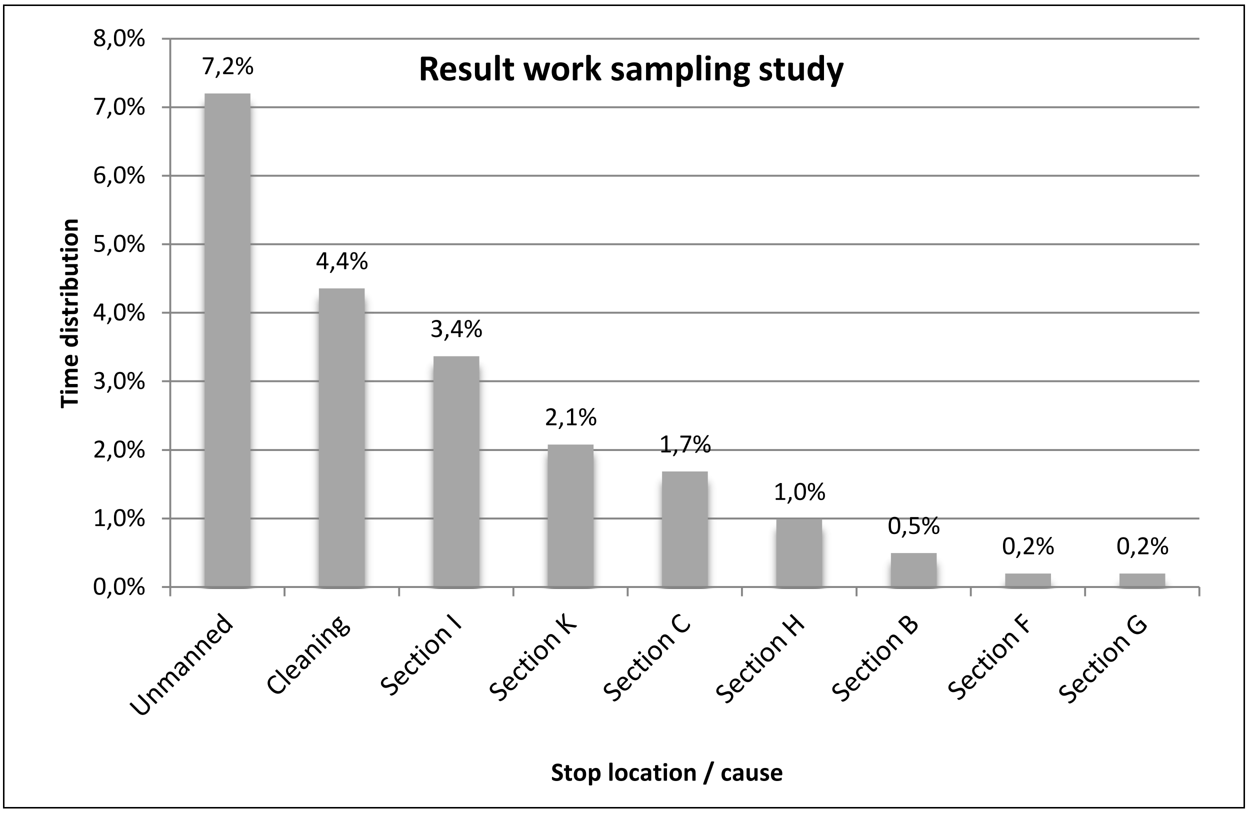


Figure 7: Pareto chart presenting the work sampling study. The causes or stop locations are ranked by magnitude.

The diagram shows that the "unmanned machine" is the activity which has the largest impact on the total downtime. The activity occurs mostly during occasions when the operator has pauses or that the shift changing operator is not there after the machine has been cleaned. The second largest downtime activity is cleaning, which is performed at the end of each working shift. Areas that are covered by the cleaning procedures are tools, sensors and floor area around the machines. There are even some administrative tasks performed during the cleaning sessions, while the machine is idle.

The remaining distribution of stops is the different machine sections where machine failure has occurred. Section I and K are responsible for the most downtime of the machine related stops. Stop causes in these sections are both triggered by automatic shutdowns and manual shutdowns identified by the operator.

4.1.2 Stop study

The stop study resulted in the Pareto chart shown in Figure 8. The procedure of the study is described in section 3.2. The total number of stops registered during the study was 127. The largest amount of machine stops were located in section I. Section K along with section G had also quite large amount of stops. The rest of the sections had considerable less stops than these three. Section I had both the largest amount of stops and the longest downtime according to the work sampling and the stop study.

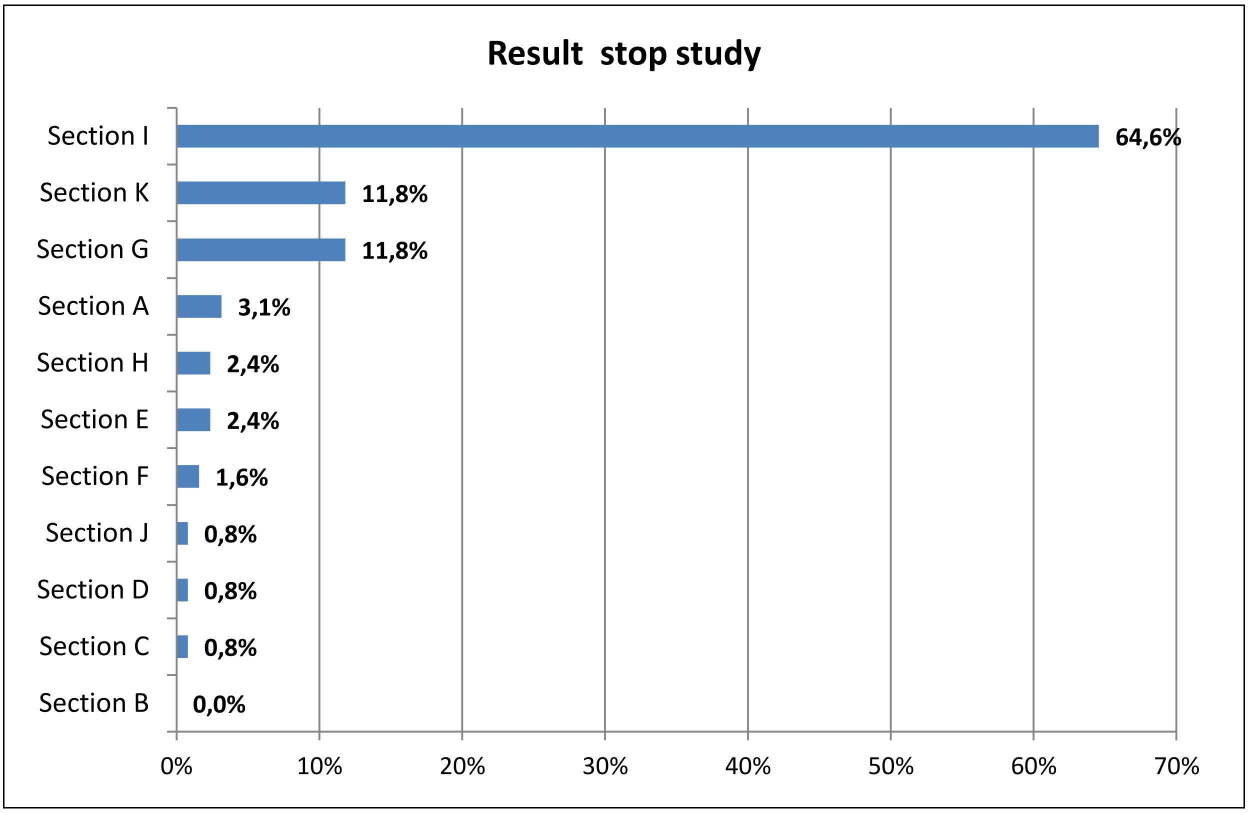


Figure 8: The result of the stop study illustrated as a Pareto chart.

4.1.3 VSM

The value stream map of the current state is presented in section 3.6. The map is representing one of the products which is produced by machine 2 (machine 2 is the main component of the studied production line within the company). It gives a brief description on how the actual value stream is composed and the lead time for the product considered.

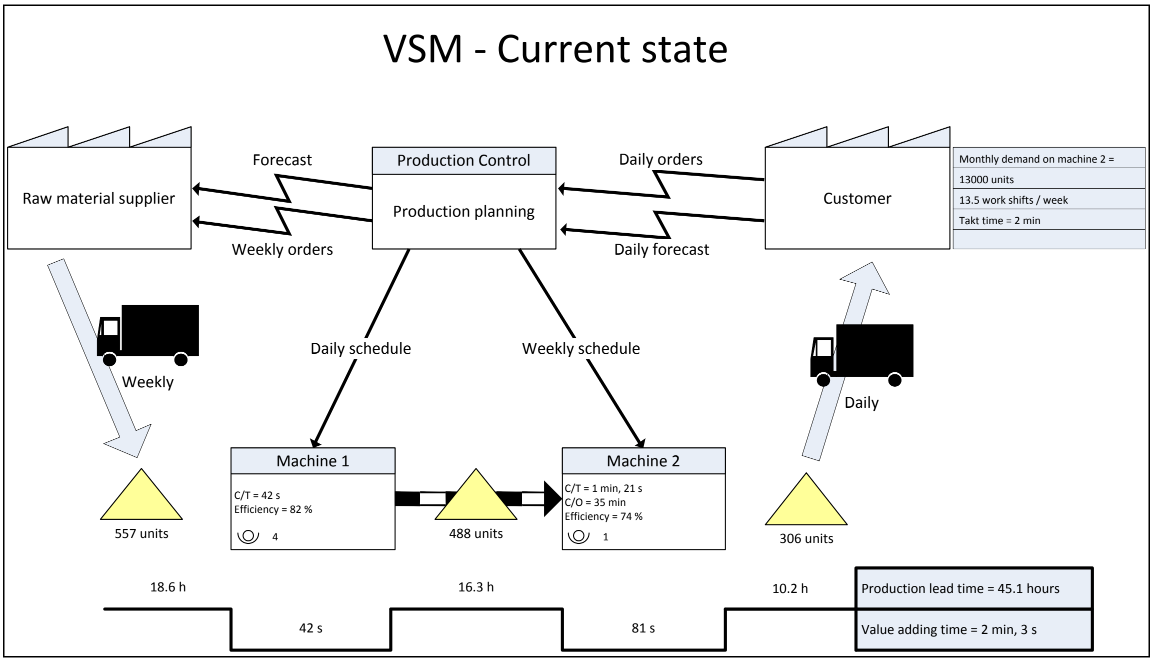


Figure 9: The current state value stream map of one selected product.

