A Production Process Analysis of a Selected Company

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ABSTRAKT

Tato bakalářská práce se zabývá analýzou výrobního procesu ve vybrané společnosti. Cílem práce je stručná analýza výrobního procesu společnosti a nalezení úzkého místa, které by bylo následně detailně analyzováno za účelem jeho zlepšení. Práce je rozdělena na část teoretickou a praktickou. Teoretická část se zabývá výrobním procesem, štíhlou výrobou a metodou SMED. Praktická část je složena z popisu společnosti, jednotlivých výrobních procesů, současné situace a aplikace metody SMED včetně návrhů na zlepšení. Praktická část je pak zakončena potenciálními ekonomickými přínosy.

Klíčová slova: výrobní proces, štíhlá výroba, plýtvání, přetypování, SMED.

ABSTRACT

This bachelor's thesis focuses on a production process analysis of a selected company. The goal of this thesis is to analyze the production process of the company on a basic level and to find a potential bottleneck that would be then analyzed with the aim of improving it. The thesis is divided into a theoretical and an analytical part. The theoretical part focuses on the production process, lean production and a SMED method. The analytical part consists of a description of the company, individual production processes, current situation and an implementation of the SMED method, including suggestions for improvements. The analytical part is then concluded with the potential economic benefits.

Keywords: production process, lean production, waste, changeover, SMED.

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CONTENTS

INTRODUCTION

The main goals of the successful businesses include achieving profits and satisfying customers' needs. In both managerial and production processes, it is essential to effectively manage resources that are available for the business in order to achieve the set goals. This is connected with industrial engineering and lean production that focuses on the efficiency of the business processes. This efficiency can be accomplished primarily by reducing and eliminating waste, i.e., processes that do not add any value. Lean production contains a set of techniques and methods that deal with this issue. If the business uses such techniques and methods, it will lead to increased productivity, reduced costs and also the business will be able to flexibly respond to changing demand and therefore deliver products on time. The aim of this bachelor's thesis is to analyze the production process of the company Cardbox Packaging s.r.o. and to find a bottleneck that would be then further analyzed for a potential increase in productivity.

The theoretical part consists of three main chapters. The first chapter provides information about the production process, transformation process, production systems and types of plant layouts. The second chapter describes lean production, the Toyota Production System that identifies all types of waste and several lean activities. The last chapter covers the SMED method as it is the main part of the analysis.

In the analytical part, the company is introduced as well as the individual production processes. Moreover, the company's current state is described where the bottleneck is identified and further analyzed. The last part of the analysis displays the economic benefits that can result from the implementation of the suggested solutions.

I. THEORY

1 PRODUCTION PROCESS

A production process is a process in an organization that converts either intermediate products or raw materials into finished products. This transformation is done using different equipment, tools, manufacturing processes, etc. (Singh 2006, 2–3) Kumar and Suresh provide more broad definition. They describe the production process as the transformation of inputs into outputs. Furthermore, each step of the production should add a certain value to the product. (2008, 3)

Tuček and Bobák describe the production process from different perspectives. Firstly, from a technical point of view, it is a sequence of operations in which all factors of production are connected and transformed into goods and services. Secondly, from an economic point of view, it is an activity designed to meet supply and demand in the market. Lastly, it is possible to categorize the production processes into various transformation groups. (2006, 24–27)

According to Shingo, the production itself can be viewed as networks consisting processes and operations and emphasizes an importance of knowing about a difference between them. A process is an ongoing stream of activities where raw materials are converted into the final products. Each of these activities encompasses one or more operations. Therefore, the operation is an action performed on raw materials, intermediate or finished products by either man, machine or equipment. (1985, 5)

1.1 Transformation process

Every production system involves some kind of transformation process wherein inputs are transformed into goods and services. In an ideal case, the process is realized in wanted quality and with minimum cost. Of course, unprocessed items like raw materials cannot provide any use or value to the customer. For this reason, the transformation process enhances these items with value and changes them into desirable goods and services. If they are sold for more than it costs to produce or provide them, including different expenses, this change can be considered as a success. In general, it is possible to say that the transformation process consists of many other subprocesses. Also, the subprocesses vary depending on the field where these conversions take place. (Gupta and Starr 2014, 20–21)

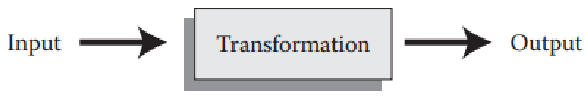


Figure 1 – Transformation process (Gupta and Starr 2014, 21)

1.2 Production systems

A system can be defined as a compilation of various components, such as machines and methods that correlate, function and contribute to a particular goal. The system is then composed of other subsystems which are interconnected and they also emphasize the relations between each of them. (Bellgran and Safsten 2010, 38–39) A production system is therefore a set of:

- Methods of lean production.
- Management tools.
- Industrial engineering techniques.

Moreover, the production system carries out production as such, i.e., the transformation and modification of inputs to final outputs (goods and services). It can be said that the objective of the system is to achieve a certain quality, flexibility, efficiency and a good service provision as these are the key factors for market success. The internal structure of the production system can be divided into 4 areas: main processes, improvement of processes, supporting processes and management. (Tuček and Bobák 2006, 12, 21–22)

Singh says that there are different types of the production system, namely job, batch and mass production. (2006, 3) Kumar and Suresh add one more type that is continuous production. (2008, 4)

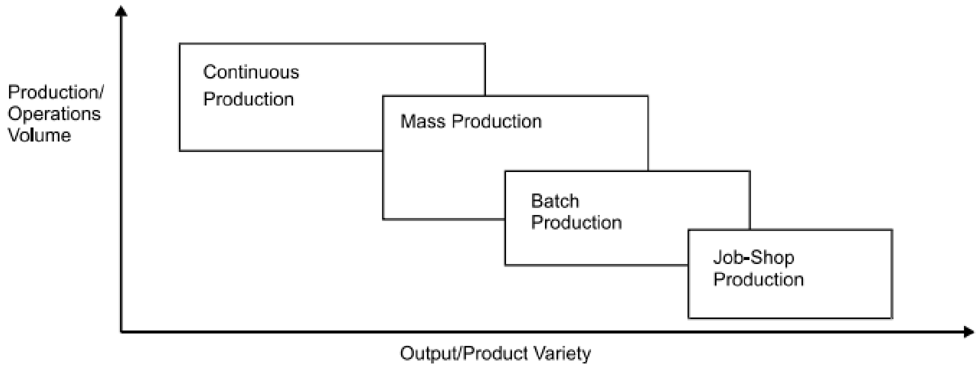


Figure 2 – Production systems (Kumar and Suresh 2008, 4)

1.2.1 Job production

Job production can be described as manufacturing done by one or more operators who work on a single specialized product until it is completely finished. Depending on the requirements of customers, it is performed within fixed cost and time. Since this production system usually involves many different and complex types of products produced in a low volume, each job can require different resources used in a specific order. Thus, one disadvantage of this production may be a higher cost of inventory. On the other hand, there are many opportunities for creative ideas and improvements. (Kumar and Suresh 2008, 4–5; Singh 2006, 3)

1.2.2 Batch production

Batch production is a manufacturing of products in a limited amount. Once a single batch of one product is finished, the next batch of the next product can proceed to its production. In contrast to job production, the cost of a single unit is lower. Furthermore, a lower investment in machines is required as a company with established batch production should have flexible machinery. Nevertheless, there are also some disadvantages, for instance, the higher costs of setups due to their frequency and the complexity of production planning. (Kumar and Suresh 2008, 5–6; Singh 2006, 3)

1.2.3 Mass production

Singh explains that mass production produces a large volume of products, however, a huge investment in machines have to be made. (2006, 3) Kumar and Suresh add it is manufacturing or assembling of parts in an ongoing process. In comparison with batch production, in a situation where one machine breaks, an entire line must be stopped. In spite of that, the cost per unit is also low and less skilled workers are needed. (2008, 6)

1.2.4 Continuous production

Kumar and Suresh note that this type of production system is specific in a way that production continuously flows through several operations until it is completely finished. Such a flow is then secured by flow lines and automated devices that transport individual material. As a result, no manpower is needed for the material handling, the cycle time is shortened and the rate of production is increased. (2008, 6–7)

1.3 Plant layout

A plant layout is an arrangement of equipment and machines in a factory. They are usually organized into groups so they can fulfill a particular goal in the most efficient way. In order to achieve a potential increase in productivity and quality, it is important to design the layout accordingly to a specific type of production. Additionally, if the layout is correctly designed and implemented it can result in reduced waiting time and transportation time. The purpose of a good plan layout is, for example, to reduce the movement waste of both workers and material, to ensure a smooth flow and to make a good use of space.

Moreover, it contributes to increased safety and overall employee satisfaction. Gupta and Starr, Singh and Groover agree on the 4 main types of layout that are: fixed layout, product layout, process layout and cellular layout. (Groover 2012, 19–21; Gupta and Starr 2014, 391–92, 394; Singh 2006, 17–19)

1.3.1 Fixed layout

This type of layout (also known as project layout) can be characterized as manufacturing or assembling of components or products at a fixed position. Everything that is required, like tools, machines and equipment is then moved to a place where the manufacturing process takes place. Of course, this also applies to workers. Thus, the product remains at the same position throughout the whole process until it is finished. This happens to be very useful when large and heavy objects are produced and moving them would be very difficult and costly. Some examples can be the manufacture of aircraft and ships. Nevertheless, most of the time these products consist of large components that are produced separately and then assembled together. It is very flexible and any process can be changed without interfering with the layout. (Groover 2012, 19–20; Singh 2006, 19–20)

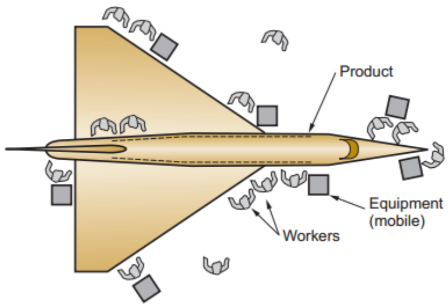


Figure 3 – Fixed layout (Groover 2012, 20)

1.3.2 Product layout

A product layout is closely associated with a flow line production. Every process of production, including equipment and machines is organized in the most efficient way. Most of the time, it is a long line or series of interconnected lines. These lines then create sequences throughout which components flow before they become the final product. Automated technology is typically used for a transport between stations where one process continuously follows the other. (Groover 2012, 21) Singh adds that this layout is used for mass production and has many advantages, such as simplified (automated) material handling, smooth flow, shorter production time and reduced inventory. (2006, 22–23)

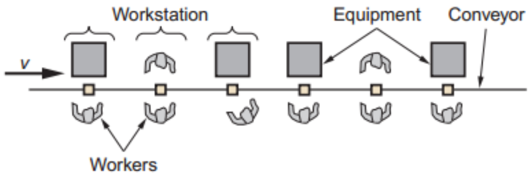


Figure 4 – Product layout (Groover 2012, 20)

1.3.3 Process layout

According to Gupta and Starr a process layout can be described as a situation where identical or related things (equipment or type of work) are brought together. Every operation has its own station and they must be allocated properly so that when one operation is finished it can move to another one. Furthermore, due to its flexibility and mobility, it is easy to set up any necessary change. (2014, 394) Groover specifies that this type of layout is usually used to produce components of larger products. Each component may require different operations for its complete production and therefore they circulate through various departments in a specific order. One of the drawbacks may be low efficiency because of machines and methods that are used. (2012, 20)

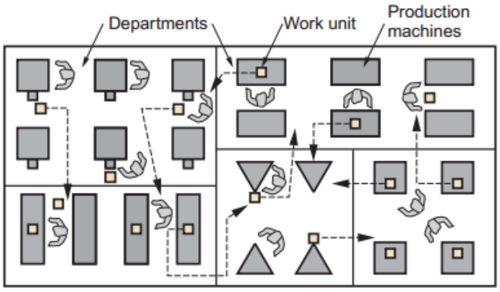


Figure 5 – Process layout (Groover 2012, 20)

1.3.4 Cellular layout

In this layout, items with similar characteristics are grouped together and manufactured in a single cell. These cells include workstations with workers, machines and equipment required for processing a particular item. It can be said that a cellular layout integrates the advantages of both process layout and product layout. The main goal is to limit the amount of movement within a single cell to a minimum and thereby productivity and efficiency can increase. (Gupta and Starr 2014, 394; Kumar and Suresh 2008, 46–47)

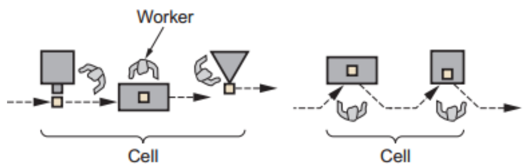


Figure 6 – Cellular layout (Groover 2012, 20)

2 LEAN PRODUCTION

Lean production can be defined as a set of different techniques and methods which can be further combined and will result in reduction and elimination of waste in various forms. Therefore, a company will then become leaner, more flexible and responsive. In general, it can be said that lean production is production where it is possible to achieve more work using fewer resources by means of eliminating waste. Even though the terms lean production and lean manufacturing are used separately, both of them have the same basis and that is lean. Using lean can lead to processes having following properties:

- Less materials used.
- Less investment required.
- Less people needed for work.
- Less inventory used.
- Less space consumed.

