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Impact of cellular manufacturing and lean production planning and control on production flow efficiency in a SME

A case study in the protective and security industry

Master thesis in Quality and Operations Management

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Abstract

Today's increasing global competition and customer requirements has had great impact on the manufacturing industry. In order to respond to this ever changing circumstances and sustaining a place on the market, many organizations have started following the lean production methodology. This is no exception for SMEs and due to their important role in modern economics there is a need to help them enhance their efficiency and competitiveness. Previous research has put a lot of focus on how the lean production methodology can be adopted and implementing into the large manufacturing enterprises but much less focus has been put on SMEs. Therefore, the purpose of this research was to get a deeper understanding of how cellular manufacturing and lean production planning and control impact production flow efficiency in a SME. A qualitative research strategy was mainly used with a single case study design. The case study was conducted within the protective and security industry, where the selected case was formed by a population of small Swedish corporation that was interested in lean production. The data collection consisted of interviews, observation, value stream mapping, time study, commonality study, benchmarking and secondary data.

The results show that cellular layout impact the production flow by creating more *standardized production steps* that impacts the changeover time and the throughput time. Creates *less waste* within the production as all tools and material are positioned exactly where they need to be. It *increases visuality* of the production, *increases teamwork* and lastly *helps to reveal hidden problems*. The result also showed that lean production planning and control techniques, pull, takt time and heijunka, impacts the production flow. By introducing pull, *the inventory control improves*, in regards to having the right material at the right time. By having takt time the *waste will be reduced*. Using heijunka helps the *production to become more stable* by balancing the capacity in the production to the customer need. These techniques further help the production to become *more predictable* and therefore, reduce the bullwhip effect. The production will also become more *visual in regards to what needs to be produced* and lastly, the *WIP will be reduced*. Therefore, both cellular manufacturing and lean production planning and control impact the production flow efficiency in SME. This research is believed to be a valuable addition to the field of lean as it tries to address how SMEs can adopt cellular manufacturing and lean production planning and control techniques into their production. This research is also believed to be an addition to the literature of production flow efficiency as the results reveal that there is a strong connection between the production flow efficiency and the two areas studied in a SME production environment.

Keywords: Production flow efficiency, SMEs, cellular manufacturing, lean production planning and control, pull, takt time, heijunka.

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This master thesis was supervised by Carl Wänström at Chalmers University of Technology and Magnus Lund CEO at Milleteknik, and to them we express our gratitude. Their experience, support and inspiration were highly valuable in the thesis process. We would also like to thank the employees at Milleteknik for their advice and support during the thesis project, especially Dan Meier the production manager and the employees working within the production for being so understanding during the whole process of the master thesis.

Gunnhildur Jódís Ísaksdóttir and Stefanía Rut Reynisdóttir
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1 Introduction

This chapter will present the background and purpose of this master thesis. The first section presents the background to the thesis, which is then followed by the purpose and the formulated research questions that are seeked out to be resolved. Lastly, the scope, limitations and outline of this master thesis will be explained.

1.1 Background

Intensified global competition, increased customer requirements, along with higher materials and energy costs in recent years have forced many organizations to continuously modify and optimize their operations (Zhou, 2012). Today, low unit cost and high quality no longer solely define the competitive advantage for manufacturing companies and these factors are more or less taken for granted by customers (Singh & Rajamani, 2012). Instead, factors such as delivery performance, product customization and environmental issues are defining the success of manufacturing companies in regards to profitability and increased market shares (Singh & Rajamani, 2012). This has had great impact on the manufacturing industry and in order to respond to this ever changing circumstances, many organizations have started following the lean production methodology to sustain their place in the market (Achanga et al., 2006; Gupta & Jain, 2013). Lean production, first used by Krafcik (1988) and followed by Womack et al. (1990), is adopted from the Toyota Production System (TPS) and focuses on elimination of waste and improving customer satisfaction (Womack et al., 1990), where waste is everything that does not add value to the customer (Kumar & Kajal, 2015). According to Shah & Ward (2003), lean production is a multi-dimensional approach that includes wide variety of different management practices. These practices are e.g. just-in-time, quality systems, work teams, cellular manufacturing, supplier management, that are integrated together in one system that produces finished products at the pace of the customer demand with as little waste as possible (Shah & Ward, 2003).

Hancock & Zayko (1998), stress that lean is also about making a product flow through a process. Rose et al. (2011) for example defines lean as a production system that focuses on creating continuous flow by eliminating all wastes. Ghirann (2012) further supports that by saying that achieving flow, both flow of material and flow of information, is one of the main goals of lean production. The concept, flow management, includes all aspects of all movements of raw materials, work in progress (WIP), or finished goods within a plant or warehouse (Modrak, 2009). Storch (1999) states that in order to reach continuous flow, there needs to be a small production lot size, ideally a single piece flow. In order to reach a single piece flow, the layout must be conductive to the overall production flow with clear pathways and clear distinguish between material input and product output (Modrak, 2009). In order to reach that type of flow, U-shaped cells, according to Modrak

(2009), are seen as the most applicable. U-shaped cells are part of a concept called cellular manufacturing, which is central to the lean philosophies (Boughton & Arokiam, 2000). The reason for that is because cellular manufacturing is designed around customer needs through the elimination of waste, reduction of lead time and improved quality, which are all essential in lean production (Kulak et al., 2005). Therefore, due to the popularity of lean production, cellular manufacturing has become a significant focal point in the manufacturing industry (Kulak et al., 2005).

Together with cellular manufacturing, there are other important factors that need to be in place in order to reach continuous flow. Liker & Meier (2006) state that having a pull system is important when achieving continuous flow. They state that the term pull is often used in combination with the term flow but it needs to be understood that those terms are strongly linked but not the same. The flow is about the state of material as it moves from process to process but pull is about when material is moved and who determines that it should be moved (Liker & Meier, 2006). Another important factor in regards to flow, is takt time, where Storch (1999) states that it is important that all processes in the value stream keep a synchronized pattern pace so that the flow will be uniform and can be maintained (Storch, 1999). Lastly, leveling is seen to be an important factor when achieving flow as Baudin (2002) states that leveling (heijunka) smoothes the incoming flow of materials and therefore helps to eliminate the bullwhip effect. Liker & Meier (2006) also state that a critical factor in achieving continuous flow is to balance the operations cycle times to the takt time since uneven work times create the wastes, waiting time and overproduction. Heijunka is therefore important in order to reach continuous flow since it involves the concepts of leveling and line balancing (Coleman & Vaghefi, 1994). Those three concepts in the lean methodology, pull, takt time and heijunka are all according to Slomp et al. (2009), the techniques part of lean production planning and control.