The VSM indicates that the value adding time is very small (0.08 % of the production lead time is value-adding) in comparison to the total production lead time. It further shows that raw material is shipped in weekly intervals to the factory. Raw material is then being processed into semi-finished goods and thereafter placed in a storage area within the company. The reason for storing the semi-finished goods is that the quality of the material (paper) improves by storing; it is getting "settled" as the operators call it. Storing the semi-finished goods for a couple of hours or days often has a positive effect on the efficiency of machine 2 – the number of stops is generally lower when "settled" paper is used. The current inventory level of semi-finished goods in the warehouse is therefore desired to some extent.

After machine 2 there is a finished goods inventory. There are daily shipments to the customer by trucks. The machines are running and manned at an average of 13.5 shifts per week.

4.1.4 Observations and interviews

The interviews showed that work procedures for operators are standardized in a written form. The work standards are quite general, which means that most of the detailed procedures are practical knowledge which is spread verbally. The execution of tasks differs a bit from individual to individual, but it also depends on experience level. The ways operators communicate are not standardized in written form, and it varies from discussing with operators at other machines about current quality issues and other problems to not communicating at all.

Most of the manual work at the machine consists of filling up raw material, supervising, maintaining, cleaning and administration. If the machine is running without any stops or other problems, the operators are busy most of the time with filling-up raw material and supervising the machine. Once there are stops and other problems, the work can be stressful to the operators. The machine efficiency is the limiting factor in the production flow, not the continuous manual work. However, the pauses that operators take, causing shutdown of the machine, reduces the machine efficiency.

Observations showed that operators attempts to fix problems themselves during the work shifts. If the problems are larger, the operators inform the mechanics. The mechanics often solve problems by "firefighting", and when a problem is fixed they leave the machine. Therefore it is a desire among the operators that mechanics assist the operators until the machine is fully stable after a stoppage. It is not unusual that the team leader of the shift is unaware of the problems at other machines, meaning that information will not reach all concerned employees.

Interviews revealed that there is an unsaid competition among the operators, which means that knowledge of how to reach a higher result is kept from the colleagues to some degree. The competition can therefore lead to a worse total result for the machine. There exists a production target level, but it is used mostly as an upper production goal. Once the production goal is reached, the machine is often turned off, even though there is still scheduled production time remaining. Since the demand is slightly higher that the supply, and there is a risk of machine breakdown or other unpredicted stops, entire production time should be used.

4.2 Analysis

Way that gathered data was analyzed is discussed below.

4.2.1 Work sampling study

The work sampling study discovered that one fifth of the scheduled production time was unavailable due to various stoppages. The study was only performed during four work shifts, which means that longer infrequent stops were not considered in results generated from this study. When estimating the average downtime of the machine, reported production results will probably be a more reliable source. When compared with historical data, indirectly obtained from company's production figures, showing five percent larger downtime than the work sampling study, the distribution of stops is the most interesting outcome from the work sampling study.

The activity "Unmanned" has the largest impact to the availability loss. Reducing downtime caused by this will potentially lead to a high productivity improvement. Today the operators take pauses either when they have achieved the production goal for the day or that they feel fatigued. It is not sustainable that the operators will have to work whole shifts without taking pauses (Rubenowitz, 2004). Letting the machine run without operator breaks is possible only if other workers are available to run it.

"Cleaning" is the second largest downtime cause. It is important because it prevents machine failures and quality defects. Most of the cleaning activities require that the machine is shut down for the operator to access the concerned sections. Some of the cleaning tasks could potentially be performed as external tasks by applying the SMED technique. Those external tasks could then be done before the shift cleaning stop. Lack of detailed standardized cleaning procedures may also lead to that some cleaning points are forgotten or that double cleaning work is done between work shifts.

Stops that occur in section I (which had the largest share of stops, according to results in section 4.1.2) are related to machine failures. During the work sampling study, most of these stops were caused by paper jamming. A couple of weeks after the study, the mechanics solved a lot of the stops by disassembling the machine parts in section I and performing a profound maintenance work. The largest cause for stops in this section, as well as section K (second largest machine related downtime) is related to quality deviations of raw material.

4.2.2 Stop study

The stop study was performed to give additional information about the characteristics of the machine stops. The outcome from this study confirmed that stops related to section I is of major concern. The operators were responsible for the data collection, thus making them more involved in the improvement project and it gave them an increased awareness about the problems. The result of the study did not come as a surprise to the operators, as it confirmed more or less the feeling about the current condition. As Barkland (2010) argues, the number of stops should be reduced by identifying the root causes for the problems and eliminating them. The stop study therefore served as one of the inputs to solving the root cause problems, by identifying those.

4.2.3 VSM

The value stream map indicates that the production lead time is rather long in comparison to the value adding time. The inventory level of raw material is probably justifiable, due to the requirement of deliveries by fully filled trucks. As a suggestion the most economical order quantity can be calculated to eventually reduce the raw material inventory.

The bottleneck of the value stream is machine 2, because it has the longest cycle time of the processes. The cycle time is one minute and 21 seconds, which is much lower than the takt time of two minutes. The gap between cycle time and takt time is partially used for managing disturbances that occur when running the machine. Improving the OEE figure will lead to an increased average efficiency that either can be utilized to produce more, increase setup frequency or cancel work shifts. The current manufacturing strategy is to deliver what is produced immediately, based on a budget planning. If the machine efficiency of the bottleneck is permanently improved, then is it important that the capacity figures in the production planning are adjusted accordingly.

4.2.4 Observations and interviews

The current state at the machine lacks work standards that are adapted to support operators in their daily work. New employees will have quite long learning time as they will have to learn by others and own practice, much because of the complexity of the work itself. Visual controls that are put up close to the machine would eventually support the operators to follow the established work standards. Communication between operators from different machines is another concern that must be improved in order to maintain the consistent quality and high machine efficiency.

Manual tasks during regular production are not controlled in that much detail. The freedom of how to perform tasks is believed to be vital for the well-being of the operators.

When there are problems, which cause the machine to stop, the operators or the mechanics do not always perceive that it is of vital importance to get the machine up again. As the operators pointed out, the mechanics could assist the operators until the machine is stable instead of leaving after fixing one issue, especially during setups. The problems that occur do not get documented by either the operators or mechanics. It is only done if there are especially extensive problems, which gives a reason for the root cause for the problem to be investigated. This fact creates a desire to work in a more systematic way with solving daily machine problems.

The unspoken competition between operators as well as shutting down the machine earlier than necessary is thought to be large obstacles to achieving higher machine efficiency. The operators need to become motivated to improve the machine efficiency. The managers have an important role in motivating the operators not to shut down the machine earlier. By emphasizing the importance of the total machine efficiency in the work group rather than individual performance, the sharing of knowledge to work smarter can be improved.

4.2.5 OEE

During the project time, OEE of the studied machines was continuously measured as a tool of keeping track of the impact that the changes would have. The obtained data was based upon following assumptions:

The machine speed was constant for all shifts (in reality, there were some minor variations between the shifts, that were adjusted by calculating a mean value).

All planned shifts were reported by the operators (in case of sickness, planned production time was maintained on the same level).

The “accumulated OEE”-figures were calculated by taking the previous four weeks into consideration, in order to give an adequate picture of the development of the OEE figure.

Nor the psychological aspects were studied – presence of an observer that followed the work, and by that, indirectly might have influenced the operator to perform better than usual.

4.2.6 Benchmarking

Visit to another production site was conducted, in order to observe and compare how similar operations and working procedures are performed there. Due to differences of produced volumes, the organizational routines on the visited site were more structured, with daily meetings where information about the latest production was exchanged between operators, team leaders and productions engineers.

One of the main differences was the use of automatic data collection, which was widely used. This allows gaining a better statistical accuracy before any investment decisions are made.

Some technical solutions to problems similar to those discovered on the studied site were found, mainly within the field of ergonomics. Some of them will be presented in the chapter about improvement suggestions (chapter 5). Those changes might not be applicable on the studied site due to high initial costs, and also maintenance reasons.

Implementing the observed automatic stop-time, stop-cause and breakdown collection methods, would contribute for a more reliable support for the decision making processes of the company investigated in the project.

4.3 Improvement plan

Information gained from machine observations and measurements and also from interviews resulted in a list of solutions (Table 1) according to their impact on the production outcome. Some of the solutions are described more detailed in chapter 5, while other are only mentioned in the table.

Solutions with low cost and short implementation time were prioritized, since those would have larger initial impact and would motivate for further implementation of other, more costly and difficult solutions. (Freivalds, 2008).