Moreover, a lean process can benefit manufacturing plants by reducing their unpredictability and disarray. Not only that lean production improves physical and financial side of things but also emotional. People are more confident while doing their job and they also perform with a better flow. (Groover 2012, 1052–53; Wilson 2009, 9–10)

In order to achieve lean production, several techniques and methods have been developed. Some of them are used more frequently than others. For instance, Kaizen is used for the reduction of production errors and to enhance the current processes by means of continuous improvement. Another example can be total quality management (TQM) that is primarily known for its focus on customer satisfaction. On the other hand, Kanban uses cards as a way of controlling and visualizing the inventory level. Some other techniques and methods are, for example, 5S, total productive maintenance (TPM) and poka-yoke. (Lata and Sharma 2017, 50–52)

Toyota, using its practices, helped to shape a basic model of lean production itself. Furthermore, lean production is something that may be characterized by 4 aspects. The first aspect is a lean plant which is essentially the foundation of lean production and which may be recognized as something identical to the concept of the Toyota Production System (TPS). The second aspect is a lean supplier network. It lifts up various practices used in the relationships with a supplier, for example, Toyota assigned its suppliers to different tiers and motivated them to further promote learning and improvement. In addition, they involved the suppliers in a production system. Another aspect is a lean product development that differs by its approach to leadership, communication, etc. Finally, the last aspect is based on building the relationships with customers and distributors. Similarly to the supplier network, Toyota created a distribution network in which the dealers would be involved in the production system by means of providing Toyota with information about customer's needs. (Salvendy 2001, 555–57)

2.1 Creation of lean production

Dennis says that to understand lean production and how it started, it is important to take a look at the mass production that preceded. Before the mass production, there was the craft production carrying several problems, such as quality of a product not being stable, production in low volumes and higher prices. Fred Winslow Taylor and Henry Ford tried to find ways how to eliminate these problems. It was Fred Winslow Taylor who invented the basis of the mass production among which were, for example, standardization of work and continuous improvement. On the other hand, Henry Ford took part in innovating ways how to make the assembly line work better by simplifying the overall assembly process. The problem was that the assembly process was not coordinated, thus resulting in unnecessary movement of workers and actions required to perform. This problem was solved when Ford came up with the moving assembly line. Despite these innovations and many improvements, the mass production still had its flaws, for instance, separation of engineers, larger machinery, lack of quality and workers hating their work. (2016, 1–7)

The creation of lean production can be traced back in Japan at the Toyota Motor Company. It was in 1950 when Eiji Toyoda went to study each aspect of Ford's manufacturing complex in order to improve Toyota's production. In that time, Toyota managed to produce only about 2 600 automobiles, whereas Ford was able to produce 7 000 automobiles per day. Nevertheless, after returning Eiji and Ohno Taiichi have agreed that the mass production is not suitable for the current situation in Japan. Therefore, they had to develop their own system considering the challenges Toyota had to face. Even though the relationships between the company and the workers were not good at first, the situation was solved later thanks to an agreement that helped to establish important part of lean production; the workers being more involved in the company. In the upcoming years, Taiichi Ohno and many other people took part in developing this new system, which is now called the TPS. Production in smaller batches and quick changeovers were only parts of this system which, in the end, helped to solve Toyota's problems one by one. The lean thinking was then embraced by Ohno in other plants of Toyota, including their suppliers. (Dennis 2016, 8–15)

2.2 Productivity

According to Mašín and Vytlačil, productivity can be generally described as a measure which expresses how efficiently resources are used when creating products. The increasing productivity results in reduced costs, more efficient use of resources, higher profit, etc. They also add that the high productivity is a key factor for businesses. It is mainly because of an increasing demand for a better quality of products/services for the same or lower price. Another reason can be an increase in the cost of producing products or providing services. There are many factors that contribute to the productivity. Nonetheless, if these factors are handled poorly it can be said that businesses create waste while producing products. (2000, 13–15, 27, 44–46) The Toyota Production System can be considered as the first system that focuses on waste and its reduction/elimination.

2.3 Toyota Production System

The Toyota Production System or the TPS is the system established in Japan. It started as an idea of raising productivity by getting rid of unnecessary waste. Taiichi Ohno, the founder of this system, describes the basis of this system as follows: "…the absolute elimination of waste." He then continues with saying that the TPS consists of two pillars that are just-in-time (JIT) and autonomation (Jidoka). A flow of processes plays a crucial role in such production that desires to increase its productivity, profitability and, in an ideal case, to reach zero inventory. This can be achieved by ensuring that every process gets everything needed in time and in the right quantity, which is essentially what JIT means. Another important aspect of the TPS is autonomation, which basically aims for the production without defective products. Using a device installed into a machine would recognize when a faulty product is being made and immediately stop the machine. Afterwards, one worker would fix the issue right away. Without this safety system, hundreds of faulty products could be produced. Outside of these two pillars, he then describes the system as something where "cost reduction is the goal." (Ohno 1988, 3–8)

Wilson gives his own description of the TPS. He describes it as a manufacturing system that aims for cost reduction using the right quantity, while still paying attention to the quality of products and processes. Moreover, it is described as the system which is integrated, constantly evolving and has a strong culture full of positive attributes. Wilson then highlighted 3 revolutionary concepts:

- Providing value to the customer.
- Reduction of lead time.
- Elimination of waste. (2009, 10–11, 22)

2.3.1 Waste

Taiichi Ohno states that to improve efficiency it is important to produce only needed quantity using minimal manpower. It is also crucial to improve efficiency at each level of production, taking into account every single line and every operator. While analyzing waste with the intention of eliminating it, those points should be kept in mind. To achieve a potential production capacity, one must eliminate waste occurring during production. Thus, Ohno categorized waste into 7 types: overproduction, waiting, transportation, processing, inventory, movement and making defective products. (1988, 18–20) Furthermore, in order to properly identify them, implementing a waste measurement system can be considered. Such system then requires 3 conditions that have to be met. Firstly, elimination of root causes using a comprehensive analysis. Secondly, measuring and controlling progress using different metrics. Lastly, creating standards that facilitate the decision-making process of identified problems. (Pieńkowski 2014, 9–10)

Overproduction

Overproduction is a state where a company produces products that are not demanded by customers. Therefore, many products are made earlier, faster and there is an unnecessary amount of them. (Arunagiri and Gnanavelbabu 2014, 2169) This kind of production may cause other types of waste to arise, for instance, when workers waste their time making redundant products, when these products have to be transported and inspected. It may happen that a company itself plans the overproduction to have enough finished products available. Nevertheless, this is not ideal and the company can end up wasting a lot of valuable resources. Overproduction can result in excess materials, workers, machines, energy, hidden problems, etc. (Dennis 2016, 33; Wilson 2009, 25)

Waiting

Waiting type of waste ensues from a worker not being active for any reason. The reason can be that a worker cannot continue in his work because of delayed material, stopped line that has to be cleared or because of waiting for a machine to finish its process. It can also happen when there are problems with equipment or when defective products have to be reworked. Additionally, waiting can cause the rise of lead time. (Dennis 2016, 31; Wilson 2009, 26)

Transportation

This type of waste takes place when something is transported from one place to another. It can be caused by poorly designed layout or because of immense equipment. Sometimes in batch production, this waste arises when large batches are moved among processes that are unnecessarily far apart. Even though this type of waste has to appear to a certain extent, it must be at least shortened to a possible minimum. (Dennis 2016, 32)

Processing

Dennis shows an example of this waste on Porsche company. In the 1980s they pursued an increase in performance so that their automobiles could reach 200 km/h. Those were engineering goals which did not focus on desires of a customer. Therefore, when a company does something more then what is required by a customer, it is called overprocessing. (2016, 32) In other words, it can be wrongly assumed that every process adds value to a product and this results in overlooking this type of waste. (Arunagiri and Gnanavelbabu 2014, 2171)

Inventory

Wilson says that every item which does not transfer into sales and is stored in inventory is waste. It does not matter if those items are raw materials, intermediate or finished products. (2009, 26) As a result, this waste can lead to a significantly higher cost of inventory. (Arunagiri and Gnanavelbabu 2014, 2171)

Movement

Movement is a highly overlooked waste. This waste occurs when workers are looking for equipment, tools and materials needed for certain operation. The efficient design of working environment is a key, otherwise, it can have a negative impact on productivity and quality. Moreover, such a design plays an important role in the security of a workplace. (Dennis 2016, 30; Wilson 2009, 26)

Making defective products

This waste appears when valuable resources, energy and time are used for fixing defective products. Not only that but also when people spent their energy, time and effort making such products. There is no little cost for correcting this waste in terms of quality. (Dennis 2016, 32; Wilson 2009, 26) It can be said that poor quality and defects cause great problems for many companies in terms of cost. This waste mostly occurs due to poor control of processes. (Arunagiri and Gnanavelbabu 2014, 2173)

2.4 House of lean production

The basic foundation of a lean system was laid by Taiichi Ohno and his TPS, however, throughout the time it was developed and enhanced even further. Many techniques and activities, such as 5S system, TPM and Single Minute Exchange of Dies (SMED) were added to the system. The House of Lean is basically a graphical outlook that displays the lean system and how is every lean activity connected to one another. It can also be a great tool that would help to visualize a lean perspective of a company for all employees or customers. The lean system is made of several parts: the foundation, the walls or pillars and the roof. The foundation consists of stability and standardization. The walls are jidoka and JIT. The roof contains the goal of this system, which is customer focus. (Dennis 2016, 24–25; Wilson 2009, 299)

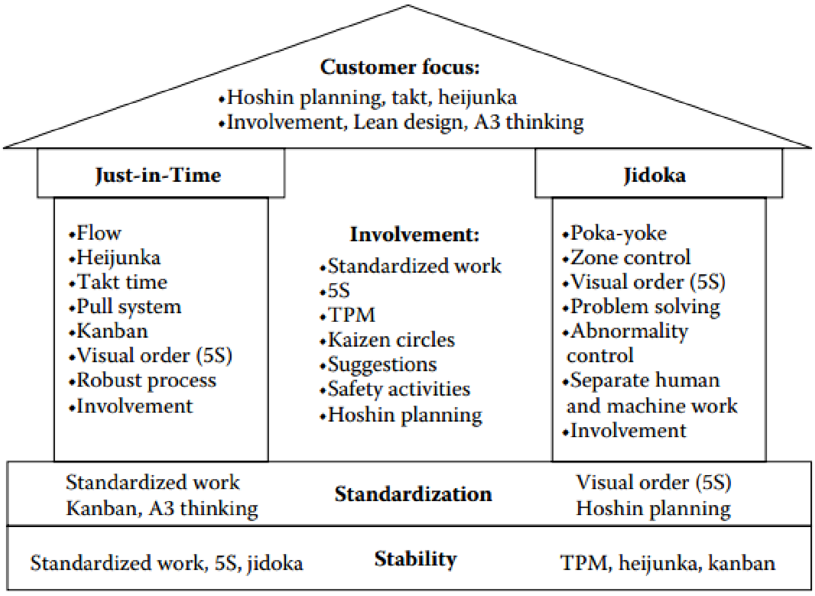


Figure 7 – Lean activities (Dennis 2016, 26)

2.4.1 Visual management

Visual management can be viewed as something simple as putting lines on places where people work on machines but there is more to it. It can be very beneficial to a company if applied correctly. The main goal is to give information in a way that it can be understood as quickly as possible. Visualization in a workplace is also closely associated with the 5S system. Christoph Roser comments in his blog on 4 different directions that can be used in visual management. The first direction is the use of data displays where information is put on digital displays or paper. The second direction uses markings where different marks and labels are used to specify what belongs where. The third direction displays where tools and parts belong using tool drawers or shadow boards where it is possible to see if any of them is missing. Finally, the last direction contains a layout that helps with inventory management and with other details during a process. (Roser 2017) Nonetheless, visual management can also be divided into 2 main domains depending on usage. The first domain provides only a visual guide to information (flow charts, name boards, plant layouts, etc.). On the other hand, the second domain uses tools to project requirements, set directions and actions (traffic lights, Kanban cards, boards, etc.). (Eaidgah et al. 2016, 191)

According to Galsworth, an important part of the lean enterprise is visualization. A visual workplace is an essentiality to a company that desires to meet required performance, to reduce lead time, to improve quality and sustain flow. Moreover, it also stabilizes the company and supports its growth. The visual workplace fundamentally helps to project information into visual devices which are simple and easily understood by anybody. These devices are then applied in the workplace. The technologies used in the visual workplace enhance work by providing better safety, making it easier to understand, making it more fluent and cheaper. Visualization also provides information about a location for things used at work, how to use these things efficiently and effectively, etc. (2005, 8–13)

2.4.2 5S system

5S is the system that greatly contributes to lean production. The purpose of this system is to focus on a workplace by means of organizing it, improving it and also ensuring that productivity, safety and quality are kept. Furthermore, it helps to get rid of unnecessary tools and equipment from the workplace and makes it generally well organized and clean. Thus, a company that implements this system can be easily recognized due to its clean environment, every item has its place that is properly marked, items are organized into boxes, boards, etc. It can be said that 5S is fairly easy to implement and does not cost much. Not only that 5S is a key part of stability but it also supports standardized work. The system is composed of 5 steps:

- Separate.
- Set to order.
- Shine.
- Standardize.
- Sustain. (Burieta 2013, 21–22; Dennis 2016, 39; Nicholas and Soni 2005, 235; Wilson 2009, 63)

Separate

Dennis describes the first step of 5S as a need to sort out things that are redundant; things not related to a certain objective. He also says that stuff like parts, bins, desks and tools that are accumulated in bigger amount, can cause numerous problems. These problems can include increased lead time, interruption of a workflow and safety issues. (2016, 45) Burieta adds that it is also important to categorize items according to whether they are needed in a workplace or whether they can be removed or must be removed. This can be done using certain criteria and procedures. Therefore, tasks can be performed more easily and space can be used more efficiently. (2013, 26–27)

Set to order

The second step is to systematically organize the remaining things (needed tools, equipment, etc.) in a workplace. Everything should have its place so that it is easy and fast to find when required. For this reason, a workflow becomes more effective and workers more productive. Additionally, it is crucial to consider where these items are placed, i.e., they should be located methodically and close to a relevant operation so that there is no extra movement. Selected location should be marked to make clear what item is placed there. In this case, visualization plays an important role. (Burieta 2013, 30–33; Intrieri 2013)