Previous research has put a lot of focus on how lean production can be adopted and implemented into large organizations but much less on how it could be adopted into small and medium enterprise’s (SMEs) (Zhou, 2012). According to Gunasekaran et al. (2000), SMEs play an important role in modern economies, due to their flexibility and ability to innovate, where they both play a critical role in providing employment opportunities as well as supporting large sized manufacturing firms. Therefore, there is a need to help SMEs improve their competitiveness (Gunasekaran et al., 2000). Due to lean production’s proven success in large companies, the methodology has become more attractive to SMEs and has left them no choice but to consider implementing it, in order to try enhance their efficiency and competitiveness (Rose et al., 2011; Zhou, 2012). Recent studies show that most of the principles and practices of lean are equally as applicable for SMEs if adopted correctly to the company (Matt & Rauch, 2013; Dorota Rymaszewska, 2014). Poppendieck (2011) and Dorota Rymaszeseka (2014) even state that the lean principles are universal and can help any company to improve. This is further stressed by Liker & Meier (2006), where they talk about the core concepts and philosophies of lean being applicable in an every situation if adopted correctly.

SMEs often do not have much control over their supply chain as the customers often dictate the rules of boundaries of cooperation (Dorota Rymaszewska, 2014). Due to that, lean implementation in SMEs should be more focused on the company's internal processes instead of the whole supply chain (Rose et al., 2011). In order to improve the internal processes in an SME using lean, there are many lean practices that can be considered (Rose et al., 2011). In this research, the focus will be on investigating the use of cellular manufacturing and lean production planning and control techniques in SMEs. The concept of cellular manufacturing does not seem to be popular in SME's as it is rare to find literature or discussions about it in SMEs (Boughton & Arokiam, 2000). Boughton & Arkoman (2000) argue that it is due to the high level of knowledge and expertise needed in order to implement cellular manufacturing that is more or less not present in SMEs. Discussions about the lean production planning and control techniques, pull, takt time and heijunka (Slomp et al. 2009) in SMEs are also rare to find in literature. Therefore, greater research is needed to understand how the lean methodology can be used in SMEs, especially in regards to flow efficiency in relation to cellular manufacturing and lean production planning and control techniques. With that said, this research is believed to be a valuable addition to the field of lean as it tries to address how SMEs can adopt cellular manufacturing and lean production planning and control techniques into their production.

1.2 Purpose and research questions (RQ)

The purpose of this research is to get a deeper understanding of how cellular manufacturing and lean production planning and control impact production flow efficiency in a SME. The main focus will be about studying how cellular U-layout and the techniques of lean production planning and control, pull, takt time and heijunka, are impacting the production flow efficiency.

According to previous research the layout design has an influence on the overall production flow performance (Domingo et al. 2007). This is further stressed by Santos et al. (2014) where they state that a sign for a layout change is when companies are having problems with their production flow. The layout defines the path that a product can take through the plant (Black, 2007). Therefore, plant layout directly affects the efficiency of the production (Ab Rashid et al. 2015). If there are obstacles in the path of the product, the flow will not be as efficient as it can be. Those obstacles are called waste in lean methodology and one of the causes of waste is poor layout (AlukaJ, 2003). As this report focuses on the lean methodology, a layout that supports lean is going to be studied.

According to Pattanaik & Sharma (2009), cellular layout helps to achieve many of the lean methodology objectives such as eliminating non-value activities like waiting times, bottlenecks, transport and WIP. However, an interesting aspect of cellular manufacturing is how that can improve the flow efficiency in SME. Thus, in order to find ways to make the production flow more efficient, cellular manufacturing needs to be studied further in relation to flow. With that said, the first research question will be seeked out to be resolved:

- *RQ1: How does cellular layout impact the production flow efficiency in a SME?*

According to Dorota Rymaszewska (2014), creating efficient production flow for SMEs can be really challenging because of the little control they have on the supply chain. Due to that, balancing the waste of unevenness, which is the result of irregular production schedule or production volumes fluctuations, becomes even more challenging for SMEs than for larger organizations (Liker, 2004). In order to balance the irregular production schedule or production volumes, the concepts of production planning and control are important to use (Jonsson & Mattsson, 2009). Richert (2002) further states that production planning and control need to be in place so that materials are not purchased to early nor too late and defects are detected early. Since the main objective with creating continuous flow is about keeping parts and components moving through the production process without a pause, the planning and control need to be in place so that the pause will not occur (Richert, 2002). When planning and control are studied in regards to the lean methodology, the main techniques are pull, takt time and heijunka (Slomp et al., 2009). Therefore, in order to understand how a production flow in relation to lean production planning can be made more efficient in SMEs, the second research question was created and will be seeked out to be resolved:

- *RQ2: How does pull, takt time and heijunka, impact the production flow efficiency in a SME?*

1.3 Scope and limitations

This research is about investigating the in-house production flow in a single SME where the focus will be on studying the flow for one product family and therefore, other products will be excluded. The focus will be on studying how the lean techniques regarding cellular layout and lean production planning and control (pull, takt time and heijunka) impact the flow efficiency and therefore, other lean techniques that might affect the flow will not be considered.

1.4 Outline

This section provides the structure of this thesis and brief description of the content in each chapter. *The first chapter* explains the background and the scope of this master thesis followed by the purpose and the formulated research questions that are seeked out to be resolved. *The second chapter* explains and presents the theoretical framework of the relevant topics of this master thesis. The theory will describe the topic of cellular manufacturing and how it is connected to SMEs as well as a detailed description of the steps of cellular layout design. The theory will also describe the topic of lean production planning and control where the focus is on the three methods, pull, takt time and heijunka. *Chapter three* will then present the research methods that was used in order to fulfill the purpose of this master thesis by describing the general research strategy, the research design, the literature review, the different data collection methods, the data analysis and lastly how reliability, validity, and ethical considerations were addressed. *The fourth chapter* will then present the empirical data that was collected in this master thesis, the company's production and products, their production flow, their current production layout and lastly, their current planning and control techniques. *The fifth chapter* will present the analysis that was performed in this master thesis both in relation to the design and the implementation of cellular manufacturing and how it impacts the production flow as well as the analysis and the design of the lean production planning and control and how it impacts the production flow. T*he sixth chapter* will present the discussions about the findings of this research along with findings that were out of the scope relation to lean and SMEs. Lastly, *the seventh chapter* will present the conclusions of this master thesis.

2 Theory

This chapter will present the theoretical framework of the relevant topics of this master thesis. The first section explains cellular manufacturing that is then followed by sub chapters explaining the types of layout options, the benefits and challenges of cellular manufacturing, cellular manufacturing in SMEs and lastly the steps of a cell design. The second section explains lean production planning and control where the focus is on the three methods, pull, takt time and heijunka.