When the results of the studies were presented to the management staff, it was confirmed by them that they suspected prevalence of the top causes, and that those causes were now confirmed in a “scientific way”. This could be helpful in further motivation of workers when participating in the improvement work, by presenting arguments based on facts (Liker, 2004).

So far, there were mostly firefighting actions taken when a problem occurred, by going more thoroughly and investigating the causes of the problems and breakdowns, those could be eliminated for reoccurring in the future.

By creating a table similar to Table 1, it would easier for the company gain a compact overview of possible problem areas, their interrelation to each other and also some solutions towards solving them.

4.4 Conclusions of current state

After analyzing the current state, it is possible to see that the company could continue the production as it is now, but there is a potential for improvement in many of the studied areas.

Table 1 - Possible improvements

Rel. value of measure: Very efficient (9) Efficient (3) Moderately efficient (1)	Investment cost: Low: < 10 000kr Medium: 10 000 - 100 000kr High: > 100 000kr	Required time consumption: Low Medium High	(1) = machine 1 (2) = machine 2

			Investments (estimated)		
Priority	**Suggested solutions**	**Points**	**Cost**	**Time required**	**OEE gain**
1	Reach the target value and register if there are any defects on the rolls (1)	214	Low	Medium	+ 2 %
2	Improve cleaning routines (1, 2)	170	Low	Medium	+ 2 %
3	Run the machine with replacements, while ordinary operators have pauses (2)	167	Medium	Low	+ 5 %
4	Implement visual control (2)	108	Low	Medium	
5	Spread knowledge about how to run the machine in an optimal way (2)	89	Low	High	
6	Implement standardized work	87	Low	High	
7	Implement 5S (2)	87	Low	Medium	
8	Improve cleaning routines for sensors (2)	84	Low	Medium	
9	Implement standardized machine settings (1)	59	Low	Medium	
10	Visualize the weekly production goals (2)	54	Low	Low	+ 5 %
11	Install low-friction tape or similar to the spindles at section A	45	Medium	High	
12	Replace section J	38	High	High	
13	Install a rake to the rolls after section D	27	Medium	Medium	
14	Automatic adjustment of the overlap	27	High	High	
15	Implement regular checks of section H	19	Low	Low	
16	Implement routines to stop defective rolls from passing on to the next process (1)	15	Low	Low	
17	Enlarge the holes in section H	9	Medium	Medium	
18	Adjust the distance behind the rolls at section B	3	Low	Low	

- "OEE gain" is based on theoretical assumptions, and was not confirmed due to too short study time.

5 Trial of solution implementation (Do)

This section will present the selected solutions that the project group produced. The selected solutions were implemented as a trial for a few weeks. Most of the improvements were tested in smaller scale for evaluation purposes. The numbers one and two in the headlines below represents machine 1 and 2. In chapter 6 the effects of the implementations will be evaluated.

5.1 Production during operator pauses (machine 2)

In the current state the operators at the machine take pause for 30 minutes every work shift. During the pauses the machine is usually stopped, but at some occasions other operators or mechanicals step in. Some of the operators also postpone the pauses to shut down the machine earlier, and by doing that could leave earlier, but still having worked their contracted hours per day.

During the work sampling study it was identified that stops derived from unmanned machine counted for about 7.2% of the downtime. Manning the machine during operator pauses will therefore have a great potential for improving the availability of the machine.

The implemented solution was letting operators from other machines run the machine when ordinary operators are having pauses. The main requirement to make this possible is to teach more operators in how to run the machine. Until more operators are taught to run the machine, free mechanics may step in to run the machine.

5.2 Reducing friction with spindles while loading rolls (machine 2)

Semi-finished material is delivered to the machine as rolls. The rolls are loaded to the machine on spindles with the use of a hoist. Due to the weight of the rolls the operators need to exert a considerable force to push the rolls to the right position. The manual task is repeated with a frequency of about five times an hour, but varies depending on the length of the rolls.

Some tests were carried out by ordinary personnel in order to study the effects of increasing the length of the rolls. The tests has shown that an increase would benefit all parts of the factory (logistics, raw material supply machine, waste numbers and amount of repetitions of changing per day), but not the ergonomics for the workers handling it. The ergonomic situation could be improved significantly by decreasing the friction on the spindles.

The most sustainable solution to this problem is to invest in new spindles with low friction surfaces. Alternatively a similar result can be obtained by milling lengthways tracks on the existing spindles to reduce the locating face. Another possible solution is to install bearings to the surface of the spindles.

5.3 Standardized machine settings (machine 1, 2)

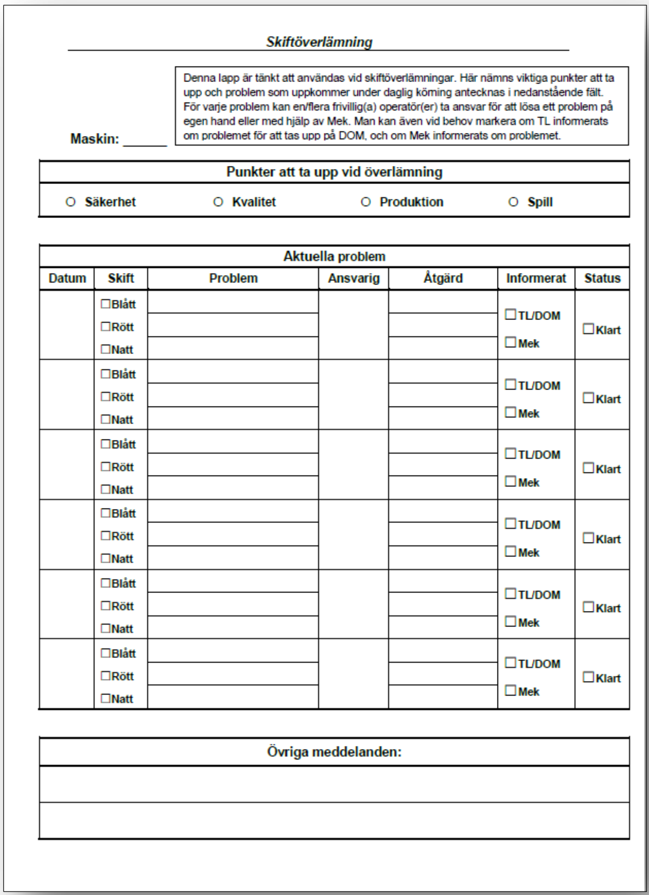
Some of the downtime can be derived from absence of standardized work. The rolls are a good example of how the material can deviate because of the different settings that are used at machine 1.

The benefits from running the machines with the same settings if possible were conveyed to the operators. If there had been more time available to the project, the work would probably been to guide the operators in standardizing the settings for machine 1 and 2.

5.4 Shift handover (machine 2)

Currently the handing-over operator tells the operator about larger problems during the previous work shift. Smaller intermittent problems are not documented or followed up by the operators. It is thus recommended to follow up problems in a more organized way.

The implemented solution is to have structured shift handover sessions. At these meetings current problems from preceding shifts are discussed. The sessions are also performed according to a standardized agenda, where current problems are discussed and actions to solve them are decided on. A sample form (Figure 10), was designed to support these meetings and document problems that occur during work shifts. These forms are filled in by the operators. In the form, one of the operators can be noted to be responsible for the follow up of the problem. Which personnel are to be informed is also possible to note, as well as actions taken to solve the problem. The form is also a way to spread information on intermittent problems to all concerned machine operators, by having the team leader bring up previous problems in the daily operator meeting.



Skiftöverlämning

Maskin: ______

Denna lapp är tänkt att användas vid skiftöverlämningar. Här nämns viktiga punkter att ta upp och problem som uppkommer under daglig köming antecknas i nedanstående fält. För varje problem kan en/flera frivillig(a) operatör(er) ta ansvar för att lösa ett problem på egen hand eller med hjälp av Mek. Man kan även vid behov markera om TL informerats om problemet för att tas upp på DOM, och om Mek informerats om problemet.

Punkter att ta upp vid överlämning

○ Säkerhet ○ Kvalitet ○ Produktion ○ Spill

Aktuella problem

Datum	Skift	Problem	Ansvarig	Åtgärd	Informerat	Status
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart
	☐Blått ☐Rött ☐Natt				☐TL/DOM ☐Mek	☐Klart

Övriga meddelanden:

Figure 10: Shift handover form.

5.5 Reach the target value and note diameter and remarks on the rolls (machine 1)

Currently it is not unusual that the quality of rolls is deviating from specification for a whole batch of rolls. This has to do with that the material quality is not monitored sufficiently and defects are not detected fast enough.

The quality of paper rolls should thereby be monitored more continuously and actions should be taken, such as changing machine parameters and clean machine sections, to reach and maintain the target value of the weight and diameter of the rolls.

The implemented solution involves that the operators at machine 1 notes on the rolls if there are any defects on them. By doing this, the operators at machine 2 are noticed in advance about the defects. The operators at machine 2 can then plan which rolls to process and in what order. Defects and remarks are assigned different codes (Figure 11), to simplify the communication between the two machines.

Markeringar vid avvikande papperskvalitet

Limklumpar	LK
Massaklumpar	MK
Fiberklumpar	FK
Ojämn tjocklek (markera med pil vilken sida det gäller)	← OF →
Särskilt tjockt papper	TP
Särskilt tunt papper	SP
Rester i kanter (markera med pil vilken sida det gäller)	← RK →
Avvikande materialbredd	AM

Om det är möjligt kan även avvikelsens placering i rullen markeras, genom att fästa en tejpbit i sidan på rullen där avvikelsen finns. På detta sätt blir operatören vid konverteringsmaskinen beredd på när pappret med defekten rullas upp.

Figure 11: Example of codes for informing of different defects.