Shine

Burieta explains the third step of this system where cleaning takes place. He says that in order to use things effectively, it is important to maintain cleanliness and functionality of every tool, equipment and machine. In general, the objective is to clean a workplace, including every machine, tool and equipment so that everything reaches a clean state. That state should be then regularly sustained. To implement this step, a certain procedure can be followed. Firstly, the workplace should be divided into areas. Secondly, each area should have its own worker who is responsible for cleaning in that particular area. Finally, it is important to perform this activity regularly and systematically. (2013, 35–36)

Standardize

The fourth step serves as a tool to maintain the previous 3 steps. It is mainly used to prevent the transition from the improved state (after applying the first 3 steps) to the previous state (pre-5S). Thus, it is crucial to maintain and revisit each aspect of this system on a regular basis. At first, standards must be defined to guide workers how to properly clean, organize and maintain. As a result, not only that workers can follow given standards, but they can also detect any irregularity and improve upon that. (Burieta 2013, 37; Intrieri 2013)

Sustain

After applying the final step, it should be ensured that these values brought to a company will remain in a company. Nevertheless, this step involves discipline. Meaning that the first 4S or any other method applied to a company will be performed as a type of work even after the project is over. It is also appropriate to introduce some sort of control, such as workers control each other, activity control cards or audits. (Burieta 2013, 39; Intrieri 2013)

2.4.3 Just-in-time

Just-in-time (JIT) is one of the two pillars of the TPS (Wilson 2009, 11) that greatly contributes to increased productivity, reduced costs and higher quality. This can be achieved if companies focus on the elimination of waste at different levels of production. For this reason, JIT "…produces only what is used or sold, in the needed quantity and at the needed time." Moreover, this system puts emphasis on inventory reduction and pursues continuous improvement. A pull method is another key aspect of JIT where production process starts only when there is a need to refill something that was used and further processed or sold to a customer. (Salvendy 2001, 544–45) Groover further adds not only that the batch size should not contain too many units but also not too few. He also describes certain aspects that should be followed in order to successfully achieve JIT, for instance, small batch sizes, delivery on time, constant production schedules and short setup time. (2012, 1050) In order to have a production system that can flexibly respond to demand and thus provide products on time, it is essential to have short changeover/setup times. This can be achieved by using a technique that has been developed by Shigeo Shingo – SMED. (Salvendy 2001, 547)

3 SMED

In the current time, to have a successful business it is crucial to master flexibility in a production process in order to satisfy customers' changing needs. The satisfaction can be achieved by means of delivering in requested time, quantity and quality. In order to keep up with this trend, it is essential to improve company's processes, to eliminate unnecessary activities and to establish certain standards. Fundamental factor of the production process is a changeover. The changeover is a time that starts when the last piece is produced and continues until the first good piece is made. Time needed to produce the first good piece counts as an operational time if it is a successful one and no further adjustments have to be made. Moreover, to achieve better production performance the changeover time has to be reduced through elimination of waste that occurs during these processes. Among the most used methods for shortening the changeover time is SMED. (Kormanec 2008, 4–13)

Single minute exchange of dies or so-called SMED is one of the methods used in lean manufacturing. This method was developed by Shigeo Shingo who brought a new look and a way to make production more efficient by reducing the changeover time. Apart from other positive effects, the reduction of the changeover time results also in the reduction of excess capitalization and overproduction, which are two forms of waste. Single minute means a number that is less than 10, thus the goal is to perform the overall changeover under 10 minutes. However, this is not always possible so the objective is to reduce the changeover time to an achievable minimum. In general, the fundamental factors of SMED are to observe and list all the activities that occur during the changeover and then to determine if they belong to internal or external setup, i.e., if they are performed while a machine is still running or when it is off. Finally, to convert the internal setup to the external setup and then shorten the remaining internal setup using various techniques. (Wilson 2009, 69–70; Kormanec 2008, 17–18) As a direct result of not implementing the quick changeovers using this or other methods, the company may face several problems, such as increased waiting time for another batch, unnecessary consumption of resources involved in such waiting and increased need for larger storage space. (Mihok et al. 2015, 568–69)

3.1 History

Shingo describes the very beginnings of SMED and how it continuously involved in this method that is known nowadays. It all started in 1950 where Shingo was involved in an improvement program at Mazda plant situated in Hiroshima. Toyo Kogyo faced a problem which was caused by large body-molding presses not working to the full capacity. The problems were bottlenecks which Toyo wanted to eliminate. Shingo immediately started inspection and asked the section manager for giving him a time to analyze this issue. Nevertheless, the manager insisted that it would be a waste of time as he was sure that the presses were the cause of the problem and the only way of fixing it is to buy more machines. Still, he was convinced by Shingo and gave him a space for his survey. When it came to change of die he observed a strange behavior from workers who could not find the last bolt needed for the new die. Afterwards, when one worker returned after more than one hour, Shingo was wondering where he found it. The worker replied that he borrowed it from the other machine. Not only that but the worker also modified the bolt in order to fit. Obviously, it was not the right solution as the borrowed bolt would be missing in the machine later when it needs to be set up. It did not take long for Shingo to realize that there are two different types of setup operations:

- Firstly, **the internal setup** (IED) where the activities, such as removing dies and mounting new ones, can be performed only when the machine is stopped.
- Secondly, **the external setup** (OED) where the activities, such as transporting old dies to storage and transporting new ones to the machine, can be performed while the machine is still running.

With these new insights an external setup operation was established, where it was made sure that all the bolts necessary for the next setup were prepared and sorted in boxes. Furthermore, all other possible activities of the setup were performed externally, which resulted in 50% efficiency increase and the bottlenecks elimination. (1985, 21–22)

Shingo comments on another encounter which occurred in 1957 where he was asked to analyze a certain problem at the Mitsubishi shipyard in Hiroshima. The problem was that the open-sided planer was not working to the full capacity, similarly to the previous encounter. After some time, he managed to streamline the operation and resolve the problem with an increase in productivity. Lastly, Shingo describes his third encounter in 1969 at Toyota Motor Company where he was told that their 1000-ton press machine takes too long to perform setups, specifically about 4 hours. In contrast with that, the Volkswagen managed to do a similar operation in only 2 hours. He, the divisional manager and few other people were supposed to overcome this time. After applying Shingo's previous experience (to separate all the activities into internal and external setup and subsequently improve each of them) they managed to cut the time to 90 minutes. Even though this was a drastic change, for the management it was not enough and after a month they wanted to shorten this time to only 3 minutes. It did not take long for him to come up with the new ideas as to convert internal setup to external setup and with a bunch of techniques used for shortening these setups. Due to this new concept, they were able to cut the time to requested 3 minutes, thus Shingo named this concept single minute exchange of dies with a thought that 10 minutes is all that is needed to perform any setup. (1985, 24–25)

3.2 SMED application

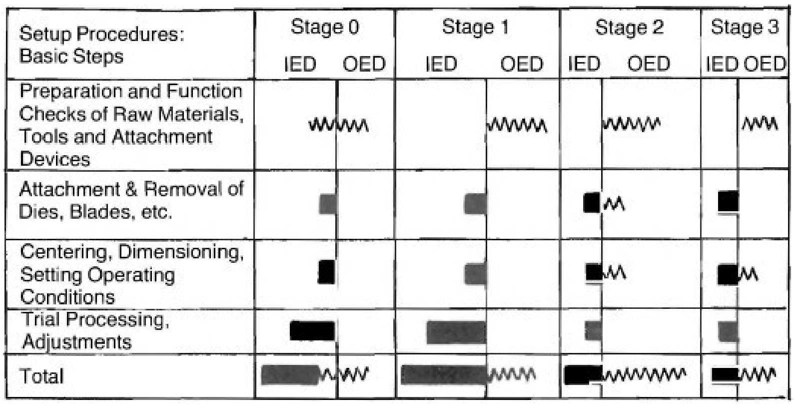


Figure 8 – SMED application (Shingo 1985, 28)

3.2.1 Stage 0

At first, it is necessary to make sure that all the activities performed in setup are observed and analyzed. It is a state where internal and external setup operations are not differentiated by workers, which leads to inefficient use of resources, i.e., doing certain activity internally while it could be done externally. The analysis itself can be done in different ways: continuously analyze production, use a work sampling study, make a video of the whole process and to interview workers. (Shingo 1985, 28–29)

3.2.2 Stage 1

Probably the most crucial part of SMED is an ability to separate internal and external setup. It is not effective if, for example, the preparation of tools and materials is done while the machine is off. It is, however, important to note how much these situations occur. While categorizing every step of setup, it is also possible to mark which internal operations can be done as external and under what conditions. The estimated time that can be saved from this stage is around 30%–50%. (Shingo 1985, 29; Wilson 2009, 70)

3.2.3 Stage 2

Another stage of the SMED application is to convert any possible internal setup to external. Even though the previous stage reduces the time quite a bit, it still does not reach the full potential of SMED itself. Implementing this step alone can result in up to 50% saving of internal setup time. Shingo describes two steps of this stage:

- To examine each step of the setup and see how many of them are misunderstood to be internal.
- To approach these steps differently and find possible ways how to convert them to external.

There can be certain operations which are performed internally but if they are re-examined in a greater detail, it may turn out that they can actually be done externally. It is essential not to be attached to old habits but to be more open-minded. (Nicholas and Soni 2005, 151–52; Shingo 1985, 29–30)

3.2.4 Stage 3

Finally, the last stage of SMED is to shorten every relevant operation of internal and external setup. Additionally, every operation should be simplified and improved so that workers can perform such a setup on demand and by themselves. Although in some cases it is possible to achieve the desired result after the previous steps, most of the time it is crucial to push even further. Moreover, the second and the third stage do not have to be performed in this specific order, they can be performed both at the same time. Example of the result after applying every stage of SMED can be Mitsubishi Heavy Industries where the internal setup time was reduced from 24 hours to 2 minutes and 40 seconds. (Nicholas and Soni 2005, 152–53; Shingo 1985, 30)

3.3 Shortening techniques

There are several techniques which can be used in shortening process of internal and external setup. External setup time can be reduced by improving the preparation and transportation of tools and necessary materials. To shorten the time of external setups, such as transportation of dies, advanced equipment can be used. These processes, however, do not reduce internal setup and their use will not be enough to achieve the desired result. Thus, it is important to shorten internal setup using, for example, parallel operations, functional clamps and reduction/elimination of time needed for adjustments. (Shingo 1985, 51–52) In addition, Kormanec adds more ways how to reduce the setup time:

- Standardize changeover activities.
- Use of trolleys and tool belts for better accessibility.
- Use additional complementary resources.
- Use technical systems. (2008, 19–24)

3.3.1 Parallel operations

In the case where a large press in the production process occurs, it is inevitable that a work has to be done at the front of the press and even at the back. It goes without saying that a worker who would operate this machine has to walk around the machine all the time, and therefore waste a precious time. The solution to his problem is having more than one worker operating the machine. Shingo says that two workers are enough to shorten the time of an operation from 12 minutes to perhaps even 4 minutes due to saved movement of workers. For proper application of parallel operation, it is important to avoid waiting. Otherwise, the technique itself will not be functional. Furthermore, safety should be emphasized so whenever an elemental operation is finished by one worker a sign should be given to the other worker. Because most of the time the places of production are very noisy, it is advised to whistle or use a buzzer. Even better safety can be achieved due to an interlock mechanism which would prevent the worker from operating at the front of the machine unless another worker who is situated at the back would turn a switch. (Shingo 1985, 53)

3.3.2 Functional clamps

Shingo comments on another technique used for shortening internal setup apart from implementing parallel operations, which is the use of attachment devices helping with clamping objects in a place using minimal effort. He also gives an example of how to make a functional clamp out of a bolt. In many setups where the bolt is used for attaching a die to a press, it usually happens that the bolt is too long and has too many threads so it takes unnecessarily long time to tighten it. However, if the bolt is shorter and takes only one turn to tighten, it then becomes a functional clamp. There are some attachment devices which help to tighten objects using only one turn, such as pear-shaped holes, u-shaped washer and u-slot. Other devices help to tighten objects with only one motion, for instance, pins, springs and wedges. In contrast to these approaches, there are interlocking methods which simply join parts together and, in some cases, that may be enough. (1985, 55–61)

3.4 Effects of SMED

As Shingo notes, the application of SMED can result not only in the reduction of overall setup time but also in getting strategic advantages by further developing and enhancing production and its many aspects. When a company produces many distinct products in small quantities it is inevitable that many setup operations occur. Because of SMED, these operations can be reduced drastically. With the reduction of stock, it is possible to use space more efficiently and also to increase productivity and capital turnover. Aside from better organization of tools, the required amount of them is also reduced. A skill needed to perform a certain activity is lower because the new operations are quick and simple, which leads to a lesser need for skilled workers. Shingo says that thanks to SMED a worker who was unskilled could perform an operation in only about 7 minutes and 30 seconds, whereas before that a skilled worked did the same operation in about 1 hour and 30 minutes. Moreover, the production flexibility increases rapidly and people in the company are more open to the new ideas, possibilities and improvements. (1985, 113–26) Some other benefits of implementing SMED are:

- Cost reduction of lot size.
- Increased safety in production.
- Elimination of errors in setup.
- Increased production capacity.
- Improved delivery times. (Díaz-Reza et al. 2016, 1237)

II. ANALYSIS

4 CARDBOX PACKAGING S.R.O.

The company Cardbox Packaging s.r.o. provides high-quality packaging for various products, such as packaging for sweets, food and cosmetics. The company uses an offset printing and other technologies to produce the packaging. Moreover, each production process is closely related to the cooperation between a customer and the company as the customer satisfaction is the company's number one priority. Using modern technology, it is possible to meet the customer requirements and thus tailor a product exactly how it is desired. (Cardbox Packaging 2015)

Cardbox Packaging s.r.o. is located in Zádveřice near Zlín and is also one of the three companies which are in a concern of Cardbox Packaging Holding GmbH with 51%. The others are located in Wolfsberg and Pinkafeld. All of these follow the lean organization as it is the fundamental factor for the future development. Greiner Packaging owns the remaining 49%. (Internal documentation)

The company was established in 2012, however, the first official production started a year later in 2013. At the very beginning, the company had only one printing machine and one cutting machine. Other machines were added to the production a few years later. (Internal documentation)