2.1 Cellular manufacturing

Cellular manufacturing is an application of a methodology called group technology (Onwubolu, 1998; Wemmerlöv & Hyer, 1989), which was developed in the 1940's by Russian called Mitrofanow (Drolet et al., 1996). The idea behind group technology is to decompose a manufacturing system into subsystems in order to improve its efficiency (Angra et al. 2008). Cellular manufacturing is based on creating manufacturing cells, which can either be machines or workstations, by grouping produced parts or products together into families depending on the required process for the product. The cells are then physically grouped together and dedicated to produce that part or product family (Balakrishnan & Cheng, 2007). According to Balakrishnan & Cheng (2007) and Yi-xin et al. (2014), cellular manufacturing is said to combine the advantages of a process layout and product layout. Therefore, the next chapter will go into more detail of the different types of layout options and what has to be taken into consideration when choosing a layout.

2.1.1 Types of layout

There are four main types of layout, *fixed product layout*, *process layout*, *product layout* and *cellular layout* (Drira et al., 2007). According to Drira et al. (2007), what layout you choose depends on product variety and production volumes. Choosing a layout is also affected by the strategic objectives of the operation but general factors that are also relevant to all operations and help decide layout design are: inherent safety, length of flow, clarity of flow, staff conditions, management coordination, accessibility, use of space and long term flexibility (Slack et al., 2010). According to Hill & Hill (2012), the objective with a layout is to arrange the delivery systems, processes, equipment, work areas, storage areas and staff to make a product with those resources as effective and efficient as possible.

When volume is low and product variety is high the *fixed product layout* is appropriate (Drira et al., 2007), see figure 1. This layout is often found in industries where there are large sized products, such as ships or aircrafts where the product does not move, but the resources move to perform the operation on the product (Drira et al., 2007; Hill & Hill, 2012). When volume and product variety is both high, *process layout* is appropriate (Drira et al., 2007), see figure 2. Process layout or functional layout is when similar processes or functions are grouped together and it can be used both for special and standard services or products (Hill & Hill, 2012). However, when volumes are high and product variety is low, *product layout* is used (Drira et al., 2007), see figure 3. Then facilities are organized by sequence of manufacturing operations and an example for service or product layout is self-service restaurant or automobile assembly (Hill & Hill, 2012). Lastly, when volume and product variety are both medium *cellular layout* is appropriate (Bulgak & Bektas, 2009), see figure 4. Cellular layout is where machines are grouped into cells to process product families of similar parts (Drira et al., 2007).

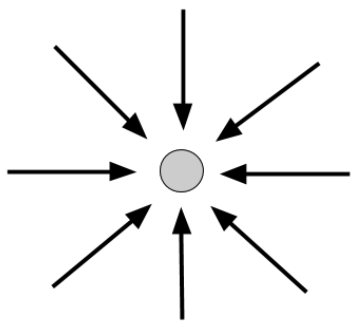

Figure 1: Fixed position layout (Slack et al., 2013)

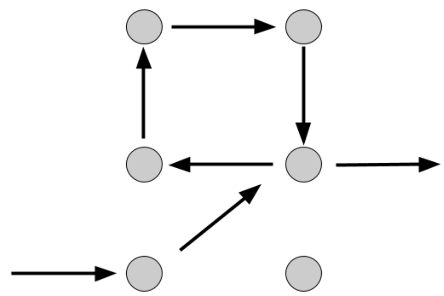

Figure 2: Process layout (Slack et al., 2013)

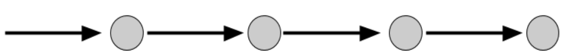

Figure 3: Product layout (Slack et al., 2013)

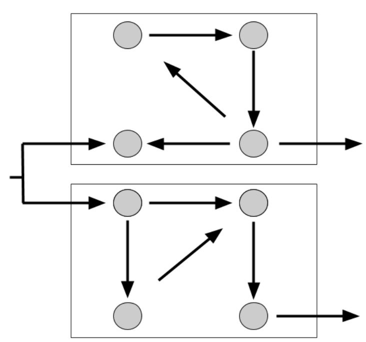

Figure 4: Cell layout (Slack et al., 2013)

2.1.2 Benefits of cellular manufacturing

Cellular manufacturing reduces cycle times if it is compared to a process layout and it increases flexibility if it is compared to a product layout (Balakrishnan & Cheng, 2007). In a process layout, similar machines are kept together, but in a cell layout, the layout is based on products, where product families are grouped together (Suresh & Meredith, 1985). In process layouts, queuing times are high, and often nearly as high as the cycle time, which affects the total throughput time (Suresh & Meredith, 1985). With cellular manufacturing on the other hand, the throughput time is more or less equal to the cycle time, depending on the degree of overlap of operations in the cell. Overlap is easy to accomplish due to the fact that machines or processes in cells are more or less very close to each other (Suresh & Meredith, 1985). By having such predictable throughput times the production can be performed just prior to the date of need. Hence, the lead times also become more predictable, which is the opposite to the process layout where delivery promises are given well in advance and include safety lead time and forecast errors etc., (Suresh & Meredith, 1985). By reducing the throughput time, WIP inventories go down that further make floor space and the working capital requirements decrease and increases the shop floor visibility (Suresh & Meredith, 1985). Wemmerlov & Johnson (1997) further strengthen that, as the benefits identified in their study of 46 plants implementing cellular manufacturing were: reduced throughput time, reduced WIP inventory, increased product quality, increased response time to customer order and reduced move distances. Further, Suresh & Meredith (1985) explain that in process layouts various operations for a given product are performed in different work centers and therefore, there is an operations wise division of responsibility. If we compare that to cellular manufacturing, all operations occur in a single cell and therefore, the control over jobs are simpler. Hence, complexity and expediting problems of process layouts are reduced drastically where paperwork is unnecessary, items can be traced quickly and inventory records are more accurate in cellular layout (Suresh & Meredith, 1985). Thus, converting a process layout to a cellular layout would allow batch size reduction without corresponding increases in machine capacity, material handling, production control, scheduling, and information system capacity. In fact, the use of cells may result in less need for these systems, even though batch sizes are reduced (Johnson, 2003).