5.6 Cleaning routines (machine 1)

At some occasions the material quality of rolls is deviating and this can in some cases have to do with inadequate cleaning of machine 1.

The solution is to introduce cleaning checklists for the operators. The use of checklists is thought to reduce the risk of producing paper with deviating quality, due to the fact that if the machine is not cleaned regularly, then the quality parameters changes dramatically.

5.7 Spread knowledge about how to run the machine in an optimal way (machine 2)

There is a variation in experience level of how to run the machine among the operators. The more experienced operators have the ability to run the machine with lower reject rate and downtime than others while having raw material with deviating paper quality. If the knowledge could be spread to all operators working at the machine, the efficiency of the machine would increase. There are even more areas that can be improved by sharing knowledge between operators, e.g. the work procedure for changing over and faster overlap adjustments when changing paper rolls.

A first step to improve the knowledge dispersion is to encourage the operators talk about problems and improvements during shift handovers. The goal is to create scheduled time for them to work with improvements.

5.8 Whiteboard to simplify communication (machine 2)

In the current state the workplace at machine 2 lacks a natural meeting place where messages and problems can be conveyed.

The solution was to install a whiteboard in a central position at the workplace (Figure 12). The operators were informed about how to use the board and the benefits it implies to use it. The board can be used to emphasize current problems and other information that needs to be spread. The OEE figures are also posted on the board to show the previous production results.

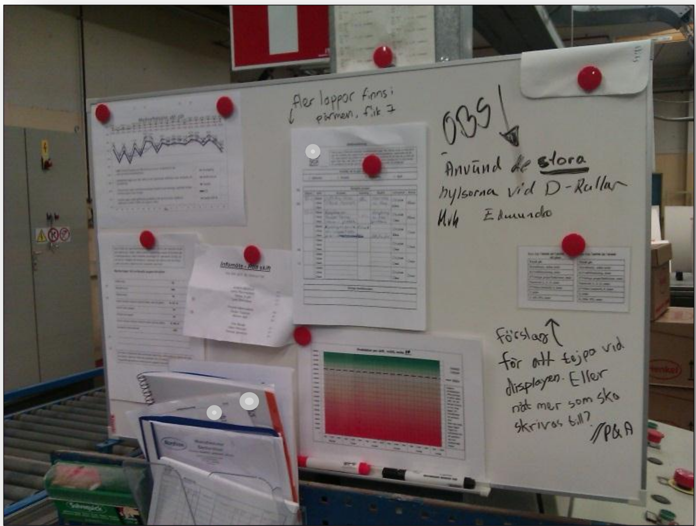


Figure 12: Whiteboard for communication.

5.9 Line direction aids (machine 2)

At some occasions the splice breaks when the rolls are changed. This leads to that the paper or the plastic will have to be put back through the machine by hand. Since this happens seldom it is easy to forget the direction of the paper or plastic. Installing it in the wrong direction will lead to unnecessary machine downtime and create additional frustration to the operator.

Another similar problematic situation is putting a double-sided tape for the splice on the wrong side of the paper. That would also cause downtime of the machine, when the paper would need to be refitted.

A solution is to put up self-explaining figures that shows the direction of the line through the machine. Also, a figure that shows which side of the paper to fasten the tape was created. These figures are placed close to the section where the operator works. Hopefully these aid will help the operators to do it right the first time, especially for those who are new or have not worked for a while.

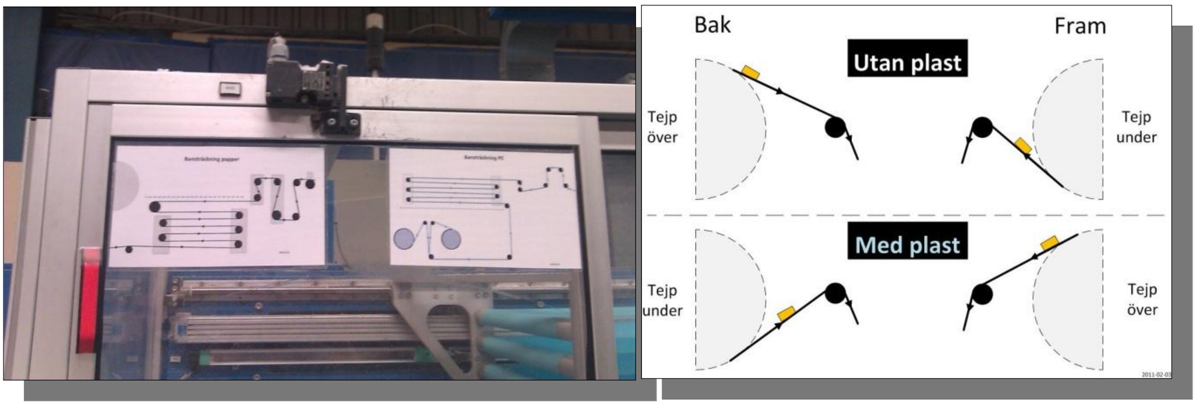


Figure 13: Guiding figures.

5.10 **Visualization of production goals (machine 2)**

One of the discussed suggestions is to visualize the weekly and daily production goal for the operators. Today the weekly production planning schedule is put on a board located far away from machine 2 and it is conveyed verbally to the operators. The goal for the week is also posted to the board.

A way to make the operators committed in reaching the production goals for the week is to encourage them to fill in their production results in a diagram after each shift. The diagram shows the daily production goal as an average of the production goal of the week. The introduction of this activity will probably increase the production efficiency by creating a team spirit to reach a common goal.

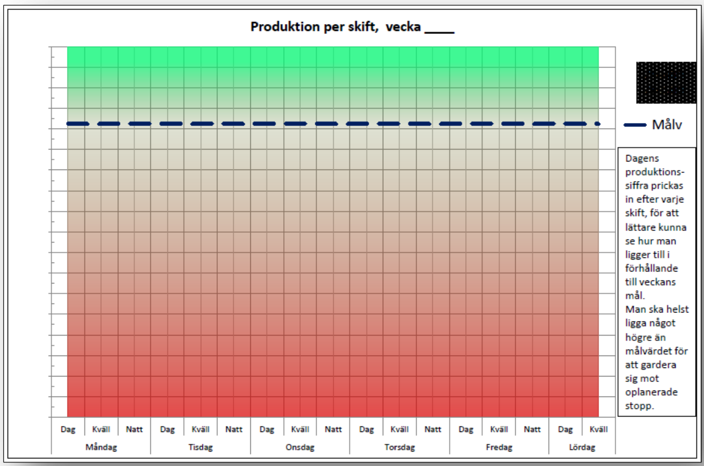


Figure 14: Visualization of production goals.

6 Achieved state (Check)

This section will present the outcome of the pilot implementations. It will be further discussed whether or not the implementations had any impact to machine efficiency or if it had any other benefits to the factory.

6.1 Result of achieved state

The result of achieved state shows an improvement in OEE with up to ten percentage points since the beginning of the project period. The solutions implemented are considered as contributing positive factors, but the interest put on the workplace during the project period cannot be excluded.

6.2 OEE

The effects of the implemented solutions were mainly evaluated by measuring the OEE value for machine 2. In Diagram 1, the plotted values represent the relative average OEE value in relation to the current OEE values in the beginning of the study. It further shows that the OEE values were increased with 5 - 10 percentage points during the study period.

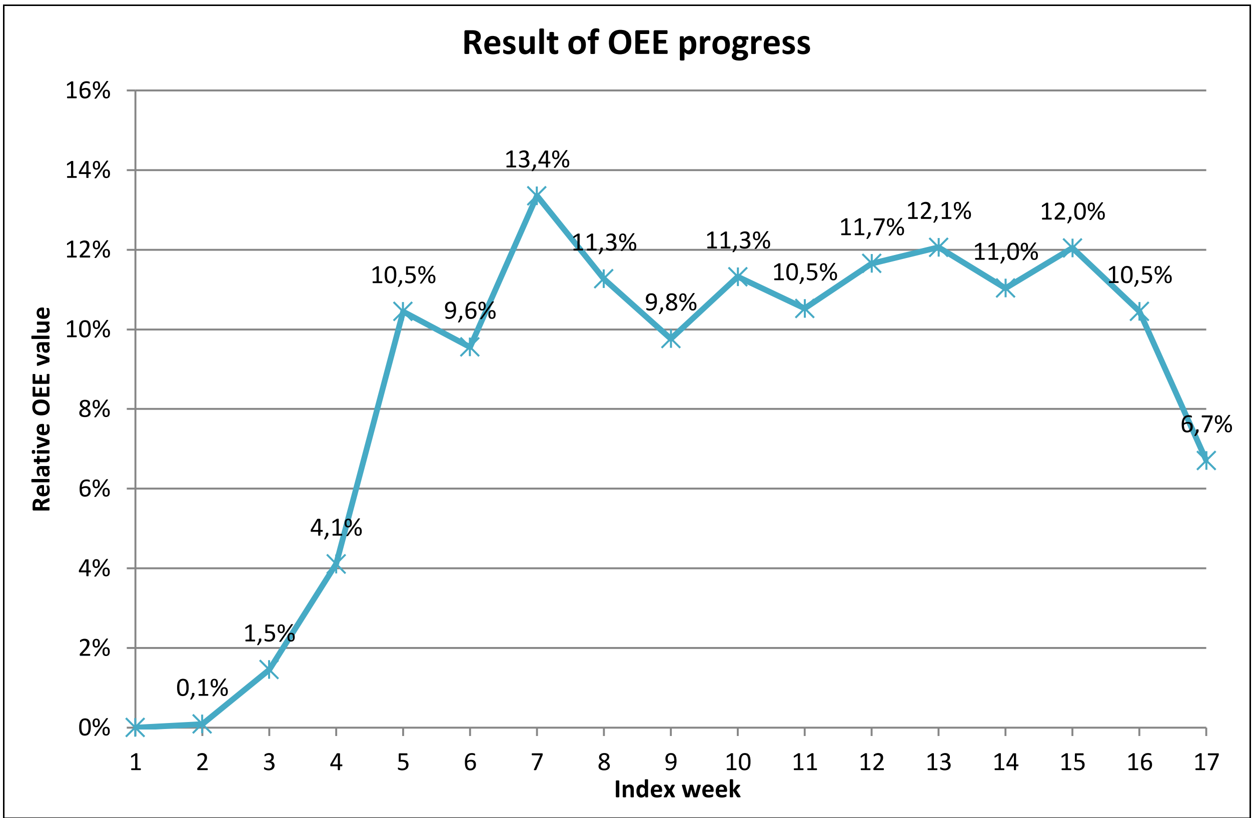


Diagram 1: The relatively moving average (4 weeks) OEE-value for machine 2.