The sales of the company in 2017 were almost 13,5 million EUR. In contrast to the previous year, the sales went up approximately about 20,5%. In general, the company was able to increase their sales throughout the years of existence. The success is based on the business model of cooperation between Cardbox Packaging s.r.o. and the companies that own them. (Internal documentation)

Figure 9 – Company logo (internal documentation)

4.1 Portfolio

The company can offer a wide range of products with a unique design. With the use of their machines and modern technologies, the company is able not only to print high-quality packaging but also to further enhance the appearance of the packaging. These include, for example, offset printing machines containing six printing units and two coating units, UV and 3D painting, embossing, gluing, insertion of windows, distinct cutting tools, etc. (Internal documentation)

As it was mentioned before, the main focus is on the paper packaging for the food industry that includes different types of boxes. Due to company's know-how, specialization and efficiency, what makes up most of the production is the packaging for cups (around 83%). Another specialization is so-called co-packing where the company creates packaging consisting of several parts. From manufacture to the composition itself the customer will have no extra work. (Internal documentation)

Figure 10 – Portfolio (author's creation)

4.2 Missions and visions

The company has following missions:

- "We help customers to achieve their goal by producing modern and innovative paper packaging. The success of a customer is a key to our success."
- "We emphasize long-term cooperation with our business partners and employees. Their satisfaction is the foundation of our business."
- "Stability, flexibility and creative solutions are the fundamental pillars of our long-term growth." (Internal documentation)

The company has following visions:

- "We are a reliable global partner of Greiner."
- "We are not afraid of complex and original projects."
- "We seek original and complex projects which lead to unique and innovative solutions." (Internal documentation)

4.3 Organizational structure

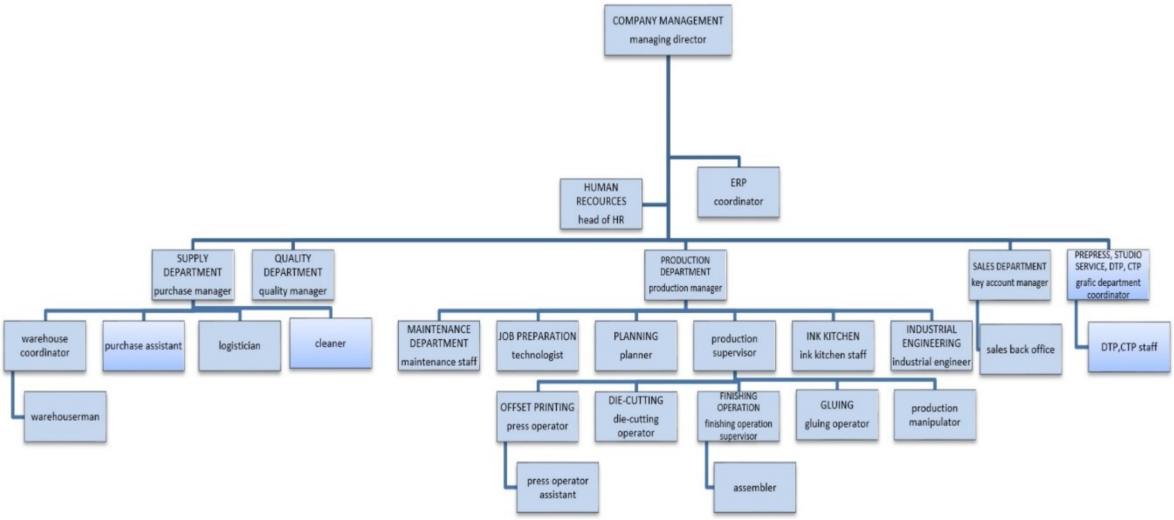


Figure 11 – Organizational structure (internal documentation)

In the current time, the company has around 86 employees. Every potential applicant for a job in this company has to go through an interview based on the main requirements of a specific position. Furthermore, after choosing a suitable person it is necessary to go through an initial medical examination and then to finally sign an employment contract together with other important internal documents, such as ethical codex, commitment to confidentiality and affidavit for no criminal offense. Additionally, every employee must be trained in safety and hygiene in the workplace, fire safety and BRC. Employees are then provided with a workwear and they are also included in the employee database. (Internal documentation)

4.4 Export and import

The ratio between the export and the import is approximately 75% to 25%.

Among the biggest customers belong these companies:

- Greiner Packaging Slušovice s.r.o.
- Greiner Packaging AG.
- Greiner Packaging Limited.
- Greiner Packaging Corp USA.

Among the biggest suppliers belong these companies:

- Mayr-Melnhof Gernsbach GmbH.
- Stora Enso Fors AB.
- Kartonfabrik Buchmann GmbH. (Internal documentation)

4.5 Certification

As a part of the industry of which products are in a direct contact with food, it is a must to have strict measures. Therefore, the manufactured products are in compliance with the internationally recognized standards. The company heeds to the best possible prevention and safety so they use the low migration inks and varnishes alongside continuous cooperation with the certified laboratories in order to improve the material used. (Internal documentation)

4.5.1 Quality Policy Cardbox Packaging, s.r.o.

"Cardbox Packaging s.r.o. produces and supplies high-quality products for a wide portfolio of customers involved in the chain of processing food and non-food products. The company has adopted a management system according to ČSN EN ISO 9001, adopted and certified the BRC Packaging system." (Internal documentation)

4.5.2 BRC/IoP certification

BRC/IoP is a global standard for packaging created by the British Retail Consortium and the Institute of Packaging. This standard contains manufacturing and other processes involved in manipulating with packaging used for a direct and indirect contact with packing used for food, cosmetics and hygiene products and certifies the conformity of the company with regulations, safety and quality. (Internal documentation)

4.5.3 FSC certification

FSC (Forest Stewardship Council) certification marks a product with a logo which implies on the fact that it was made using the recycled material or material from the forests with the proper FSC certificate. Thus, it provides the customer with an information that the product they are buying takes in a count the environment. (Internal documentation)

4.5.4 FDA/IMS certification

FDA/IMS certification approves the compliance with the hygienic requirements needed for the production of packaging used for food where the FDA standard is dedicated to the US processors. (Internal documentation)

5 PRODUCTION PROCESS

The goal of this bachelor’s thesis is to analyze a production process of the company on a basic level and to find a potential bottleneck that would be then analyzed with the aim of demonstrating a potential increase in productivity of the company. In this part of the analysis, the student was getting familiar with the production process, with its individual parts and with processes related to them. Everything was done through a direct observation of a workplace, student’s and internal documentation and discussions with employees.

Everything starts when customers contact the company with their request. The sales department gets an order that will be inserted into a system with an order number, a serial number and other relevant information, such as information about the customer and design. Afterwards, the order is taken to the purchase manager, technologists, planner and studio where all the necessary processes take place. The production planner plans every order at his discretion so that it meets the requirements of the customer. At the meetings, it is decided which order has a priority and what is going to be produced first. Only then a final plan can be created and introduced to the other departments. The studio transfers a graphic form of packaging into the aluminum plates using the CTP machine and creates the printing plates. There is one printing plate for each printing unit in the printing process. The purchase manager makes sure that the needed materials are prepared before the start of production. During these processes is created a job bag. The job bag provides information about the following orders to everyone in the plant and therefore it is an important part of the start of the production process. The job bag itself consists of information about a paper size, a date of dispatch, a required amount, a sample piece, printing inks that are going to be used, operations that will be performed, etc. Once everything is ready, it is possible to start the production process as such.

The production process can be divided into several operations. It starts with a transportation of material from a storage (1) to the first operation, i.e., a printing (2). The following operation is a die cutting (3). Furthermore, the whole process can be followed by the additional operations depending on the customers’ requirements or as needed. These operations include a gluing (4) and a manual processing (5). The final operation is a wrapping (6) of the finished products. It is also important to note that after every operation a pallet is marked with a new label that includes, among other things, an upcoming operation. Only before the last operation (the wrapping), the pallet is marked with the final label.

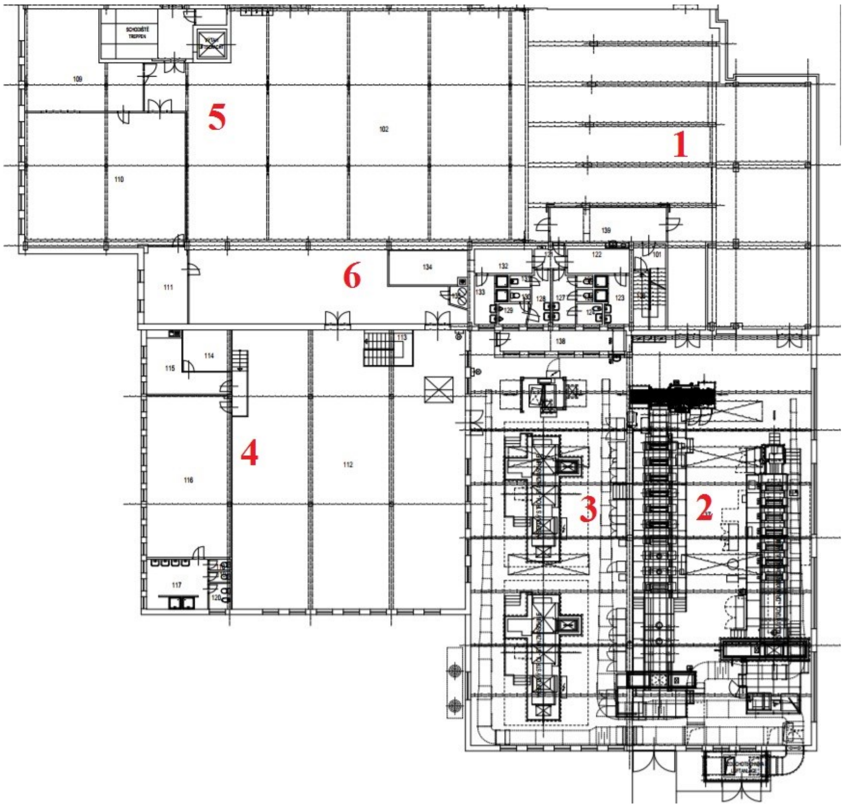


Figure 12 – Layout (author's creation based on internal documentation)

5.1 Storage

Material necessary for the production is stored in the storage located near the print station. After the pallets of paper are transferred to the storage, based on the plan, they are assigned to a specific sector with a mark A1, A2, B1, B2 and so on. Every pallet is marked with an order number to make it clear what material is used for which order. Moreover, each of them has its own label with various information, for example, a name of a product, a weight, a number of paper sheets on the pallet, a barcode and an ID. The storage is equipped with a whiteboard on which the individual sectors are listed and the order numbers next to them. This is the system that greatly contributes to a better organization and visualization of the workplace. Thus, every operator knows clearly where the material for the particular order is stored. The printing inks that are already prepared for the upcoming orders are also stored at this place (CMYK colors for general replenishment + Pantone colors for the specific orders). They are placed in the storage racks with the appropriate order number including expected production date.

Figure 13 – Storage (author's creation)

5.2 Printing

The first operation of the production process is the printing. The company has currently two printing machines. The first one is KBA 105 that is an older model and consists of 6 printing units and 1 coating unit. The second one is KBA 106 which consists of 6 printing units and 2 coating units. Both of these machines are managed by the main printing operator who is responsible for the final product and his assistant who prepares paper, inks, etc. The printing speed of both machines is about 12 000 paper sheets per hour on average. The printing machines print packaging on the paper sheets of different sizes but mostly it is the B1 format. On a single paper sheet can be printed up to 57 segments, which of course depends on the size of the segment (packaging) itself, however, most of the time the company prints around 16 segments on a single paper sheet.

Figure 14 – KBA 106 and KBA 105 (author's creation)

The printing units themselves are loaded with one specific ink each. Firstly, the CMYK model that includes cyan, magenta, yellow and key (black) color is used. Secondly, the Pantone colors are used (they are mixed in advance to achieve the desired color). In addition, the coating units add additional gloss to further enhance the final product and to prevent any smudging. It is necessary to do certain operations before the printing can start:

- Transport the pallet of paper in front of the machine and load it into the feeder system.
- Replenish the CMYK inks if needed.
- Add the Pantone inks into the inking units.
- Load the printing plates into the printing units.
- Customize the coating unit based on customer's requirements.

After all these steps are completed the printing can start. The company uses offset printing and therefore specific processes occur. First of all, the machine takes one paper sheet at a time from the feeder which then continues to the first printing unit. In the printing unit, the paper is passed between the blanket cylinder and the impression cylinder. From the plate cylinder (on which the printing plate is loaded) the ink and image transfer to the blanket cylinder and due to a pressure, the paper receives the printed image (see Figure 15). Then the paper goes through all other printing units undergoing the same process (the process is done only in those printing units that have needed ink for the current packaging). Finally, the paper passes through the coating unit and gets its final treatment. After that, the paper is stacked on the pallet at the end of the machine. Furthermore, it is important that the quality of a product is checked by the main printing operator who compares the currently printed packaging with the sample piece. If the colors do not match, the individual printing units have to be adjusted in the press software. If the printed packaging is identical with the sample piece, the printing process can continue.