In product layouts, the flow in the production is smooth and logical which results in low WIP inventory, short cycle time, low materials handling cost, low labour skill requirements and simple production planning and control (Abdul-Hamid et al., 1999). These benefits are very similar to the cellular layout where Wemmerlöv & Hyer (1989) and Singh (1993) say that cellular manufacturing lowers material and tool handling, simplifies planning, reduces setup times and reduces WIP. Product layouts on the other hand lack flexibility because of the specialty of machines and material handling equipment. Due to that specialty it only provides an efficient process solution for the specific product or product family to whom it is dedicated to (Miyake, 2006). The layout requires further a high level of capital investment to be set up and introducing new products or make substantial changes is difficult (Abdul-Hamid et al., 1999). The cellular manufacturing however is a building block for flexible manufacturing systems (Onwubolu, 1998). Abdul-Hamid et al. (1999) further explains that by stating that cellular layout covers all the four types of flexibility, which are wide range of products, design changes, changes in capacity and process flexibility. The wide range of products flexibility factor represents the ability to manufacture a wide range of different types of product, with different processing requirements. The design changes flexibility factor represents the ability to accommodate design changes for the manufactured products (Abdul-Hamid et al., 1999). The changes in capacity flexibility factor measure the ability of the plant to operate profitably at different production volumes. And lastly, the process flexibility factor is the ability to change products within a given mix and with low set-up times (Abdul-Hamid et al., 1999). They state that not many layouts can achieve process flexibility but cellular layout can, because of the short setup time required (Abdul-Hamid et al., 1999). This is further stressed by Miyake (2006), where he stresses that increased flexibility, responsiveness and the opportunity to improve the workers morale and motivation is the main reasons why manufacturers are motivated to embrace the cellular layout over the product layout. However, to obtain flexibility it is recommended to have an interconnected flow and one piece flow (Suciu et al., 2011).

2.1.3 Challenges of cellular manufacturing

Regardless of the benefits of cellular manufacturing, there has been reluctance amongst industry to adopt cellular manufacturing principles (Baker & Maropoulos, 2000). Where Greene & Sadowski (1984) describe that there are two main disadvantages with cellular manufacturing, increased capital investment and lower machine utilization. The reason for increased capital investment is because a cell system requires the machines to be divided into specialized cells where each cell must contain all machines necessary to produce the parts assigned to that cell (Greene & Sadowski, 1984). If two operations require the same machine, there needs to be two machines bought for each cell. This means that machines are added to prevent crossing from cell boundaries, which increase capital invested (Greene & Sadowski, 1984). The reason for lower machine utilization is also because of the number of machines needed in a cell layout, if compared to process layout, then average machine utilization is typically lower (Balakrishnan & Cheng, 2007). The lower machine utilization is also due to the fact that cells are usually designed with the maximum amount of flexibility possible to handle the maximum number of different parts types (Greene & Sadowski, 1984). Where the flexibility is one of the critical dimensions of enhancing the competitiveness of organizations (Askin et al., 1997). However, when the part mix changes over a period of time, there can become imbalance in cell loading which creates imbalance in cell utilization and machine utilization (Greene & Sadowski, 1984). Askin et al. (1997) further states that unstable machine utilization due to dynamic and random variation in part demand can be major difficulty with cell systems. However, as described above, cellular manufacturing has advantages and disadvantages and because of the disadvantages some firms have avoided implementing cellular manufacturing. But, most of the disadvantages result from improper initial cell design and configuration (Greene & Sadowski, 1984). Therefore, the design of the cell is an extremely important issue in order for the cell system to be flexible (Askin et al., 1997). These design techniques will be described in chapter 2.1.5.

2.1.4 Cellular manufacturing in SMEs

Cellular manufacturing is an approach that both can enhance flexibility and efficiency in today's small to medium lot production environments (Wu et al., 2007). It has for many years been promoted as the preferred way of arranging resources in a shop floor, but according to Boughton & Arokiam (2000), SMEs often do not have the same requirements, knowledge and expertise necessary to adopt cellular manufacturing as larger enterprises. They further stress that the risks of moving to cellular manufacturing are greater when there is no clear focus about what needs to be done and how it can be reached and therefore, the concept of cellular manufacturing in SME needs to be considered differently (Boughton & Arokiam, 2000). Cellular manufacturing for example does not always need to physically separate operations into cells, it can also be constrained by practical, technical and organisational factors (Subash Babu et al., 2000).

Boughton & Arokiam (2000) did a study within the UK SME community and defined benefits and barriers of SME and cellular manufacturing. They identified that the benefits of cellular manufacturing in SME were reduction in throughput time, reduction in changeover time, reduction in WIP, improved quality and improved job satisfaction. Overall planning and control operation was also more straightforward in cellular environment than former arrangement. All of these benefits are further stressed by Collett & Spicer (1995) that conducted study at small manufacturing company that implemented cellular manufacturing, and identified the same benefits as previously stated. On the other hand, the barriers of using cellular manufacturing in SME according to Boughton & Arokiam (2000), were lack of sufficient space, disruption to production, duplication of resources, introduction of new products, sharing of key resources, difficulty of moving machines, under utilization of resources and demand variability (Boughton & Arokiam, 2000). When moving from existing manufacturing system to cellular manufacturing system there is always going to be disturbance to existing production and SME's have concerns about that because of their high delivery schedules and problems meeting demand. Introduction of new products was also a concern of SME's because changes in product may cause cell to become redundant (Boughton & Arokiam, 2000). These results show that using cellular manufacturing in SMEs gives really similar benefits and barriers as to the larger enterprises. The required knowledge and resources needed to implement it is on the other hand a bigger challenge for SMEs than it is for larger enterprises.

2.1.5 Cell design

The design of a cellular manufacturing system includes four steps: *cell formation, group layout, group scheduling* and *resource allocation* (Wu et al., 2007), see figure 5. According to Kandiller (1994), *cell formation* is the first step when designing a cellular manufacturing system. Cell formation includes grouping parts with similar processing requirements into part families and associated machines into cells (Wu et al., 2007;

Kandiller, 1994). The decisions taken in this first stage, presides over all other decisions involved in the design process (Kandiller, 1994). The second stage is the *group layout*, which includes both positioning the cells themselves (inter-cell layout) and the workstations within the cell's (intra-cell layout) to reach optimal flow of parts (Baker & Maropoulos, 2000; Wu et al., 2007). Further, Black & Hunter (2003) describe that standardized step in cell design are important since it provides framework for performing work at designed takt time that are determined to be the best way to perform a task. Also, standardized work helps identifying and making improvements in work procedures and maintains a smooth flow of work (Black & Hunter, 2003). According to Wu et al. (2007), the third stage is then *group scheduling,* which includes scheduling parts and part families for production. Greene & Sadowski (1983) further describe it as internal control of the jobs within each cell where they explain scheduling as “the determination of the order of the jobs onto each machine and the determination of the precise start time and completion time of each job on each machine” (Greene & Sadowski, 1983, p. 138). Lastly, the final stage in designing a cellular manufacturing system is the *resource allocation* stage, which is about assigning the resources to the right place, tools, personnel and materials (Wu et al., 2007). In doing so it is important to eliminate waste so the cell will be designed to utilize people and all assets fully (Black & Hunter, 2003) .