The OEE measurements were performed a couple of weeks before index week 1, in order to calculate the average OEE of the current state before the project started. The largest increase of OEE happened the first five weeks. The OEE increased about 10 percentage points to be stabilized at that higher level. The OEE drop in reference index week 17 can be considered as non-representative for the total project, as the involvement of the project team was phased out after week 15. This could be used as an indicator of that when there is a solid interest about the performed work, then the work is performed better, which encourages of hiring a production engineer.

The most significant contributing factor of the OEE improvement was the availability. As the machine does not have the ability to log the machine speed, the project team monitored the current speed of the machine every time it passed by. The observations showed that the speed was about the same the whole project time. The quality has improved slightly since the beginning, it can be responsible for about one to two percentage points of the increased OEE, but there is no distinct data to confirm that.

6.3 Follow-up of the implemented solutions

The implemented solution was tried for a couple of weeks to see if the machine efficiency could be increased could increase machine efficiency. The solution to run the machine during pauses was fulfilled to some degree. One more operator is learning to run machine 2, but it may be required to teach even some more to be able to cope if someone is absent. Ideally, all operators should be able to operate all machines of the company, so that more alternative working conditions could be achieved.

One test was carried out by the project group to evaluate the effects of reducing the friction on the spindles. In the test, the spindles were coated with a Teflon based tape. Operators perceived that the coating reduced the friction significantly, but unfortunately the tape deteriorated gradually. The described sustainable solution in section 5.2 has not yet been implemented, but the process to implement it has started.

The shift handover has had a positive acceptance among the operators. The shift handover forms have been used more or less as they were planned. In the beginning of the implementation, the project team supported the operators to use the new forms and the suggested meeting agenda. How this implementation is followed-up after the implementation period is not evaluated.

The strategy to follow-up the quality of the rolls in a better way has had some effect to the improved availability of machine 2. The operators at machine 1 have also marked rolls that contain defects with different codes. The defects marking have made it easier to plan which rolls to process.

Since the cleaning checklists at machine 1 have been filled in during a short period of time, it is hard to determine if it had any effect on the quality issue.

The visual control solutions have been the most apparent implementations to the workplace. Operators now have a place to post current problems for the rest of the work team to read at the machine. The whiteboard also gives feedback of the production results to the operators working at machine 2. The presentation of OEE diagrams on the whiteboard started a discussion among the operators about how their behavior affects the graphs.

6.4 Analysis

Implementing improvements at the machines have had a positive impact on the machine efficiency. It may also be questioned what effect the presence of the project team had to the achieved results. During the project, the operators have reported that the work environment has improved. Whether the results have been affected by the authors' presence or not, the results still confirm an improvement of the efficiency. Attention has been paid to the problems concerning the machine and possible improvement areas have been identified, which the operators at the machine have been involved in. The achieved state is not granted to last, especially if there is no one following up the improvement work continuously. This will be further discussed in chapter 8.

OEE for machine 2 is much dependent on the paper quality from machine 1. The steep drops in OEE for a couple of weeks in diagram 1 are probably caused by big problems at machine 1. Further improvement work should consequently be focused to reduce variations at machine 1.

It is hard to point out what solutions had the largest effect on the result, but all solutions did contribute to the total improvement. The solutions based on visual control was considered as the most obvious and prioritized improvements, which contribute in making the factory more visual to employees and visitors.

The implemented solutions are considered as a template for what can be achieved by applying Kaizen at a limited factory area. The most important outcome of the implemented solutions is not the solutions themselves, but the systematic process of improving.

6.5 Conclusions of achieved state

As it is stated previously, some improvements of the efficiency factors (OEE measurement) were noticeable during the time improvements were applied. By introducing new routines for keeping track of the performed improvement work, would make the operators aware that some changes are made, and a widespread improvement work might eventually be given a well needed start.

7 Future state (Act)

In this chapter, further applications of selected trial implementations are presented. Recommendations to the company regarding the further improvement work will thereafter be presented.

7.1 Standardization

The implemented solutions in chapter 5 serve as templates of Kaizen improvements. The character of the improvements was of "small extent", requiring low time-, or monetary investments to implement. It is this type of improvements that the company should continue to work with.

Most of the implemented solutions were considered as successful and should consequently be standardized. The recommended solutions (described thoroughly in chapter 5) to be standardized are:

- Whiteboards at the machines
- Sample forms for structured shift handover and problem follow-ups
- Production during operator pauses
- Checklists for cleaning and maintaining the machines
- Diagrams to follow-up production goals
- Continuous OEE measurements

The list of solutions resulted in achieving higher machine efficiency during the studied period. In order to make the solutions permanent, they must be incorporated in the company's current written work standards, as well as explaining the significance of following the work standards to the workers.

7.2 Recommendations

When working with further improvements, the recommendation is to follow a systematic work flow (Figure 15), that is similar to the PDCA cycle. The work flow also reflects the steps of this project.

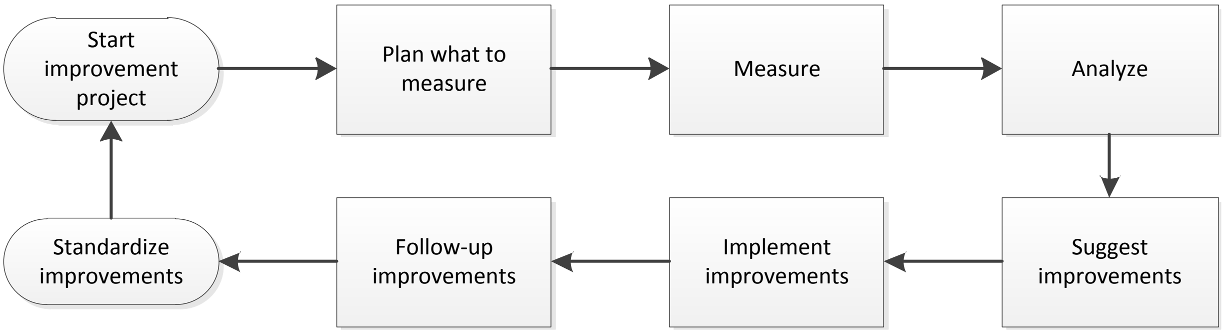


Figure 15: The suggested design of continuous improvement work.

One of the purposes with the project was recommending a work method for further improvement of production availability of the company. The suggested method to measure availability was OEE, as used in this project.

In order to be able to measure the current state and identify possible improvements of the availability, the following methods (described in chapter 3) are suggested:

- Work sampling study
- Stop study
- Tree diagram or similar
- Matrix diagram

As the outcome of the trial implementations turned out positive, the recommendation is to implement those improvements to other lines within the factory. Another recommendation is improving the quality of the material from machine 1, as it still limits the availability of machine 2.

During observation of one setup for machine 2 it was revealed that some setup tasks could be performed in advance. A list of suggestions for reducing setup time was developed, which operators are recommended to consider (Appendix A).

One of the main recommendations to the company would be hiring a process engineer who would be responsible for coordinating the daily improvement work within the factory. Based on observations and interviews performed during the study period at the company, it was revealed that a majority of the staff would appreciate to have routines with clear role definitions and responsibilities of the work tasks.

This would also relieve the management team from tasks that they may have little time to perform, as well as better confidence for the workers when they see that the improvements are taking place.

One important prerequisite for improving efficiency of the machines would be allocating scheduled time for the operators to work with improvements. This would emphasize the interest and importance of working with improvements continuously. Engaging the majority of the workers in adopting the philosophy of continuous improvement is also a key factor for success. Although it is not an easy task, taking into consideration that the average length of employment within the company is approximately 25 years (according to the company manager). Thus, the role of a process engineer also could not be underestimated.

8 Discussion

The selection of methods used in this study was primary based upon literature studies. This resulted in achieving a good overview of the most commonly used and acknowledged methods to implement in the project.

Since the stop study and the work sampling study were conducted under a limited time period, several aspects could have influenced the results – without the possibility of identifying which one had the most significant impact. Possible interruption factors were:

- Weather – the production process is sensitive to sudden changes of temperature and level of humidity outside the factory.
- Production sequence – according to the interviews, some operators experienced that quality of the products shifted, depending on the sequence of produced raw material from machine 1.
- Presence of the observation team on the workplace could have affected the operators to perform in a different way as they normally do (also known as the Hawthorne effect). (Rubenowitz, 2004)

By having a possibility to perform a follow-up study, some clarification might have been added to the parameters discussed above.

The use of OEE as the main source of measuring achieved improvements could be questioned. An example is that the fact that a single missed shift, for example due to absence of the operator, would cause a significant drop in OEE figures.