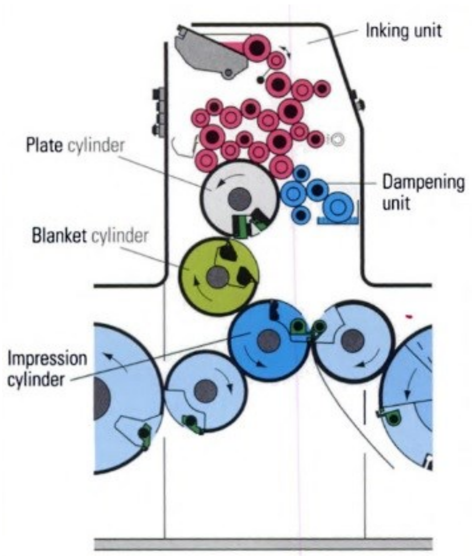


Figure 15 – Offset printing unit (Kipphan 2001, 54)

5.3 Die cutting

After the whole order is printed the pallets are transported to the cutting machines. The company owns two cutting machines. The first one is Bobst Novacut, which was recently bought and the second one is Iberica JRK 105, which has been in the company for some time. The cutting speed moves around 8 000 paper sheets per hour for Bobst and 6 500 paper sheets per hour for Iberica. The die cutting machine is made up of several sections: feeder, platen, stripping, blank separation and delivery. Each machine is operated by one worker who is responsible for managing the whole machine and its surroundings, including maintaining the machine, loading the pallets into the feeder system, etc. Before the whole process can start it is important to:

- Load the pallet into the feeder system.
- Change the tools used for cutting, stripping and blanking.
- Adjust each section of the machine for a concrete product.

After all these operations are completed the cutting process can start. In the first place, the feeder system loads the paper sheets one by one into the machine. The paper sheets then continue to the platen section. In this section, the main cutting occurs where the segments are cut from the paper sheet using cutting plate and cutting die. In case that packaging has some sort of internal part that needs to be removed (windows, openings, …) the stripping section removes the internal waste. The process then continues to the blank separation section where the segments (blanks) are separated from the paper sheets and piled on the pallet (this operation can sometimes be performed in manual processing).

The remaining paper goes to waste. Moreover, after every 200th segment, the whole paper sheet is laid on the top for better stability. Generally, when the die cutting has finished the pallets with the segments continue to the final wrapping, however, occasionally the whole process can continue with gluing or manual processing.

Figure 16 – JRK 105 and Novacut (author's creation)

5.4 Gluing

The gluing is a process which can follow after the die cutting but it is important to say that this happens only when it is required by the customers. The company has one gluing machine Heidelberg ECO 105. The machine can reach a speed of 150 meters per minute, nevertheless, the amount of gluing per hour highly depends on a structure of packaging. The gluing machine is managed by one operator who is responsible for loading the segments into the machine, preparing the machine and controlling it throughout the whole process. At the end of the machine, there are another two workers who place the glued segments into the boxes and then move them to the pallet. The preparation of the machine can take from 2 to 8 hours depending on the complexity of packaging. The gluing process starts with the feeder system sending the segments one by one into the machine. The segment then goes through different sections where its individual parts bend and stick to each other with glue. Finally, the segments are then stacked and picked up by the workers who put them into the boxes. The pallets with the boxes then continue to the wrapping machine.

Figure 17 – ECO 105 (author's creation)

5.5 Manual processing

In some cases, the packaging may need some additional adjustment or treatment before shipping to a customer, thus the manual processing can occur after the die cutting. However, the manual processing can also take place regardless of the other operations, for instance, when a customer provides the company with an already printed segment and requires doing certain operations, such as folding the packaging and co-packing. The manual processing is performed by 15 workers who operate as needed. These operations include following:

- Packing the segments into boxes.
- Picking the faulty segments.
- Separating the cut segments from the paper sheets.
- Folding the packaging.
- Co-packing.
- Cleaning of the segments.

5.6 Wrapping

The wrapping operation is the last operation that must be performed before a final product can be either stored in the storage or shipped directly to the customer depending on the dispatch date. The company owns one wrapping machine Cyklop managed by one operator. The process differs with every customer. In general, it starts with putting a wooden lid on the pallet in order to cover the upper segments and to gain more stability. After that, the pallet is wrapped around with a stretch film and then a strapping tape is applied. Finally, the stretch film is used again for the final wrapping of the pallet.

During this process, the final label is put on the pallet. The final label includes the weight of the pallet, the amount of the packaging, the order number, the name of the product and other.

6 CURRENT STATE

While the student was getting familiar with processes and operations in the production, it was noted by the company that the printing operation is currently a problematic spot, however, this was not always the case. Sometime before 2017 the company had a different problem which was basically the cutting machine not performing efficiently enough to ensure a smooth flow of processes. Nevertheless, the company solved this problem by focusing on better quality tools and setup/changeover time. Since then, the printing operation is not able to keep up with the overall flow and as a result, the cutting machines suffer from significant downtime. Moreover, in 2018 the company bought a new cutting machine that should have an even bigger impact on the already lagging operation. This phenomenon can be seen in an analysis of downtime that is done by the company each month (see Table 2 for the cutting machine that is still used and Table 1 for the cutting machine that was already replaced by the new one). Even though Table 1 shows the analysis of downtime of the machine that is not used anymore, it can be expected that the new cutting machine will have similar values if not worse. The tables consist of several columns and every column represents a cause of downtime and its length in hours for the entire month. Additionally, the yellow color indicates that the values in that particular column cannot be influenced.[1]

Table 1 – Downtime analysis of JRK 106 (translation based on internal documentation)

	Cutting + blanking tools	Maint.	Waste	Paper	Mentor	Feeder + unloader	Assistance on another machine	Kanak	Preview	Waiting for the printed material	Turner	Training + consultations	Electro	Machine repairs	Total
Jan-17	4,76	16,66	4,165	0	0	1,785	2,975	0	1,19	27,37	0	0	0	1,19	**60,095**
Feb-17	8,925	42,84	0	0	0	0	0	0	4,165	49,98	0	12,495	22,61	3,57	**144,585**
Mar-17	17,85	10,71	0	5,95	2,42	0	0	0	0	36,89	0	9,52	0	7,735	**91,035**
Apr-17	1,19	35,105	0	0	0	0	1,19	0	4,02	14,875	0	2,31	3,57	4,76	**65,45**
May-17	9,52	29,75	0	2,16	0	0	0	0	0	90,44	0	1,19	1,19	3,57	**138,04**
Jun-17	41,65	30,94	0	0	0	0	9,52	1,84	0	68,425	0	1,785	0	22,015	**176,715**
Jul-17	0	24,99	0	3,57	0	0	3,12	0	0	1,19	0	2,975	0	17,85	**52,955**
Aug-17	0	47,6	0	0	0	0	0	0	0	26,775	0	5,62	122,57	19,04	**218,365**
Sep-17	0	32,13	0	0	0	0	5,95	0	0	79,135	0	2,38	1,19	9,52	**130,305**
Oct-17	1,19	38,08	0	7,14	0	0	10,115	0	0	113,05	0	1,19	0	20,825	**191,59**
Nov-17	14,28	33,32	1,19	0	0	0	0	0	0	82,11	0	3,57	0	7,14	**141,61**
Dec-17	0	28,56	5,355	0	0	8,33	13,09	0	0	54,74	0	18,445	0	7,01	**130,9**
Total for 17	**99**	**371**	**11**	**19**	**2**	**10**	**46**	**2**	**9**	**645**	**0**	**61**	**151**	**124**	**1542**
Percentage for 17	**6,45%**	**24,04%**	**0,69%**	**1,22%**	**0,16%**	**0,66%**	**2,98%**	**0,12%**	**0,61%**	**41,84%**	**0,00%**	**3,99%**	**9,80%**	**8,06%**	**100,00%**

[1] The values in Table 1 and Table 2 were multiplied by a coefficient due to sensitive data.

Table 2 – Downtime analysis of JRK 105 (translation based on internal documentation)

	Cutting + blanking tools	Maint.	Waste	Paper	Mentor	Feeder + unloader	Assistance on another machine	Kanak	Preview	Waiting for the printed material	Turner	Training + consultations	Electro	Machine repairs	Total
Jan-17	8,33	35,7	0	0	0	3,57	0	0	0	5,355	0	0	5,95	0	**58,905**
Feb-17	0	47,6	0	0	0	0	0	0	0	67,235	0	2,975	5,95	11,9	**135,66**
Mar-17	10,115	19,04	0	2,12	0	0	0	0	0	0	0	4,76	0	5,95	**42,245**
Apr-17	1,19	36,89	0	0	0	0	0	0	0	0	0	1,19	22,61	5,355	**67,235**
May-17	0	74,375	0	0	0	0	0	0	0	57,715	0	1,19	0	2,39	**135,66**
Jun-17	3,57	64,26	0	0	0	0	0	0	0	65,45	0	0	0	9,52	**142,8**
Jul-17	0	16,66	0	0	0	0	0	0	0	4,165	0	0	0	30,94	**51,765**
Aug-17	0	17,85	0	0	0	0	0	0	0	57,715	0	4,76	0	7,14	**87,465**
Sep-17	0	45,22	0	0	0	0	0	0	0	28,56	0	4,76	0	9,52	**88,06**
Oct-17	3,48	45,815	0	0	0	0	0	0	0	124,95	0	3,57	0	7,735	**185,64**
Nov-17	0	73,78	0	0	0	2	0	0	0	97,58	0	1,19	0	5,95	**180,88**
Dec-17	0	26,18	0	0	0	0	2,975	0	0	80,92	0	15,47	0	0	**125,545**
Total for 17	**27**	**503**	**0**	**2**	**0**	**6**	**3**	**0**	**0**	**590**	**0**	**40**	**35**	**96**	**1302**
Percentage for 17	**2,05%**	**38,67%**	**0,00%**	**0,16%**	**0,00%**	**0,43%**	**0,23%**	**0,00%**	**0,00%**	**45,29%**	**0,00%**	**3,06%**	**2,65%**	**7,40%**	**100,00%**

In the column named "Waiting for the printed material" it can be seen that there are higher values compared to the other columns. The cutting machines are waiting for the material from the printing machines and therefore, there is a time when the machines are idle. There can be many reasons why the printing machines do not deliver on time, for example, machine failure, maintenance and poorly created printing plates. This state has an impact on productivity and consequently reduces it. Some of the causes are inevitable but on some can be worked on. The company performs approximately 450[2] changeovers per printing machine every month. A single changeover takes about 35 minutes on average which means that a large percentage of time (roughly 25% of the scheduled run time) is used for the changeovers. Furthermore, it is assumed that if these changeovers are shortened, it may result in an increase in productivity and hence reduce the number of downtime hours of the cutting machines. For the reasons mentioned above, it was decided that this analysis will continue towards the changeovers with the aim to shorten them. In the description of the company's production process, it was mentioned that the company has two printing machines, however, it takes longer to perform the changeover on the older machine (KBA 105) and thus the focus will be put there.

[2] The value was multiplied by a coefficient due to sensitive data

6.1 Printing machine KBA 105 and its surroundings

The printing process was described in chapter 5.2 and now before the changeover analysis itself, the student will briefly comment on visualization of the KBA 105 workplace, including its orderliness and safety. Not only that the visual aspects have a significant impact on the efficiency of different operations and processes, but they may also contribute to the faster and smoother changeover.

The company does not have 5S implemented but they are trying to use certain visual elements. In front of the machine, there is a storage rack where all the necessary supplies needed for certain operations are stored. Next to the storage rack, there is a shadow board with tools and alongside that the hygienic zone where items for cleaning are located. As for the storage rack, most of the chemical supplies are placed there, for instance, a special powder and a chemical cleaner that is used for cleaning/removing ink from an ink roller of the printing units. The company uses a Kanban system and thus each item is stored in its appropriate place, it is very clear where the items are and most importantly if any of them need to be replenished by a supplier. The shadow board with the sorted tools is located next to the storage rack. The advantage of the shadow board is that each item has its intended place and if any of them is missing, it is easy to see what it is. Sometimes it is recommended to put the names or the properties (length, type, etc.) of these items next to them. This, however, may not be necessary if the operators are experienced enough. Most of the time, three screwdrivers were missing but maybe they were just being used. Nonetheless, one of them was found somewhere at the place where it does not belong. In some cases, the entire shadow board was blocked by stacked pallets and, of course, this prevented any access to the tools. The hygiene zone is divided into two sections. The first section is red where a dustpan, smaller and larger cleaning brush are located (for cleaning floors) and the other section is blue where a small cleaning brush is placed (for cleaning surfaces). Each item has a proper color and is labeled with a name. The company has floor markings throughout the whole shop floor for individual sectors, locations, transport routes and for safety purposes. It was observed that occasionally when the pallets of paper were transported in front of the machine, some of them would interfere with the transport route (see Figure 19). Moreover, some of the marking lines are already fading and cannot be seen so well.

Figure 18 – The storage rack and the shadow board (author’s creation)

Figure 19 – The pallets of paper in front of the machine (author’s creation)

Next to the printing machine is a long table where the operators put items, such as all kinds of cleaners, rags, rubber gloves, powders and ink cans. This table is very conveniently placed next to the printing units of the printing machine. Therefore, no unnecessary movement is generated if everything important is placed on the table and the operators know where it is placed. The operators place the same or similar items required for the printing processes across the table. Although this table does not have well-established order nor any visual devices (see Figure 20), it was observed that mostly the operators had a good grasp of what is where. Nevertheless, it is recommended to introduce the 5S method or at least some visual devices. First of all, it would be appropriate to get rid of any objects that are worthless like empty cans. After that, the whole table can be divided into areas that would be marked with colors and names based on what specific items are placed there. In this way, each item would have its particular place that is visually labeled and hence possibly prevent potential waste that may occur (searching for stuff, etc.). At the end of the machine, there is a free space where the operators put the ink cans with the CMYK colors and the Pantone colors for the upcoming orders. Furthermore, there is also a tool cart that is sometimes used if needed. Unfortunately, except for one drawer the other drawers are not organized whatsoever. These drawers contain a mixture of different things, for example, a cleaning brush, a brush for painting and a wrench. It is recommended to organize each drawer using a tool foam organizer or some kind of a tool sorter.