Figure 5: Cell design process

According to Wemmerlöv & Hyer (1986), designing a cellular system is a complex undertaking that involves both the manufacturing system as well as related support systems. The difficulties of cell design are normally seen as identifying the part or product types that are suitable to manufacture together (Singh, 1993). With that said, converting an entire production into a production cells is not always possible as the parts that cannot be associated with a specific product family should not be placed in a specific cell (Green & Sadowski, 1984). However, according to Singh (1993), there are number of other issues that have to be taken into consideration when designing a cell. These issues are the type of material handling equipment, the level of the cell flexibility and the cell layout. Further, Singh stresses the importance of making the cell compatible with the operational goals such as high production rate, low WIP or high machine utilization. With that said, the material handling inside a cell can be performed in several different ways. Light products are usually transferred manually from one workstation to the next while larger products are usually placed on mobile carts that are easily transferred from one workstation to the next (Miyake, 2006). For the level of machine flexibility, restrictions on number of part types or machine types can be constraints in the cell design (Singh, 1993). Then lastly, the cell layout that is normally described being used in lean production systems, is the U-shaped layout (Miltenburg, 2001). Then, machines, workstations and employees are moved into U-shaped configuration in which the production operations are performed (Miltenburg, 2001). Various U-shaped cell systems with different characteristics on how to organize and manage a cell have been designed, where the cells can either be manned (low degree of automation) or unmanned (high degree of automation) and either dependent on other cells within the factory or independant (Wemmerlöv & Hyer, 1989). Creating an independent cell is often a common goal for companies, but it is not always economical or practical to try to achieve that level of independence (Wemmerlöv & Hyer, 1987). For the manned cells, either a single operator or a team of operations perform the task of the cell (Miyake, 2006), see figure 6 and 7. The operator(s) then either stands still or moves to perform the assigned tasks, where the most applied cell systems within the production industry, are the sub cell, shared cell, rabbit chase and expand rabbit chase (Pan, 2014).

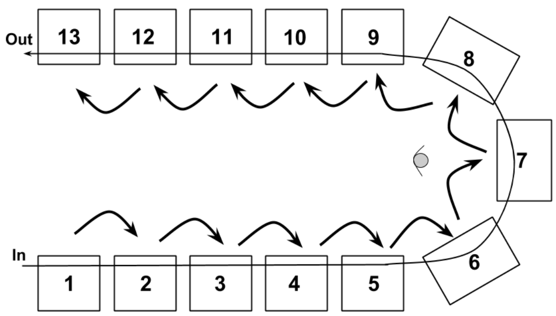

Figure 6: Single worker (Miyake, 2006)

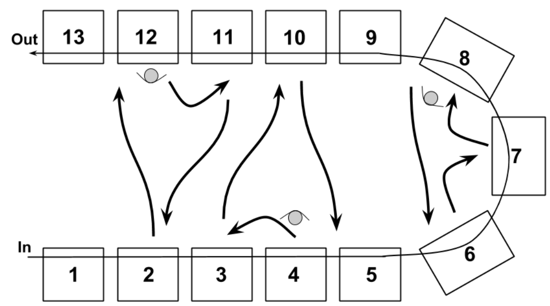

Figure 7: Distributed (Miyake, 2006)

According to Pan (2014), the sub cell and the shared cell systems are about dividing the production cell into several smaller units, which collaborate with each other to finish the tasks of the production process, see figure 8 and 9. For the sub cell, the operators are only responsible for the work within their unit of the cell and between each unit there is a buffer area that is used to reduce the losses when the production is not in balance. For shared cell on the other hand, the operators are responsible for the work in their unit. Instead of the WIP handover only being within a buffer area, between each unit, the operators can hand over the WIP at an intersection point, depending whether the neighboring operator is busy or not, that is both inside and outside of their unit. However, eventually there is a buffer area that they cannot cross, to hand over WIP. Therefore, the operator's competence level and knowledge of the process tasks is higher in a shared cell system then in a sub cell system. These systems both have the possibility of using separate operators standing still on different units within the cell or use multifunction walking operators that can cover few stations of the cell at a time, for example operator one could be responsible for work stations 1, 2,12 and 13 , depending on the required output of the cell (Black & Schroer, 1993).

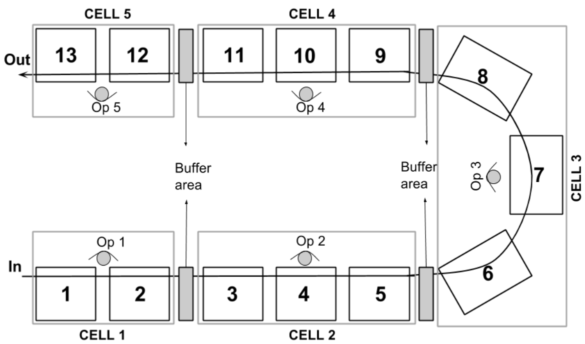

Figure 8: Sub cell (Pan, 2014)

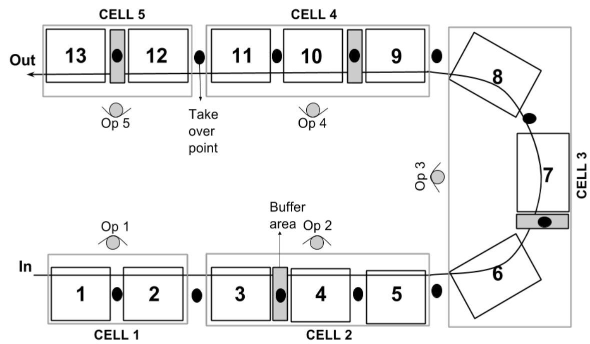

Figure 9: Shared cell (Pan, 2014)

The other two cell systems, the rabbit chase and the expanded rabbit chase cell systems, are the opposite of the former two since they have one production cell that the operators share, see figure 10 and 11 (Pan, 2014). In a rabbit chase cell, the operators are responsible to produce one product from start to finish in the correct sequence and therefore they have to be proficient on all the workstations within the cell (Pan, 2014; Black & Schroer, 1993). In an expanded rabbit chase cell on the other hand, the operators share the cell, but instead of producing one product from start to finish, there are few operators working the cell where the operator's hands over WIP to the next operator when he is available. Therefore, the stations that each operator has to cover can vary a lot from product to product as hand-over of WIP is possible at any station within the cell. In other words the expanded rabbit chase cell is a self-balancing system (Pan, 2014). These systems eliminate the need of a precise line balancing analysis for the stations within the cells which is on the other hand necessary for the sub and shared cell systems. Further, there are no buffer areas between stations in the rabbit chasing and the expended rabbit chase system that leads to no extra WIP building up within these cell systems (Pan, 2014). Instead, there is a problem of faster workers catching up to slower workers, which leads to the possibility of series being formed and therefore, the output of the cell being dictated by the slowest worker (Black & Schroer, 1993).