Other aspects that could have been performed in the project, but remained on the planning stage (advising the company to implement them):

- Deeper and more extensive implementation of the “5 S”
- More focus on the entire value stream
- Deeper understanding of the processes, and knowledge about mechanical and electrical parts, so that more concrete recommendations regarding machine configurations could be given to the company
- Deeper use of theory and methods

Regarding the results gained from benchmarking, knowledge and solutions concerning similar problems could be exchanged on a deeper level. But not all of the results and ideas could be implemented at the company, mainly due to high overhead costs that would arise because of the differences of organization size between the companies.

The size of the studied company makes it also difficult to handover all the work considering leading and encouraging further improvement work to a specific person within the company, since the working load would be too high. Nevertheless, as the project revealed, showing close interest and performing continues follow-ups of the work has a positive effect on the OEE parameters.

Delimitations with the suggested methods are:

- Work sampling study: knowing duration of the study so that an adequate current state condition could be obtained. This is a time consuming method, which is depended if it is a “good or bad” production day.
- Stop study: manual data collection is one of the major problems; the operators might not have filled out all the times when the stop occurred, also, it is hard to always know the exact cause of each particular stop, causing misleading information.
- OEE: by varying the machine speed during the shift (without notification) it is possible to influence the production outcome. The produced quality is based on the rejected rate, which might not be that accurate.
- Tree diagram: multiple causes might refer to the same problem, which might make the “5 why” method hard to implement.
- Matrix diagram: estimation of cost, time needed to implement and the outcome of the solutions are all parameters that are hard to predict.
- Interviews: give a subjective description of the problem, based on personal experience and “the human factor”.

Delimitations with the suggested recommendations are:

- Hiring a production engineer is a large investment, which should the properly investigated before implementation.
- The “5S” and similar actions require longtime commitment, both from the managers and workers, and also knowledge that the results would not be visible directly.

During the project three main parts of sustainable development were taken into consideration; the social, economical and environmental.

Social – factors such as encouragement for taking breaks when needed and also showing appreciation of the work performed by the operators, which would improve the work environment. Also, some of the workers began to suggest their own improvements, which were adopted and implemented.

Economical – by increasing productivity and lowering the level of scrap products, economical sustainability is increased.

Ecological – by reducing the scrap rate, the impact on the environment would be decreased, with lower consumption of raw materials and electricity.

Disregarding some lack of knowledge about specific parts of the production line, the applied methods gave a good overview of the current state of the company, and also indicated what could be done to maintain and progress the improvement work.

9 Conclusion

The purpose of the study regarding suggestion of new methods to increase the efficiency was fulfilled. Suggestions were, based on the performed studies, contemplated and then proposed for implementing into the company. Some of the recommendations were implemented during a trial period, with positive response from the managers and the workers. The unimplemented recommendations are also described in the report, allowing the company to implement those if they have the chance.

The initial goals were partly accomplished.

- Efficient tools, such as OEE, are established as a reliable way of measuring efficiency and improvements.
- A study to be able to point out the most common stop-causes was performed, and suggestions that might decrease or eliminate those stops were given.
- Since the trial implementations of new routines were conducted with mixed results regarding their effect on the efficiency and reception by the operators, more extensive studies are needed.
- No solid implementation plan regarding further implementation within the rest of the company was designed, mostly due to time shortage.

The company wants to achieve a higher efficiency, and since there is an improvement potential, it can be achieved by following the recommendations given in the future state chapter.

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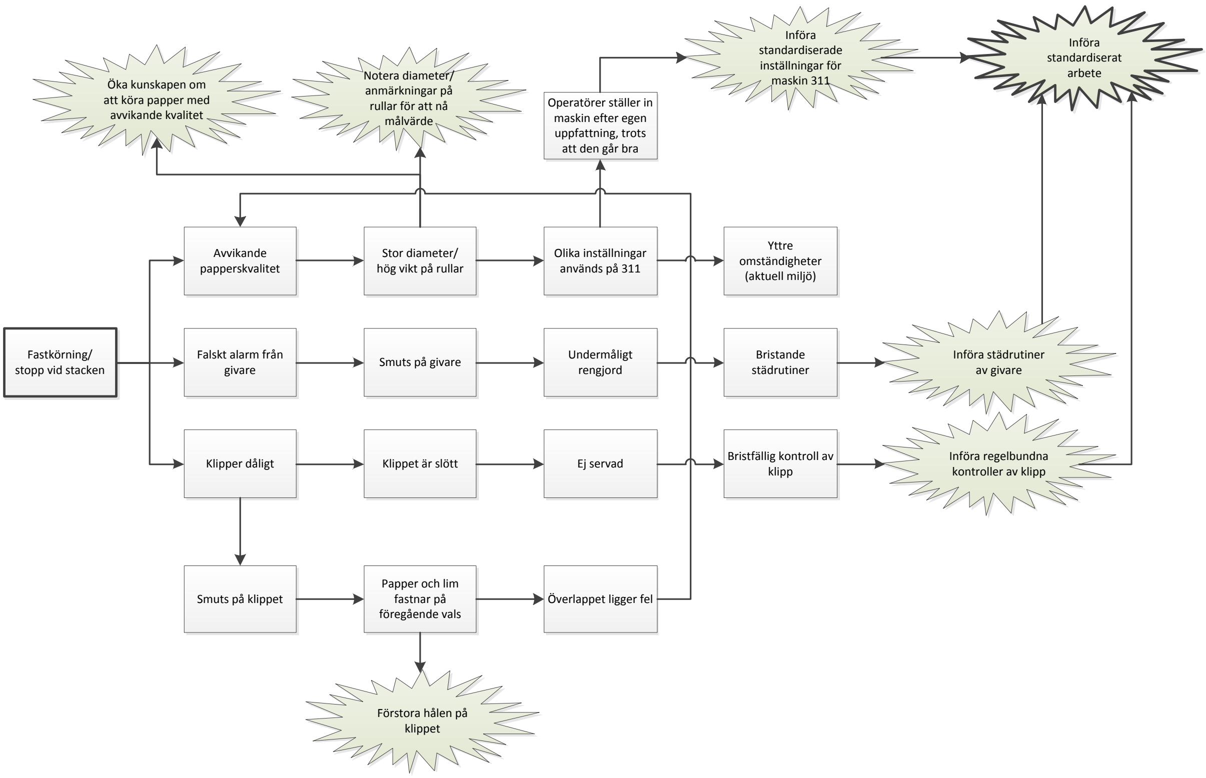
Appendix A

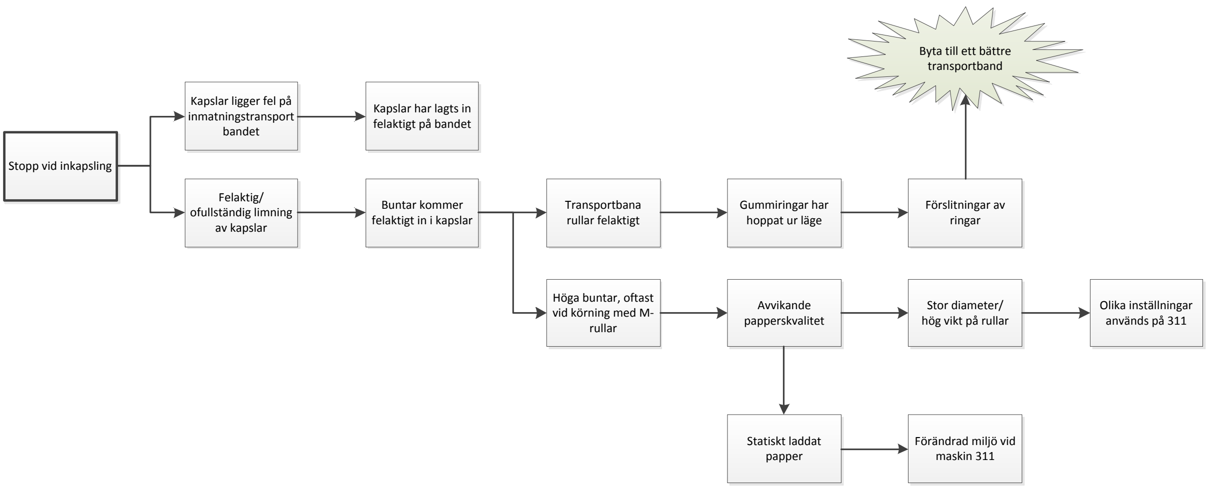
SMED-idéer

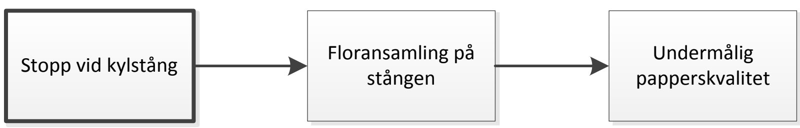
- Förbered lådorna genom att ställa fram rätt pall och lossa buntband i förväg.
- Vänta med att lägga tillbaka överblivna kapslar i kartonglådorna, gör det efter omställningen.
- Kör fram pall med kapslar i förväg, samt öppna kartong med kapslar i förväg.
- Fyll inte på kapslar o lådor hela vägen upp, gör det sen.
- Ha en skylt vid inkapslingen, för att visa hur lådorna ska ligga.
- Slutmarkering för kapslar och lådor för att inte behöva lägga i för mycket innan omställning.
- Lathund vid PLC för att visa inställningar som gäller vid de olika sorterna.
- Vänta med att trä på den andra pappersrullen och plastrullen.
- Införa en lathund/checklista för omställningar, som är särskilt utformad för nybörjare.
- Ha en mekaniker/operatör som hjälper till vid omställning.