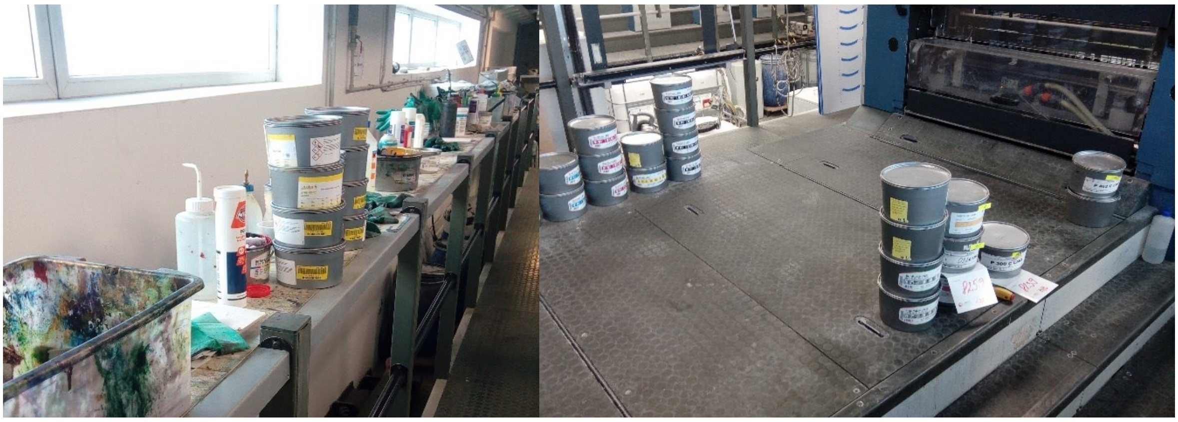


Figure 20 – The storage areas (author's creation)

Figure 21 – The tool cart (author's creation)

6.2 Changeover analysis

As already mentioned, the company produces different types of packaging that differ in shape, size, design and colors. Not only that each customer requires packaging for their particular product, but also some of them may require more types of packaging in a single order. As a result, many changeovers have to take place. This applies to the printing machines, cutting machines and also, if needed, to the gluing machine. The chapter 6 explains why to focus on the printing machines. The machine KBA 105 was picked because the changeovers are usually performed more slowly in comparison with the newer machine KBA 106. Moreover, KBA 106 has an automatic loading of printing plates and more experienced operators.

In general, the changeover consists of several core operations that have to be carried out. After completing the previous batch, the printing machine has to be stopped and preparations for another production will commence. First of all, the assistant has to transport the pallets of paper needed for the next order in front of the press (this is mostly performed externally). The remaining ink (that is not used for the next order) is removed from the inking unit and then another printing ink replaces it. This operation is repeated based on how many Pantone colors are used. Sometimes, the ink rollers have to be cleaned before adding another ink. This usually happens when shifting from darker to a lighter color or vice versa. After that, the previous printing plates are removed from each printing unit and replaced by the new ones. Meanwhile, the main printing operator manages the press software where he modifies each printing unit and prepares an order. After everything is ready, the main operator has to print the first test batch where he checks if the quality of the printed segments is in accordance with a sample piece. If the quality is not acceptable, adjustments must be made. This process has to be repeated until the first good batch is printed.

It is important to note that each changeover is different in a way. It can be said that each of them has its core operations that have to be performed every time (those described above), however, these operations can differ in the number of times they are performed. There are also some processes and operations that occur only in specific cases. For example, filling a coating unit with a special material that further enhances the packaging with the desired effect (gloss, semi-gloss, semi-matt and others).

During the time spent in the company, the student observed the course of several changeovers from which some were filmed. One of them was then selected and analyzed in order to shorten the changeover time and thus potentially increase productivity. The video was picked primarily based on a length of the changeover (typical changeover) and because it covers all the core operations, and therefore some improvements could be also applied to other changeovers. The analyzed changeover has 35 minutes and 45 seconds. In this part of the analysis, the changeover was divided into parts that contain individual activities/operations, their duration and whether they are performed internally or externally, i.e., the first step of SMED was implemented. Because the changeover is performed by two operators, it is crucial to analyze the changeover from the perspective of both. The entire table showing the first step of SMED can be found in Appendix I and II.

7 IMPLEMENTING SMED

In the previous chapter, the first step of SMED was implemented. This chapter continues with the implementation of the second and the third step of SMED (see Appendix III and IV). There are also recommendations and comments on some of the changes.

11	4:09	4:30	21 (0)	Moving to the unloader	I	**E**
12	4:30	4:41	11 (0)	Loading the last pallet from the previous order	I	**E**
13	4:41	6:08	87 (0)	Transporting and placing the pallet to the intermediate storage	I	**E**
14	6:08	6:39	31 (0)	Moving back to the printing machine	I	**E**

Figure 22 – Example 1 (author's creation)

The unloader of the printing machine has a pallet located in it on which individual paper sheets are stacked. This pallet then continuously decreases based on the added weight. When the required amount is printed, the stack of paper sheets is moved on a new pallet and then transported to the intermediate storage. In this case, the last stack of paper sheets from the previous order was located in front of the unloader (already prepared on the new pallet) and therefore it would not interfere with the new ongoing printing. Of course, under the unloader must be prepared the new pallet, however, this can be done while the new order is being printed as there is some time before the pallet inside of the unloader is fully stacked with the paper sheets. In order to shorten the changeover time, it is recommended to the main operator to perform such operations while the new order is being processed.

3	3:25	3:36	11 (0)	Moving a can with the removed ink to a table	I	**E**
4	3:36	4:10	34 (0)	Cleaning hands with a rag	I	**Elim.**
5	4:10	4:20	10 (0)	Moving back to the first printing unit (1) + its closing	I	**Elim.**
6	4:20	4:35	15 (0)	Moving to the table and checking which ink should be used	I	**E**
7	4:35	5:00	25 (0)	Going for the ink can + going back with it to the first printing unit (1)	I	**E**

Figure 23 – Example 2 (author's creation)

It was observed that the assistant repeatedly moved things from one place to another despite the fact that, for example, the can with the removed ink can be placed on the printing unit. Even though the can with the new ink is also placed on the printing unit, there is a space for both. Thus, the can with the removed ink can be moved to another place when the changeover is finished. Furthermore, the assistant wasted some time with cleaning his hands. This could be easily prevented if the assistant would use gloves. Not only that he had to check which ink was supposed to be used next, but he also needed to go for that particular ink. This generated unnecessary movement and a waste of time. It is recommended to prepare the ink cans needed for the upcoming order and place them on the specific printing unit while the previous order is still being processed.

43	17:20	20:50	210 (0)	Waiting + conversating + walking	I	**Elim.**
44	20:50	21:10	20 (0)	Writing down on a paper + checking the polymer plates near the printing machine	I	**E**
45	21:10	22:06	56 (0)	Writing down on the paper + sorting the upcoming orders	I	**E**
46	22:06	22:25	19 (0)	Moving from the printing machine to the storage of the polymer plates	I	**E**
47	22:25	23:58	93 (0)	Looking for and pulling out the polymer plates for the upcoming orders	I	**E**
48	23:58	24:25	27 (0)	Moving the polymer plates to the printing machine	I	**E**
49	24:25	24:52	27 (0)	Moving the previously used polymer plates back to the storage	I	**E**
50	24:52	25:21	29 (0)	Putting the polymer plates back and moving to the printing machine	I	**E**

Figure 24 – Example 3 (author's creation)

It often happened that the main operator was waiting for the assistant to complete his operations that had to be finished in order to continue. In his "spare time," he dealt with the polymer plates that were not necessary for the current setup. It is advisable for the main operator to help with the assistant's operations in order to speed up the whole changeover. The main operator may remove the remaining ink from one printing unit (one of two on which they must operate) and replace it with the new ink while the assistant simultaneously operates on the other printing unit. As a result, the total changeover time can be shortened by a few minutes.

32	13:52	14:22	30 (5)	Moving to the printing plates and manipulating with them	I	**Short.**
33	14:22	14:37	15 (10)	Moving the printing plate (1) to the first printing unit + placement	I	**Short.**
34	14:37	14:58	21 (0)	Moving to the printing plates and manipulating with them	I	**Elim.**
35	14:58	15:09	11	Moving the printing plate (2) to the second printing unit + placement	I	
36	15:09	15:17	8 (0)	Moving to the printing plates	I	**Elim.**
37	15:17	15:28	11	Moving the printing plate (3) to the third printing unit + placement	I	
38	15:28	15:45	17 (10)	Moving the printing plate (4) to the fourth printing unit + placement	I	**Short.**
39	15:45	16:06	21 (10)	Moving the printing plate (5) to the fifth printing unit + placement	I	**Short.**

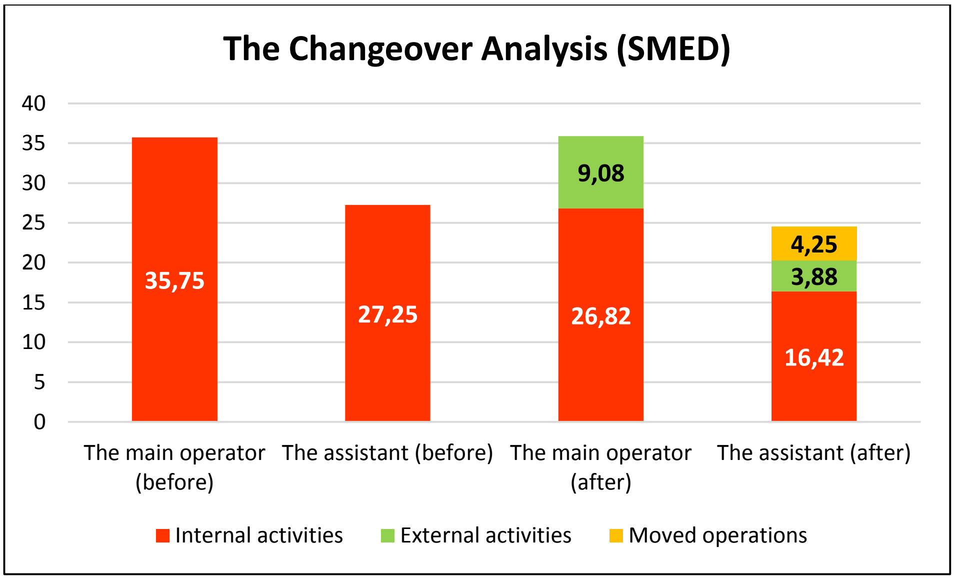
Figure 25 – Example 4 (author's creation)

The main operator moved and placed each printing plate to its respective printing unit. The last printing plate was about to be placed by the assistant because at that time he still operated on one of the printing units. The main operator had to figure out where each printing plate should be placed. Additionally, all of them were placed between the end of the machine and the last printing unit. This resulted in unnecessary walking. By placing the printing plates next to the appropriate printing units while still processing the previous order, there would be no unnecessary handling and walking.

7.1 Results

Using the SMED method, the total changeover time was reduced from 35 minutes and 45 seconds to 26 minutes and 49 seconds. After eliminating some redundant activities and converting some operations from internal to external, it was possible to shorten the changeover time. Moreover, this change can be achieved without any investment. Some of the activities that have been eliminated are, for instance, conversating, waiting, looking and going for things. The operations/activities that have been converted from internal to external are, for example, preparing the needed ink cans and transporting things to the storage. Another significant change resulted from applying parallel operation where the main printing operator helps the assistant to remove the previously used ink and add a new one. The changeover operations/activities were adjusted and organized into the new changeover plans that can be found in Appendix V and VI. It should be noted that the times listed in the changeover plans are only approximate.

Chart 1 – Before and after SMED (author's creation)



The economic evaluation of the shortened changeover time can be displayed in both financial savings and lost profit per month in CZK. The company has performed 427[3] changeovers (KBA 105) last month and the saved time that resulted from implementing the SMED method is 8 minutes and 56 seconds (0,15 hour). In order to calculate the financial savings, it is important to know the company's machine hour rate that is in this case 3 420 CZK.[4]

$$427 * 0{,}15h = 64{,}05h$$

$$3\,420 * 64{,}05h = 219\,051\ CZK$$

Thus, the company can save 219 051 CZK per month as a direct result of shortening the changeover times. To calculate the lost profit per one printing machine per month it is essential to know the lost profit per machine hour that is 15 845 CZK[5] and then:

$$15\,845 * 64{,}05h = 1\,014\,872\ CZK$$

---

[3] The value was multiplied by a coefficient due to sensitive data

[4] The value was multiplied by a coefficient due to sensitive data

[5] The value was multiplied by a coefficient due to sensitive data

The lost profit per one printing machine per month is 1 014 872 CZK. Nevertheless, these numbers are just theoretical and should serve as an example of the benefits and impacts arising from SMED.

CONCLUSION

The aim of this bachelor's thesis was to analyze a production process of Cardbox Packaging s.r.o. Before the analysis itself, the student had to get acquainted with the theory. After that, it was possible to start with the analysis of the production process, which included, among other things, the description of the company and the individual production processes. During the time spent in the company, a bottleneck was found. This bottleneck was then analyzed to potentially increase productivity. After proposing possible solutions, the economic benefits were presented.

The theoretical part of this thesis was divided into three chapters. Firstly, the production process was described on a basic level, including transformation processes occurring in a production and related systems. Secondly, the concept of lean production was defined. Additionally, the Toyota Production System was included as an essential part of this "lean thinking" where the elimination of waste is the main goal. This system is highly connected with productivity as well as the individual types of waste that were characterized by Taiichi Ohno. Furthermore, additional activities of lean production were mentioned. Lastly, the SMED method was described in a great detail as it was the main method that was used in the analytical part.

The analytical part started with an introduction of the company that included information, such as portfolio, missions, visions and organizational structure. This was followed by a chapter describing the various processes of the company's production. After looking at the internal documentation and confirmation from the company, the bottleneck was found. It was pointed out that the cutting machine suffered from long downtime hours that were caused by waiting for the printed material. Nonetheless, some of these downtime hours can be influenced in some way. It was assumed that due to a higher frequency of changeovers on the printing machines, shortening their time could cause higher productivity. The changeover itself was analyzed using the SMED method. The individual operations/activities of the changeover were either shortened, eliminated, converted from internal to external or moved to another operator. Based on this, a new changeover plan was created. At the end of the analytical part, the estimated economic benefits were displayed that could possibly result from the provided suggestions.