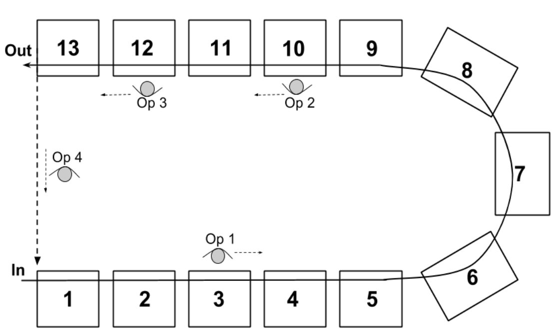

Figure 10: Rabbit chase (Pan, 2014)

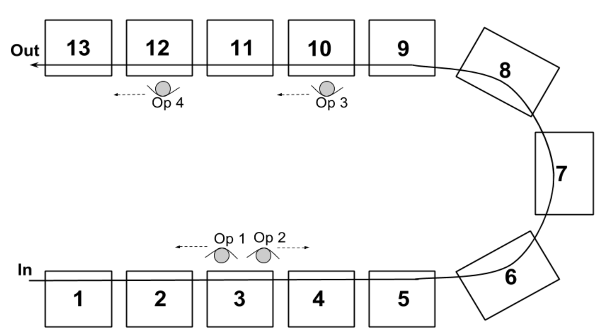

Figure 11: Expanded rabbit chase (Pan, 2014)

2.2 Lean production planning and control

Production planning and control concepts are important techniques to use in today's competitive environment in order to meet the customer demands and expectations (Stevenson et al., 2005). The main objectives with production planning and control concepts are to reduce WIP, minimize throughput times and lead times, lower inventories, improve responsiveness to changes in demand and improve delivery performance. Therefore, choosing the right production planning and control system is a crucial decision (Stevenson et al., 2005). However, due to SMEs having little control of the supply chain, using these concepts can often become challenging (Dorota Rymaszewska, 2014). Further, Persona et al. (2004) state that SMEs often do not have the resources (capital, manpower and time) to invest in these concepts. However, the implementation of lean principles and practices can be equally applicable for SMEs as well as large enterprises if adopted correctly to the company (Matt & Rauch, 2013) Therefore, the implementation of the lean production planning and control techniques has been popular, where three techniques have shown to be successful in identifying and eliminating sources of variability in the production system (Slomp et al., 2009). These techniques are *pull system*, *takt time* and *heijunka* (Slomp et al., 2009). This is further stressed by Bokhorst and Slomp (2010) where they talk about that the constraints of the pull and takt time techniques provide the drive to reduce the variability in the production system as well as help simplify the control of the system.

2.2.1 Pull system

Creating flow is one of the main focus of lean production (Hancock & Zayko, 1998; Rother & Shook, 2003; Rose et al., 2011). According to Liker & Meier (2006), there are different ways of achieving flow or some degree of flow, where they mention the traditional batch and queue flow, push, supermarket pull (kanban), sequenced pull, FIFO sequenced flow and continuous flow which is the ideal state of lean, see figure 12. Developing continuous flow refers to only producing one piece at a time, with each item passed immediately from one process step to the next without waste in between (Rother & Shook, 2003).

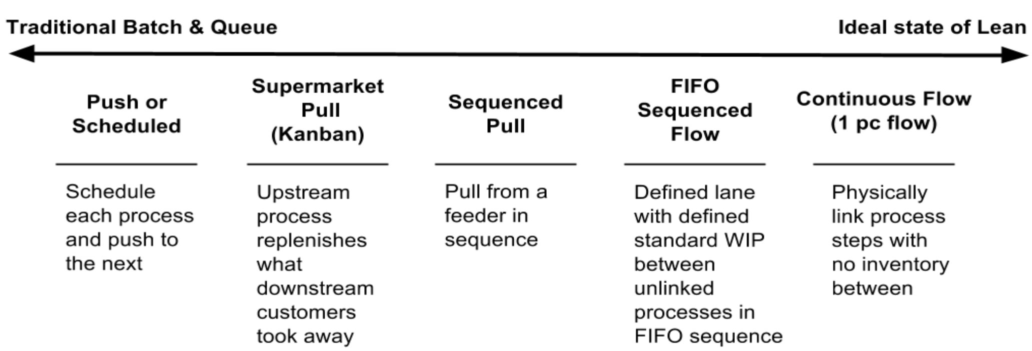

Figure 12: Continuum of flow (Liker & Meier, 2006)

Rother & Shook (2003) state that achieving continuous flow is not always possible and therefore it should only be implemented in the value chain where it is possible. The reason for that is because firstly, some processes are designed to operate at very fast or slow cycle times and need to change over to serve multiple product families. Secondly, some processes are far away and shipping one piece at a time is not realistic, and lastly some processes have too much lead time or are too unreliable to couple directly to other processes in a continuous flow (Rother & Shook, 2003). This is further stressed by Liker & Meier (2006) where they state that achieving continuous flow or single-piece flow is extremely difficult and will never be possible in many situations due to it requirement of a highly refined processes.

When continuous flow cannot be achieved, placing a pull system between processes is a method to keep control of the system (Rother & Shook, 2003). Pull system is characterized by the practice of downstream processes pulling products from previous processes as needed and therefore all processes only perform work to replenish outgoing products (Spearman & Zazanis, 1992). The purpose of placing a pull system between two processes is to give accurate production instructions to the upstream process and avoid predicting downstream demand and scheduling the upstream process. Hence, controlling production between flows (Rother & Shook, 2003). The goal of the pull system is to align the entire production to the desired output and only spend resource on producing what is valued by the customer (Janes & Succi, 2009). However, before deciding to use pull system, continuous flow must have been introduced first to as many process steps as possible (Rother & Shook, 2003).