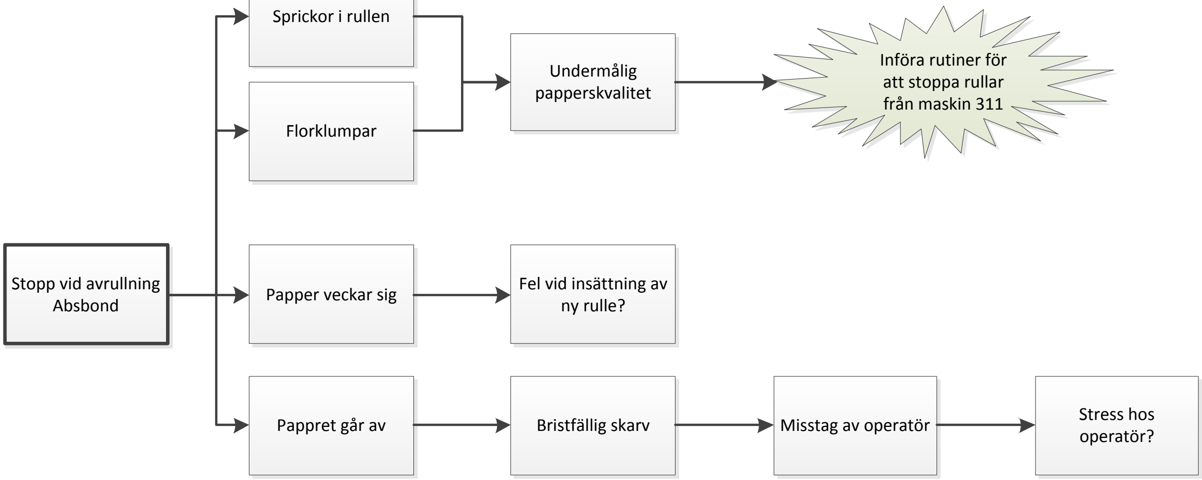
Appendix B

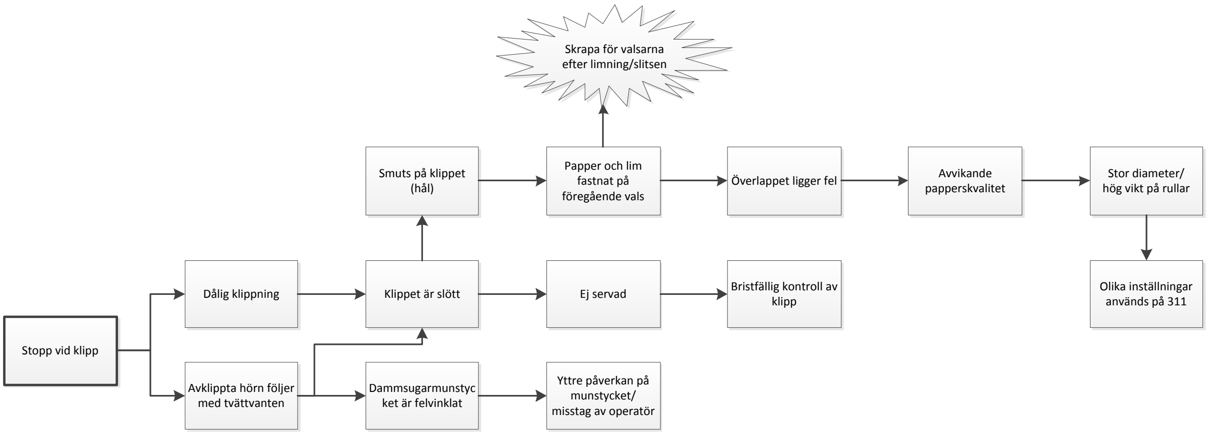
Tree diagrams



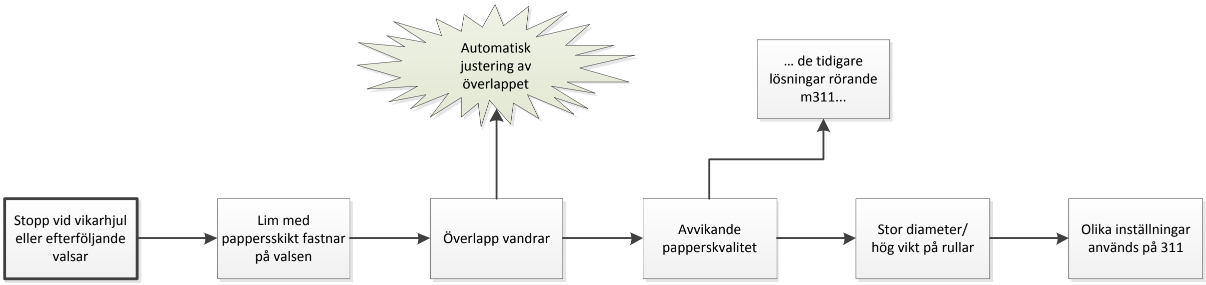


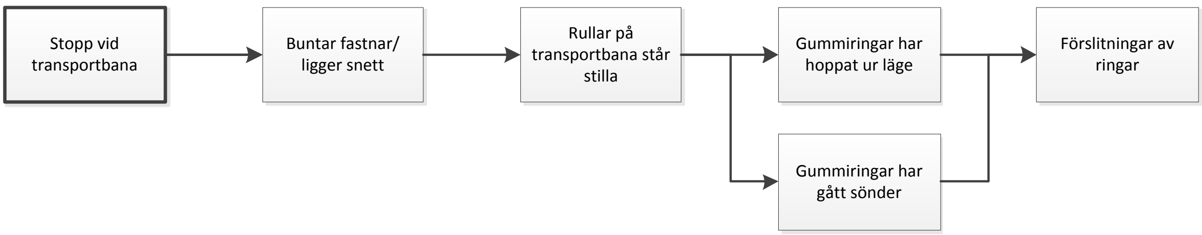


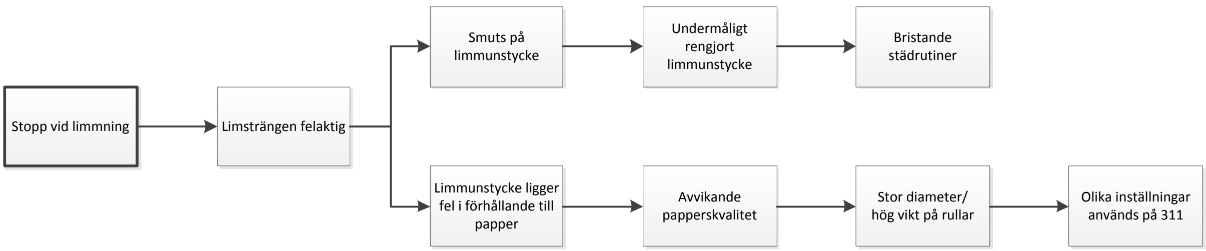

Stopp vid avrullning Absbond
Sprickor i rullen
Florklumpar
Undermålig papperskvalitet
Införa rutiner för att stoppa rullar från maskin 311
Papper veckar sig
Fel vid insättning av ny rulle?
Pappret går av
Bristfällig skarv
Misstag av operatör
Stress hos operatör?

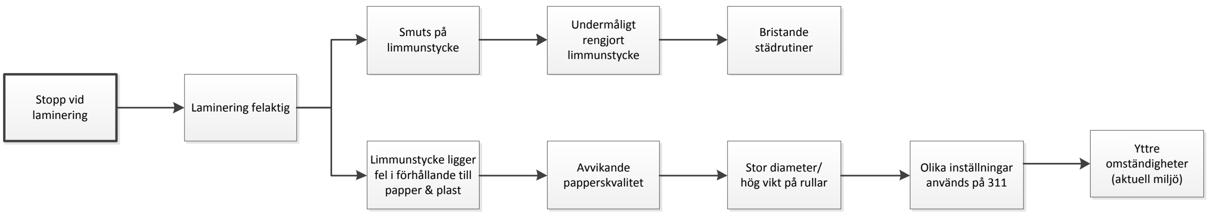

Skrapa för valsarna efter limning/slitsen
Smuts på klippet (hål)
Papper och lim fastnat på föregående vals
Överlappet ligger fel
Avvikande papperskvalitet
Stor diameter/ hög vikt på rullar
Olika inställningar används på 311
Dålig klippning
Klippet är slött
Ej servad
Bristfällig kontroll av klipp
Stopp vid klipp
Avklippta hörn följer med tvättvanten
Dammsugarmunstycket är felvinklat
Yttre påverkan på munstycket/ misstag av operatör