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LIST OF ABBREVIATIONS

BRC	British Retail Consortium
CMYK	Cyan, Magenta, Yellow, Black
CTP	Computer to Plate
FDA	Food and Drug Administration
FSC	Forest Stewardship Council
ID	Identification
IED	Inner Exchange of Die
IMS	Interstate Milk Shippers
IOP	Institute of Packaging
JIT	Just-in-time
OED	Outer Exchange of Die
SMED	Single Minute Exchange of Dies
TPM	Total Productive Maintenance
TPS	Total Production System
TQM	Total Quality Management
UV	Ultraviolet

LIST OF FIGURES

LIST OF TABLES

LIST OF CHARTS

APPENDICES

APPENDIX P I: THE CHANGEOVER ANALYSIS (MAIN OPERATOR)

MAIN PRINTING OPERATOR					
	Time (min:s)		Duration		
N.	**From**	**To**	**(s)**	**Operations/activities**	**I/E**
1	0:00	0:15	15	Grabbing a job bag and a label from the previous order	I
2	0:15	0:40	25	Moving the job bag and the label to the finished pallet from the previous order	I
3	0:40	0:55	15	Preparing the pallet in the unloader	I
4	0:55	1:45	50	Loading paper/order in a computer	I
5	1:45	2:54	69	Loading and preparing order in press software	I
6	2:54	3:40	46	Setting up and starting rubber blankets cleaning	I
7	3:40	3:48	8	Moving to the printing unit (1)	I
8	3:48	3:56	8	Applying a cleaner into the printing unit (1)	I
9	3:56	4:01	5	Moving to another printing unit (2)	I
10	4:01	4:09	8	Applying the cleaner into the printing unit (2)	I
11	4:09	4:30	21	Moving to the unloader	I
12	4:30	4:41	11	Loading the last pallet from the previous order	I
13	4:41	6:08	87	Transporting and placing the pallet to the intermediate storage	I
14	6:08	6:39	31	Moving back to the printing machine	I
15	6:39	6:47	8	Preparing the feeder in front of the machine	I
16	6:47	6:57	10	Looking at the pallets of paper	I
17	6:57	7:25	28	Moving to the assistant + conversating	I
18	7:25	7:56	31	Removing the previous pallet from the feeder + preperation	I
19	7:56	8:25	29	Transporting the new pallet of paper into the feeder	I
20	8:25	9:36	71	Placing and adjusting of the pallet in the feeder	I
21	9:36	10:00	24	Moving to the press software	I
22	10:00	10:43	43	Operating on the press software (needed before moving to a densitronic)	I
23	10:43	10:54	11	Writing down the individual color values on a paper	I
24	10:54	11:45	51	Moving to the densitronic and waiting for other operator to finish	I
25	11:45	12:18	33	Setting the color values in the densitronic software	I
26	12:18	12:46	28	Preparing the new pallet under the unloader	I
27	12:46	13:00	14	Moving to the assistant	I
28	13:00	13:06	6	Conversating with the assistant	I
29	13:06	13:14	8	Moving to the computer	I
30	13:14	13:27	13	Operating on the computer	I
31	13:27	13:52	25	Waiting	I
32	13:52	14:22	30	Moving to the printing plates and manipulating with them	I
33	14:22	14:37	15	Moving the printing plate (1) to the first printing unit + placement	I
34	14:37	14:58	21	Moving to the printing plates and manipulating with them	I
35	14:58	15:09	11	Moving the printing plate (2) to the second printing unit + placement	I
36	15:09	15:17	8	Moving to the printing plates	I
37	15:17	15:28	11	Moving the printing plate (3) to the third printing unit + placement	I
38	15:28	15:45	17	Moving the printing plate (4) to the fourth printing unit + placement	I
39	15:45	16:06	21	Moving the printing plate (5) to the fifth printing unit + placement	I
40	16:06	16:39	33	Moving in front of the machine + writing something down	I
41	16:39	17:08	29	Waiting	I
42	17:08	17:20	12	Removing the previous testing batch from a table	I
43	17:20	20:50	210	Waiting + conversating + walking	I
44	20:50	21:10	20	Writing down on a paper + checking the polymer plates near the printing machine	I
45	21:10	22:06	56	Writing down on the paper + sorting the upcoming orders	I
46	22:06	22:25	19	Moving from the printing machine to the storage of the polymer plates	I
47	22:25	23:58	93	Looking for and pulling out the polymer plates for the upcoming orders	I
48	23:58	24:25	27	Moving the polymer plates to the printing machine	I
49	24:25	24:52	27	Moving the previously used polymer plates back to the storage	I
50	24:52	25:21	29	Putting the polymer plates back and moving to the printing machine	I
51	25:21	27:15	114	Operating on the press software + starting the first test batch	I
52	27:15	28:40	85	Printing and completing the first test batch	I
53	28:40	29:25	45	Quality control of the printed segments + adjustments	I
54	29:25	29:35	10	Moving the printed paper sheet to the densitronic	I
55	29:35	30:40	65	Measuring the color values	I
56	30:40	30:46	6	Moving back to the press software	I
57	30:46	30:57	11	Adjustments of the colors in the software	I
58	30:57	31:35	38	Testing a barcode functionality	I
59	31:35	32:10	35	Inserting the barcode rating into the system	I
60	32:10	33:48	98	Starting and completing the second test batch	I
61	33:48	34:33	45	Quality control of the newly printed segments + adjustments	I
62	34:33	35:08	35	Moving the printed paper sheet to the densitronic + measuring the color values	I
63	35:08	35:45	37	Last adjustments + starting the first good batch	I
Total time:				35 minutes and 45 seconds	

APPENDIX P II: THE CHANGEOVER ANALYSIS (ASSISTANT)

ASSISTANT					
	Time (min:s)		Duration		
N.	From	To	(s)	Operations/activities	I/E
1	0:00	0:15	15	Moving to the first printing unit (1)	I
2	0:15	3:25	190	Removing the remaining ink from the previous order using a spatula	I
3	3:25	3:36	11	Moving a can with the removed ink to a table	I
4	3:36	4:10	34	Cleaning hands with a rag	I
5	4:10	4:20	10	Moving back to the first printing unit (1) + its closing	I
6	4:20	4:35	15	Moving to the table and checking which ink should be used	I
7	4:35	5:00	25	Going for the ink can + going back with it to the first printing unit (1)	I
8	5:00	5:20	20	Opening and preparing the ink can	I
9	5:20	6:15	55	Applying the new ink into the inking unit using the spatula	I
10	6:15	6:32	17	Moving to another printing unit (2)	I
11	6:32	7:05	33	Removing the remaining ink from the previous order using a spatula	I
12	7:05	7:20	15	Conversating with the main printing operator	I
13	7:20	9:20	120	Removing the remaining ink	I
14	9:20	9:35	15	Moving the can with the removed ink to the table	I
15	9:35	9:50	15	Applying a cleaner on a rag and cleaning the can	I
16	9:50	10:20	30	Putting on gloves + moving the cleaner and the rag to the printing unit (2)	I
17	10:20	10:40	20	Applying the cleaner on the rag	I
18	10:40	11:42	62	Cleaning the inking roller with the rag	I
19	11:42	11:49	7	Throwing out the used rag	I
20	11:49	12:05	16	Applying the cleaner on another rag	I
21	12:05	13:00	55	Cleaning the inking roller with the new rag	I
22	13:00	13:06	6	Conversating with the main printing operator	I
23	13:06	13:25	19	Cleaning the inking roller	I
24	13:25	14:01	36	Removing the gloves and cleaning the spatula	I
25	14:01	14:21	20	Moving the rag and the gloves to the table	I
26	14:21	14:33	12	Checking which ink should be used next + going for the ink can	I
27	14:33	14:41	8	Moving the can to the cleaned printing unit (2)	I
28	14:41	14:50	9	Manipulating with the printing unit	I
29	14:50	15:50	60	Applying the new ink into the inking unit using the spatula	I
30	15:50	15:58	8	Putting away the ink can and the spatula	I
31	15:58	16:05	7	Going for the printing plates	I
32	16:05	16:20	15	Moving the printing plate to the printing unit + placement	I
33	16:20	16:35	15	Moving to the first printing unit	I
34	16:35	16:40	5	Opening the printing unit	I
35	16:40	17:11	31	Waiting for the previously used printing plate to go out	I
36	17:11	17:19	8	Putting the previously used printing plate next to the printing unit	I
37	17:19	17:46	27	Loading the new printing plate into the printing unit	I
38	17:46	18:00	14	Tightening wheels for a proper grip of the new printing plate	I
39	18:00	18:05	5	Closing the printing unit	I
40	18:05	18:10	5	Moving to the next printing unit	I
41	18:10	18:15	5	Opening the printing unit	I
42	18:15	18:48	33	Waiting for the previously used printing plate to go out	I
43	18:48	18:54	6	Putting the previously used printing plate next to the printing unit	I
44	18:54	19:18	24	Loading the new printing plate into the printing unit	I
45	19:18	19:35	17	Tightening the wheels for a proper grip of the new printing plate	I
46	19:35	19:40	5	Closing the printing unit	I
47	19:40	19:42	2	Moving to the next printing unit	I
48	19:42	19:47	5	Opening the printing unit	I
49	19:47	20:17	30	Waiting for the previously used printing plate to go out	I
50	20:17	20:24	7	Putting the previously used printing plate next to the printing unit	I
51	20:24	20:49	25	Loading the new printing plate into the printing unit	I
52	20:49	20:58	9	Tightening the wheels for a proper grip of the new printing plate	I
53	20:58	21:09	11	Closing the printing unit	I
54	21:09	21:13	4	Moving to the next printing unit	I
55	21:13	21:17	4	Opening the printing unit	I
56	21:17	21:49	32	Waiting for the previously used printing plate to go out	I
57	21:49	21:55	6	Putting the previously used printing plate next to the printing unit	I
58	21:55	22:20	25	Loading the new printing plate into the printing unit	I
59	22:20	22:34	14	Tightening the wheels for a proper grip of the new printing plate	I
60	22:34	22:39	5	Closing the printing unit	I
61	22:39	22:43	4	Moving to the next printing unit	I
62	22:43	22:47	4	Opening the printing unit	I
63	22:47	23:18	31	Waiting for the previously used printing plate to go out	I

64	23:18	23:24	6	Putting the previously used printing plate next to the printing unit	I
65	23:24	23:48	24	Loading the new printing plate into the printing unit	I
66	23:48	24:00	12	Tightening the wheels for a proper grip of the new printing plate	I
67	24:00	24:07	7	Closing the printing unit	I
68	24:07	24:11	4	Cleaning hands with the rag	I
69	24:11	24:14	3	Moving to the next printing unit	I
70	24:14	24:18	4	Opening the printing unit	I
71	24:18	24:51	33	Waiting for the previously used printing plate to go out	I
72	24:51	24:56	5	Putting the previously used printing plate next to the printing unit	I
73	24:56	25:22	26	Loading the new printing plate into the printing unit	I
74	25:22	25:37	15	Tightening the wheels for a proper grip of the new printing plate	I
75	25:37	25:43	6	Closing the printing unit	I
76	25:43	26:22	39	Moving the old printing plates to trash	I
77	26:22	27:15	53	Moving at the end of the printing machine	I
78	27:15	35:45	510	Acitivites that do not influence the changeover	I
Total time:				35 minutes and 45 seconds	

APPENDIX P III: IMPLEMENTING SMED (MAIN OPERATOR)