Kanban (Supermarket pull)

Pull systems can take on many forms to suit different types of circumstances, but all of them have one thing in common and that is about releases of production instructions, as they are adjusted according to the internal system status to prevent inventory from growing beyond specified limit (Hopp & Spearman, 2004). The most known pull system is the kanban system (supermarket pull) (Spearman et al., 1990). Kanban system is an information system that controls the production. It controls the necessary products in the necessary quantities at the necessary time in every process of a factory (Monden, 2011). According to Matzka et al. (2012), a kanban system can either be a two card or one card. The classical version of kanban is called two card kanban system (Hopp & Spearman, 2004), see figure 13. Then every component type and part has a special container designed to hold a specific (preferably small) quantity (Schonberger, 1983). There are two cards and two containers and the cards are placed in the container with information about the part number, container capacity and other relevant information. The two kanban cards are called “production kanban” and “withdrawal kanban”, where the first one serves the work center producing the part number and the latter one serves the work center using it (Schonberger, 1983). Production begins when the material handler, with a withdrawal card, removes a container from the inbound stock. The withdrawal card tells the handler where the parts are needed. The production card is then removed from the container and placed on the production cardboard, which tells the worker that the production can begin. When the worker takes the first component out of the container, he removes the withdrawal card from the container and places it where the cards are stored and then keeps on processing the parts. The material handler collects the withdrawal cards regularly and the process repeats (Hopp & Spearman, 2004). According to Rother & Shook (2003), the customer process goes to the supermarket and withdraws what is needed when it is needed but the supplier process produces to replenish what was withdrawn. Therefore, a production kanban triggers production of parts while a withdrawal kanban is a shopping list that instructs the material handler to get and transfer parts (Rother & Shook, 2003). The dual card kanban system suits well for manufactures that are not prepared to adopt strict control rules to the buffer inventory. However, five conditions are essential for two card kanbans systems and they are: moderate distance between two stages, fast turnover of Kanbans, some WIP in a buffer is needed, external buffer to the production system and synchronization between the production rate and speed of material handling (Huang & Kusiak, 1996).

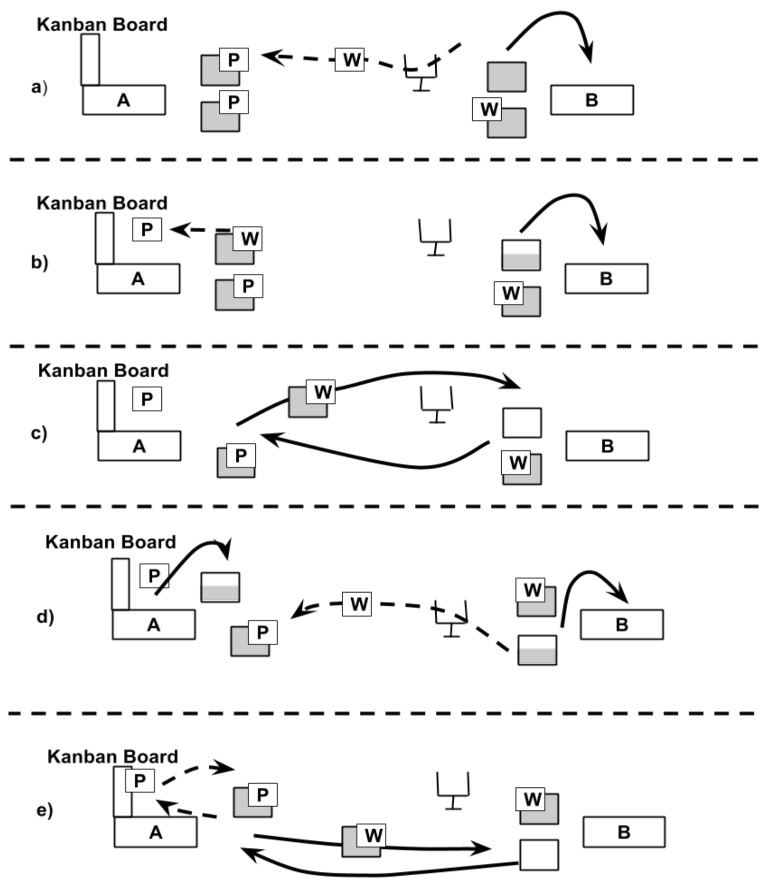

Figure 13: Two card kanban (Adapdet from Wånström, 2015)

With the one card kanban system, there is no distinctions made between the two kanban cards like in a dual card system and therefore, only one is used (Matzka et al., 2012), see figure 14. According to Schonberger (1983) companies can start by implementing a one card kanban system and then add the production kanban later, if that seems beneficial. Schonberger (1983) describes the single card kanban as a system where standard containers are used, where the quantity per container is exact, so that inventory is easy to count and control. The number of full containers at the production place should be determined by the management with the goal to have as few as possible since too many creates too much inventory in the system (Schonberger, 1983). He also states that the parts included in the kanban system should be used every day since the maximum capacity of containers for one part number should not exceed 1/10 of day's usage. The quantity in the container should also be small so that at least one container is used up daily (Schonberger, 1983). Further, there are five essential requirements for having a one card kanban system and those are: small distance between any two subsequent stages, fast turnover of Kanbans, low WIP, small buffer space and fast turnover of WIP and synchronization between the production rate and speed of material handling (Huang & Kusiak, 1996).

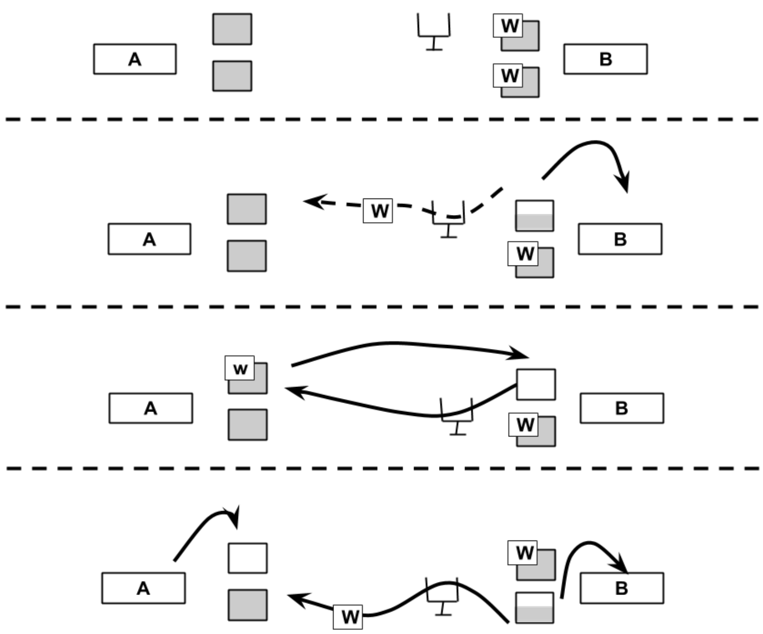

Figure 14: One card kanban (Adapted from Wånström, 2015)

Sequenced pull and FIFO

In some cases, it is not practical to keep inventory of all possible part variation between two processes in a pull system as is needed in kanban system. Examples of situations that an inventory between processes are not suitable are when custom parts are produced where each part produced is unique, when parts that have a short shelf life or when costly parts are produced that are used infrequently. Then, sequence pull or a FIFO ("first in, first out") lane between two decoupled processes can be used to maintain a flow between the processes (Rother & Shook, 2003). Sequenced pull means that the supply process produces a fixed quantity in a fixed sequence from the downstream shop directly in front of an order from the customer process (Rother & Shook, 2003; Di Micco et al., 2008). FIFO lane is however, when a specific quantity of inventory is located between supply process and customer process, see figure 15. The specified quantity has a defined maximum amount and when that is reached, the production of the supply process stops until the customer process consumes material (Araújo & Alves, 2012). They also describe that FIFO is a way of controlling the WIP because the production needs to stop and therefore cannot overproduce. Furthermore, they discovered that this type of pull system can be successful if the process has different cycle times and instability. The FIFO line approach can also be referred to as the CONWIP approach (Rother & Shook, 2003).