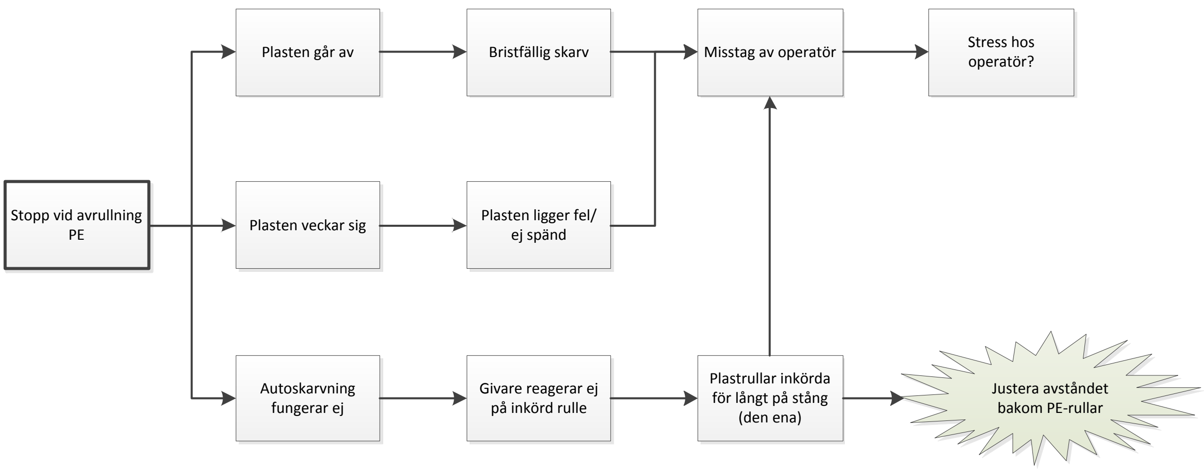

Stopp vid justering mellan M&D-sida rullar
Limmunstycke ligger fel i förhållande till papper (vid limningen)
Avvikande papperskvalitet
Stor diameter/ hög vikt på rullar
Olika inställningar används på 311

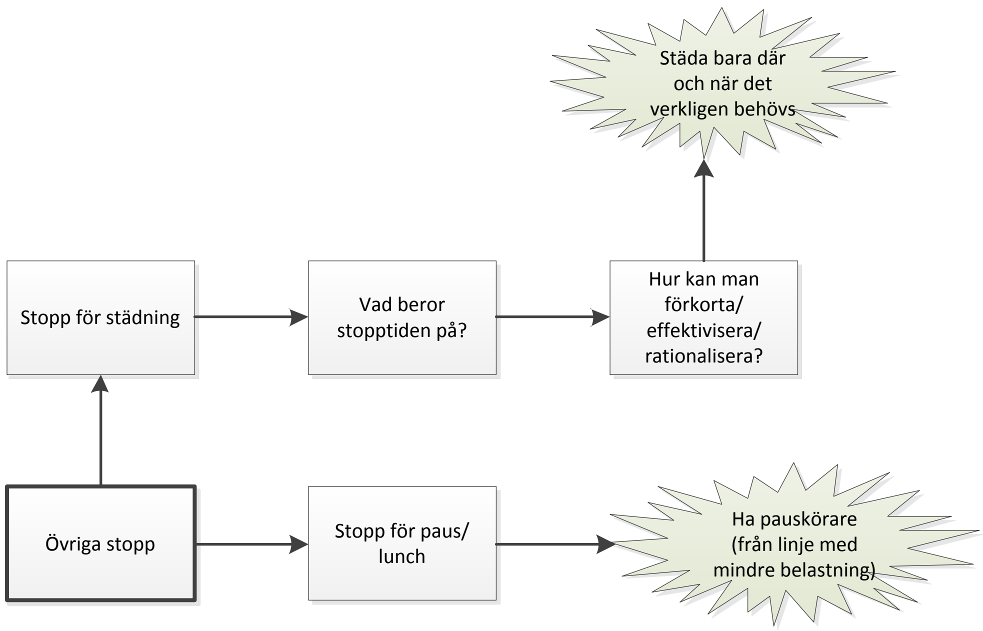

Automatisk justering av överlappet
... de tidigare lösningar rörande m311...
Stopp vid vikarhjul eller efterföljande valsar
Lim med pappersskikt fastnar på valsen
Överlapp vandrar
Avvikande papperskvalitet
Stor diameter/ hög vikt på rullar
Olika inställningar används på 311


Stopp vid transportbana
Buntar fastnar/ ligger snett
Rullar på transportbana står stilla
Gummiringar har hoppat ur läge
Förslitningar av ringar
Gummiringar har gått sönder


Stopp vid limmning
Limsträngen felaktig
Smuts på limmunstycke
Undermåligt rengjort limmunstycke
Bristande städrutiner
Limmunstycke ligger fel i förhållande till papper
Avvikande papperskvalitet
Stor diameter/ hög vikt på rullar
Olika inställningar används på 311


Stopp vid laminering
Laminering felaktig
Smuts på limmunstycke
Undermåligt rengjort limmunstycke
Bristande städrutiner
Limmunstycke ligger fel i förhållande till papper & plast
Avvikande papperskvalitet
Stor diameter/ hög vikt på rullar
Olika inställningar används på 311
Yttre omständigheter (aktuell miljö)


Stopp vid avrullning PE
Plasten går av
Bristfällig skarv
Misstag av operatör
Stress hos operatör?
Plasten veckar sig
Plasten ligger fel/ ej spänd
Autoskarvning fungerar ej
Givare reagerar ej på inkörd rulle
Plastrullar inkörda för långt på stång (den ena)
Justera avståndet bakom PE-rullar


Städa bara där och när det verkligen behövs
Stopp för städning
Vad beror stopptiden på?
Hur kan man förkorta/ effektivisera/ rationalisera?
Övriga stopp
Stopp för paus/ lunch
Ha pauskörare (från linje med mindre belastning)

Appendix C

Raw data - work sampling study

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Date	Duration (h)	Running	Cleaning	Material shortage	Unmanned	Avrullning absbond	Avrullning PE	Lamineringsdel	Limmning	Justering M & D-sida	Vikning	Kylstång (rengöring)	Klipp	Buntning/Stacker	Transportbana	Inkapsling	Summa	produkt	downtime
2			85,7%	4,4%	0,0%	0,9%	0,0%	0,5%	1,7%	0,0%	0,0%	0,2%	0,2%	1,0%	3,4%	0,0%	2,1%			14,3%
3		28	866	44	0	9	0	5	17	0	0	2	2	10	34	0	21	1010		
4	2010-11-23	8	243	12		6						2	2	8	10		1	284	740400	
5	2010-11-25	5,5	163	8		3		5	4					2	13			198	740400	
6	2010-11-29	7,5	219	11					13						2		17	262	740500	
7	2010-12-01	7	241	13											9		3	266	740500	
8																				
9																				
10																				
11																				
12																				
13																				
14				Running	Cleaning	Material	Unmann	Avrullni	Avrullni	Laminer	Limmnir	Justerin	Vikning	Kylstång	Klipp	Buntnin	Transpo	Inkapsling		
15				85,7%	4,4%	0,0%	0,9%	0,0%	0,5%	1,7%	0,0%	0,0%	0,2%	0,2%	1,0%	3,4%	0,0%	2,1%		
16																				
17						Running	85,7%													
18						Running	79,5%			lunchtid/rast		unmanned uppmätt			unmanned 2					
19				inkl. lunch		Unmann	7,2%			6,25		0,9			7,15	%				
20						Cleaning	4,4%													
21						Buntnin	3,4%													
22						Inkapslir	2,1%			Unmann	7,2%									
23						Laminer	1,7%			Cleaning	4,4%									
24						Klipp	1,0%			Section	3,4%									
25						Avrullni	0,5%			Section	2,1%									
26						Vikning	0,2%			Section	1,7%									
27						Kylstång	0,2%			Section	1,0%									
28						Material	0,0%			Section	0,5%									
29						Avrullni	0,0%			Section	0,2%									
30						Limmnir	0,0%			Section	0,2%									
31						Justerin	0,0%													
32						Transpo	0,0%													
33																				

Appendix D
Raw data - stop study

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1																
2																
3																
4																
5				Avrullning A	Avrullning P	Laminering	Limmning	Justering me	Vikning	Kylstång (rer	Klipp	Buntning/ St	Transport- b	Inkapsling		
6				3,1%	0,0%	0,8%	0,8%	2,4%	1,6%	11,8%	2,4%	64,6%	0,8%	11,8%		
7				4	0	1	1	3	2	15	3	82	1	15		127
8	date/shift	17-nov	kväll						1	3		9				
9			natt							1		6				
10			dag							3		17				
11		18-nov	kväll					2				1		1		
12			natt	2								6				
13			dag				1	1				4				
14		19-nov	kväll							2		3		2		
15			natt	1								8		3		
16			dag													
17		20-nov	kväll													
18			natt													
19			dag			1				2		6	1	2		
20		22-nov	kväll													
21			natt													
22			dag								2	8		1		
23		23-nov	kväll													
24			natt							1		4		3		
25			dag	1					1	3	1	10		3		
26		24-nov	kväll													
27			natt													
28			dag													
29		25-nov	kväll													
30			natt													
31			dag													

Appendix E
Matrix diagram of suggested solutions

Suggested solutions Stop location/cause	Weight	Spread knowledge about how to run the machine in an optimal way (2)	Reach the target value and register if there are any defects on the rolls (1)	Implement standardized machine settings (1)	Implement standardized work	Improve cleaning routines for sensors (2)	Implement regular checks of section H	Enlarge the holes in section H	Replace section J	Implement routines to stop defective rolls from passing on to the next process (1)	Install a rake to the rolls after section D	Adjust the distance behind the rolls at section B	Automatic adjustment of the overlap	Install low-friction tape or similar to the spindles at section A	Implement 5S (2)	Improve cleaning routines (1, 2)	Run the machine with replacements, while ordinary operators have pauses (2)	Visualize the weekly production goals (2)	Implement visual control (2)
Unmanned / cleaning	18				3	3					1				3	9	9	3	3
Section I	10	3	9	3	1	3	1												
Section K	8	3	9	3	1				3										
Section A	5	3								3									9
Section E	5	1	9	1									3						
Section C	5														3	1			
Section F	4		1										3						
Section H	3						3	3			3								
Section G	1																		
Section J	1								9										
Section D	1		3												3	3			
Section B	1											3							9
Ergonomics	5	3			3				1					9	3		1		
Total score		89	214	59	87	84	19	9	38	15	27	3	27	45	87	170	167	54	108