MAIN PRINTING OPERATOR						
	Time (min:s)		Duration			
N.	From	To	(s)	Operations/activities	I/E	Change
1	0:00	0:15	15 (0)	Grabbing a job bag and a label from the previous order	I	E
2	0:15	0:40	25 (0)	Moving the job bag and the label to the finished pallet from the previous order	I	E
3	0:40	0:55	15	Preparing the pallet in the unloader	I	
4	0:55	1:45	50	Loading paper/order in a computer	I	
5	1:45	2:54	69	Loading and preparing order in press software	I	
6	2:54	3:40	46	Setting up and starting rubber blankets cleaning	I	
7	3:40	3:48	8	Moving to the printing unit (1)	I	
8	3:48	3:56	8	Applying a cleaner into the printing unit (1)	I	
9	3:56	4:01	5	Moving to another printing unit (2)	I	
10	4:01	4:09	8	Applying the cleaner into the printing unit (2)	I	
11	4:09	4:30	21 (0)	Moving to the unloader	I	E
12	4:30	4:41	11 (0)	Loading the last pallet from the previous order	I	E
13	4:41	6:08	87 (0)	Transporting and placing the pallet to the intermediate storage	I	E
14	6:08	6:39	31 (0)	Moving back to the printing machine	I	E
15	6:39	6:47	8	Preparing the feeder in front of the machine	I	
16	6:47	6:57	10 (0)	Looking at the pallets of paper	I	Elim.
17	6:57	7:25	28 (0)	Moving to the assistant + conversating	I	Elim.
18	7:25	7:56	31	Removing the previous pallet from the feeder + preperation	I	
19	7:56	8:25	29	Transporting the new pallet of paper into the feeder	I	
20	8:25	9:36	71	Placing and adjusting of the pallet in the feeder	I	
21	9:36	10:00	24	Moving to the press software	I	
22	10:00	10:43	43	Operating on the press software (needed before moving to a densitronic)	I	
23	10:43	10:54	11 (0)	Writing down the individual color values on a paper	I	E
24	10:54	11:45	51	Moving to the densitronic and waiting for other operator to finish	I	
25	11:45	12:18	33	Setting the color values in the densitronic software	I	
26	12:18	12:46	28 (0)	Preparing the new pallet under the unloader	I	E
27	12:46	13:00	14 (0)	Moving to the assistant	I	Elim.
28	13:00	13:06	6 (0)	Conversating with the assistant	I	Elim.
29	13:06	13:14	8	Moving to the computer	I	
30	13:14	13:27	13	Operating on the computer	I	
31	13:27	13:52	25 (0)	Waiting	I	Elim.
32	13:52	14:22	30 (5)	Moving to the printing plates and manipulating with them	I	Short.
33	14:22	14:37	15 (10)	Moving the printing plate (1) to the first printing unit + placement	I	Short.
34	14:37	14:58	21 (0)	Moving to the printing plates and manipulating with them	I	Elim.
35	14:58	15:09	11	Moving the printing plate (2) to the second printing unit + placement	I	
36	15:09	15:17	8 (0)	Moving to the printing plates	I	Elim.
37	15:17	15:28	11	Moving the printing plate (3) to the third printing unit + placement	I	
38	15:28	15:45	17 (10)	Moving the printing plate (4) to the fourth printing unit + placement	I	Short.
39	15:45	16:06	21 (10)	Moving the printing plate (5) to the fifth printing unit + placement	I	Short.
40	16:06	16:39	33 (0)	Moving in front of the machine + writing something down	I	E
41	16:39	17:08	29 (0)	Waiting	I	Elim.
42	17:08	17:20	12 (0)	Removing the previous testing batch from a table	I	E
43	17:20	20:50	210 (0)	Waiting + conversating + walking	I	Elim.
44	20:50	21:10	20 (0)	Writing down on a paper + checking the polymer plates near the printing machine	I	E
45	21:10	22:06	56 (0)	Writing down on the paper + sorting the upcoming orders	I	E
46	22:06	22:25	19 (0)	Moving from the printing machine to the storage of the polymer plates	I	E
47	22:25	23:58	93 (0)	Looking for and pulling out the polymer plates for the upcoming orders	I	E
48	23:58	24:25	27 (0)	Moving the polymer plates to the printing machine	I	E
49	24:25	24:52	27 (0)	Moving the previously used polymer plates back to the storage	I	E
50	24:52	25:21	29 (0)	Putting the polymer plates back and moving to the printing machine	I	E
51	25:21	27:15	114	Operating on the press software + starting the first test batch	I	
52	27:15	28:40	85	Printing and completing the first test batch	I	
53	28:40	29:25	45	Quality control of the printed segments + adjustments	I	
54	29:25	29:35	10	Moving the printed paper sheet to the densitronic	I	
55	29:35	30:40	65	Measuring the color values	I	
56	30:40	30:46	6	Moving back to the press software	I	
57	30:46	30:57	11	Adjustments of the colors in the software	I	
58	30:57	31:35	38	Testing a barcode functionality	I	
59	31:35	32:10	35	Inserting the barcode rating into the system	I	
60	32:10	33:48	98	Starting and completing the second test batch	I	
61	33:48	34:33	45	Quality control of the newly printed segments + adjustments	I	
62	34:33	35:08	35	Moving the printed paper sheet to the densitronic + measuring the color values	I	
63	35:08	35:45	37	Last adjustments + starting the first good batch	I	

APPENDIX P IV: IMPLEMENTING SMED (ASSISTANT)

ASSISTANT						
	Time (min:s)		Duration			
N.	From	To	(s)	Operations/activities	I/E	Change
1	0:00	0:15	15 (0)	Moving to the first printing unit (1)	I	Elim.
2	0:15	3:25	190 (0)	Removing the remaining ink from the previous order using a spatula	I	Move
3	3:25	3:36	11 (0)	Moving a can with the removed ink to a table	I	E
4	3:36	4:10	34 (0)	Cleaning hands with a rag	I	Elim.
5	4:10	4:20	10 (0)	Moving back to the first printing unit (1) + its closing	I	Elim.
6	4:20	4:35	15 (0)	Moving to the table and checking which ink should be used	I	E
7	4:35	5:00	25 (0)	Going for the ink can + going back with it to the first printing unit (1)	I	E
8	5:00	5:20	20 (10)	Opening and preparing the ink can	I	Move
9	5:20	6:15	55 (0)	Applying the new ink into the inking unit using the spatula	I	Move
10	6:15	6:32	17 (10)	Moving to another printing unit (2)	I	Short.
11	6:32	7:05	33	Removing the remaining ink from the previous order using a spatula	I	
12	7:05	7:20	15 (0)	Conversating with the main printing operator	I	Elim.
13	7:20	9:20	120	Removing the remaining ink	I	
14	9:20	9:35	15 (0)	Moving the can with the removed ink to the table	I	E
15	9:35	9:50	15 (0)	Applying a cleaner on a rag and cleaning the can	I	E
16	9:50	10:20	30 (0)	Putting on gloves + moving the cleaner and the rag to the printing unit (2)	I	E
17	10:20	10:40	20	Applying the cleaner on the rag	I	
18	10:40	11:42	62	Cleaning the inking roller with the rag	I	
19	11:42	11:49	7 (0)	Throwing out the used rag	I	E
20	11:49	12:05	16	Applying the cleaner on another rag	I	
21	12:05	13:00	55	Cleaning the inking roller with the new rag	I	
22	13:00	13:06	6 (0)	Conversating with the main printing operator	I	Elim.
23	13:06	13:25	19	Cleaning the inking roller	I	
24	13:25	14:01	36 (0)	Removing the gloves and cleaning the spatula	I	E
25	14:01	14:21	20 (0)	Moving the rag and the gloves to the table	I	E
26	14:21	14:33	12 (0)	Checking which ink should be used next + going for the ink can	I	E
27	14:33	14:41	8 (0)	Moving the can to the cleaned printing unit (2)	I	E
28	14:41	14:50	9 (5)	Manipulating with the printing unit	I	Short.
29	14:50	15:50	60	Applying the new ink into the inking unit using the spatula	I	
30	15:50	15:58	8 (5)	Putting away the ink can and the spatula	I	Short.
31	15:58	16:05	7 (0)	Going for the printing plates	I	Elim.
32	16:05	16:20	15 (10)	Moving the printing plate to the printing unit + placement	I	Short.
33	16:20	16:35	15	Moving to the first printing unit	I	
34	16:35	16:40	5	Opening the printing unit	I	
35	16:40	17:11	31	Waiting for the previously used printing plate to go out	I	
36	17:11	17:19	8	Putting the previously used printing plate next to the printing unit	I	
37	17:19	17:46	27	Loading the new printing plate into the printing unit	I	
38	17:46	18:00	14	Tightening wheels for a proper grip of the new printing plate	I	
39	18:00	18:05	5	Closing the printing unit	I	
40	18:05	18:10	5	Moving to the next printing unit	I	
41	18:10	18:15	5	Opening the printing unit	I	
42	18:15	18:48	33	Waiting for the previously used printing plate to go out	I	
43	18:48	18:54	6	Putting the previously used printing plate next to the printing unit	I	
44	18:54	19:18	24	Loading the new printing plate into the printing unit	I	
45	19:18	19:35	17	Tightening the wheels for a proper grip of the new printing plate	I	
46	19:35	19:40	5	Closing the printing unit	I	
47	19:40	19:42	2	Moving to the next printing unit	I	
48	19:42	19:47	5	Opening the printing unit	I	
49	19:47	20:17	30	Waiting for the previously used printing plate to go out	I	
50	20:17	20:24	7	Putting the previously used printing plate next to the printing unit	I	
51	20:24	20:49	25	Loading the new printing plate into the printing unit	I	
52	20:49	20:58	9	Tightening the wheels for a proper grip of the new printing plate	I	
53	20:58	21:09	11	Closing the printing unit	I	
54	21:09	21:13	4	Moving to the next printing unit	I	
55	21:13	21:17	4	Opening the printing unit	I	
56	21:17	21:49	32	Waiting for the previously used printing plate to go out	I	
57	21:49	21:55	6	Putting the previously used printing plate next to the printing unit	I	
58	21:55	22:20	25	Loading the new printing plate into the printing unit	I	
59	22:20	22:34	14	Tightening the wheels for a proper grip of the new printing plate	I	
60	22:34	22:39	5	Closing the printing unit	I	
61	22:39	22:43	4	Moving to the next printing unit	I	
62	22:43	22:47	4	Opening the printing unit	I	
63	22:47	23:18	31	Waiting for the previously used printing plate to go out	I	

64	23:18	23:24	6	Putting the previously used printing plate next to the printing unit	I	
65	23:24	23:48	24	Loading the new printing plate into the printing unit	I	
66	23:48	24:00	12	Tightening the wheels for a proper grip of the new printing plate	I	
67	24:00	24:07	7	Closing the printing unit	I	
68	24:07	24:11	4 (0)	Cleaning hands with the rag	I	**Elim.**
69	24:11	24:14	3	Moving to the next printing unit	I	
70	24:14	24:18	4	Opening the printing unit	I	
71	24:18	24:51	33	Waiting for the previously used printing plate to go out	I	
72	24:51	24:56	5	Putting the previously used printing plate next to the printing unit	I	
73	24:56	25:22	26	Loading the new printing plate into the printing unit	I	
74	25:22	25:37	15	Tightening the wheels for a proper grip of the new printing plate	I	
75	25:37	25:43	6	Closing the printing unit	I	
76	25:43	26:22	39 (0)	Moving the old printing plates to trash	I	**E**
77	26:22	27:15	53 (10)	Moving at the end of the printing machine	I	**Short.**
78	27:15	35:45	510	Acitivites that do not influence the changeover	I	

APPENDIX P V: THE CHANGEOVER PLAN (MAIN OPERATOR)

THE CHANGEOVER PLAN					
MAIN PRINTING OPERATOR					
	Time (min:s)		Duration		
N.	From	To	(s)	Operations/activities	I/E
1	0:00	0:15	15	Preparing the pallet in the unloader	I
3	0:15	1:24	69	Loading and preparing order in press software	I
4	1:24	2:10	46	Setting up and starting rubber blankets cleaning	I
5	2:10	2:18	8	Moving to the printing unit (1)	I
6	2:18	2:26	8	Applying a cleaner into the printing unit (1)	I
7	2:26	2:31	5	Moving to another printing unit (2)	I
8	2:31	2:39	8	Applying the cleaner into the printing unit (2)	I
9	2:39	5:49	190	Removing the remaining ink from the previous order using a spatula	I
10	5:49	6:54	65	Applying the new ink into the inking unit using the spatula	I
11	6:54	7:09	15	Moving the printing plate (1) to the first printing unit + placement	I
12	7:09	7:20	11	Moving the printing plate (2) to the second printing unit + placement	I
13	7:20	7:31	11	Moving the printing plate (3) to the third printing unit + placement	I
14	7:31	7:41	10	Moving the printing plate (4) to the fourth printing unit + placement	I
15	7:41	7:51	10	Moving the printing plate (5) to the fifth printing unit + placement	I
16	7:51	7:59	8	Preparing the feeder in front of the machine	I
17	7:59	8:30	31	Removing the previous pallet from the feeder + preperation	I
18	8:30	8:59	29	Transporting the new pallet of paper into the feeder	I
19	8:59	10:10	71	Placing and adjusting of the pallet in the feeder	I
20	10:10	10:34	24	Moving to the computer	I
21	10:34	11:24	50	Loading paper/order in the computer	I
22	11:24	12:07	43	Operating on the press software (needed before moving to a densitronic)	I
23	12:07	12:58	51	Moving to the densitronic (and waiting for other operator to finish)	I
24	12:58	13:31	33	Setting the color values in the densitronic software	I
25	13:31	13:39	8	Moving to the computer	I
26	13:39	13:52	13	Operating on the computer	I
27	13:52	16:25	153	Waiting for the assistant to finish the exchange of the printing plates + other necessary operations + preparations	I
28	16:25	18:19	114	Operating on the press software + starting the first test batch	I
29	18:19	19:44	85	Printing and completing the first test batch	I
30	19:44	20:29	45	Quality control of the printed segments + adjustments	I
31	20:29	20:39	10	Moving the printed paper sheet to the densitronic	I
32	20:39	21:44	65	Measuring the color values	I
33	21:44	21:50	6	Moving back to the press software	I
34	21:50	22:01	11	Adjustments of the colors in the software	I
35	22:01	22:39	38	Testing a barcode functionality	I
36	22:39	23:14	35	Inserting the barcode rating into the system	I
37	23:14	24:52	98	Starting and completing the second test batch	I
38	24:52	25:37	45	Quality control of the newly printed segments + adjustments	I
39	25:37	26:12	35	Moving the printed paper sheet to the densitronic + measuring the color values	I
40	26:12	26:49	37	Last adjustments + starting the first good batch	I
41	Transporting the last pallet from the previous order to the intermediate storage and preparing the new pallet under the unloader				E
	New total time:			26 minutes and 49 seconds	

APPENDIX P VI: THE CHANGEOVER PLAN (ASSISTANT)

THE CHANGEOVER PLAN						
ASSISTANT						
N.	Time (min:s) From	To	Duration (s)	Operations/activities	I/E	
1	Preparing the pallets of paper in front of the machine, the printing plates next to the printing units, the ink cans on the printing units and other necessary things (cleaners, rags, etc.)				E	
2	0:00	0:10	10	Moving to the printing unit	I	
3	0:10	2:43	153	Removing the remaining ink from the previous order using a spatula	I	
4	2:43	3:03	20	Applying the cleaner on the rag	I	
5	3:03	4:05	62	Cleaning the inking roller with the rag	I	
6	4:05	4:21	16	Applying the cleaner on another rag	I	
7	4:21	5:35	74	Cleaning the inking roller with the new rag	I	
8	5:35	6:45	70	Applying the new ink into the inking unit using the spatula	I	
9	6:45	6:55	10	Moving the printing plate to the printing unit + placement	I	
10	6:55	7:10	15	Moving to the first printing unit	I	
11	7:10	16:25	5	Opening the printing unit	I	6x
12			33	Waiting for the previously used printing plate to go out	I	
13			6	Putting the previously used printing plate next to the printing unit	I	
14			24	Loading the new printing plate into the printing unit	I	
15			17	Tightening the wheels for a proper grip of the new printing plate	I	
16			5	Closing the printing unit	I	
17			3	Moving to the next printing unit	I	
18	Moving the old printing plates to trash and removing the previously used ink cans and rags from the printing units				E	