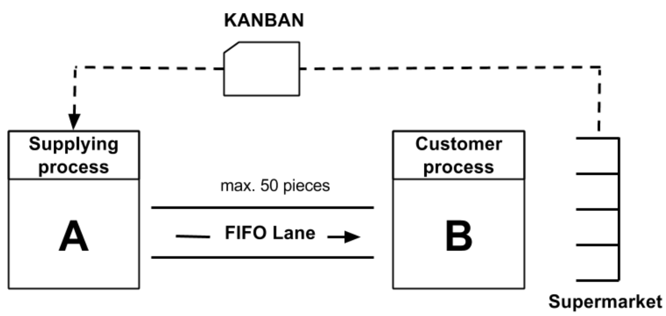

Figure 15: FIFO lane (Adopted from Rother & Shook, 2003)

2.2.2 Takt time

Takt time is a concept that is used for designing work and is one of the prerequisite needed to create continuous flow (Liker & Meier, 2006). Takt time is the pace that is equivalent to the rate at which a customer requires a product and therefore it defines the ideal pace of a production process to keep up with the customer demand (Slomp et al., 2009; Bertoncelj & Kavcic, 2012; Schneider et al., 2015). In many cases, the customer requirements are not clearly defined and therefore, identifying them is one of the first tasks when adopting lean along with making the process stable. Womack & Jones (1996) determine takt time as dividing the *amount of available production time in that given period* into the *numbers of customer orders in a given period*. In order to get the available production time, which is the actual operational availability, all breaks are subtracted from the total production time (Bertoncelj & Kavcic, 2012). The customer demand on the other hand, is the average customer demand over a given period (Bertoncelj & Kavcic, 2012).

Takt time control can be used in many different kinds of volume-variety environments, but it is mainly used in high volume production environments, where product variety is usually limited (Bokhorst & Slomp, 2008; Bokhorst & Slomp, 2010). Then, the operations are divided into steps which all have to produce according to takt time (Bokhorst & Slomp, 2008). The WIP is fixed and equals the number of steps found in the process, where each step contains one job that is transferred to the next station after each takt (Bokhorst & Slomp, 2008). Many companies on the other hand are working within the low volume high product variety environment, where different products have different customer demand rates and require different process steps (Slomp et al., 2009). All of these different products are being produced within the same production system that makes the implementation of takt time more complicated but still highly applicable (Slomp et al., 2009). In these type of environments Slomp et al. (2009) proposes that the whole or parts of the production system should be seen as a one production unit where products arrive and leave the unit according to the takt time, which he refers to as generalized takt time control, see figure 16. That is, the output of the production unit is takt time driven, whereas the internal production processes are not (Bokhorst & Slomp, 2008). Further, many companies experience fluctuations in customer needs that leads to constant changes of the takt time (Bertoncelj & Kavcic, 2012). This leads to the importance of designing or making the production process adaptable enough to enable those changes of demand (Bertoncelj & Kavcic, 2012).

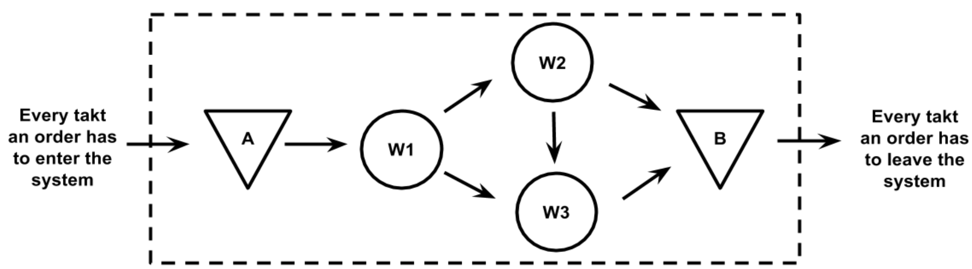

Figure 16: Generalized takt time control (Slomp et al., 2009)

Establishing takt time is critical in avoiding the natural tendency to produce too fast and build up inventories (Womack & Jones, 1996). This is further stressed by Slomp et al. (2009) where they state that takt time helps keeping inventory build ups at minimum. It also makes the production more predictable and improves the control that organization have on their production system. Introducing takt time, will further help achieve flow of a product by casing all of it process steps to be grouped and balanced to the calculated takt time (Pattanaik & Sharma, 2009). If the cycle time of the process steps then exceeds the takt time, the inability of the process to meet the customer demand is easily revealed (Schneder et al. 2015). These process steps are bottleneck stations of the process and should be prioritised improvement initiatives (Sane et al., 2014). On the other hand, if a process is improved beyond the actual customer need, either resource can be reduced or additional sales can be pursued by the organization (Liker & Meier, 2006). In other words, if the rate of the production is faster than the takt, job buffers will increase and build up excess inventories that are considered as waste. Further, when the cycle time is faster than the takt time the risk of overproducing increases (Nutti & Lindström, 2008). This type of overcapacity also often leads to production problems being hidden (Nutti & Lindström, 2008). However, if the rate of the production is higher than the takt, the process is unable to deliver and fulfill the customer need (Yassine et al., 2014).

2.2.3 Heijunka (Leveling)

Heijunka is a production planning method (Coleman & Vaghefi, 1994). Heijunka plays an essential role in lean methodology and is also referred to as production smoothing or leveling the production schedule (Hüttmeir et al., 2009). According to Coleman & Vaghefi (1994), heijunka is not only about mixing the production model to match the demand, it is also about the concepts of leveling and line balancing. Leveling describes the effort to balance the workload to the capacity of the process and line balancing attempts to balance the workloads at each process to each other (Coleman & Vaghefi, 1994). Lippolt & Furmans (2008) further describe heijunka as the notion to level a production system by removing ups and downs in volume caused by batch processing and customer order fluctuation in order to reach a constant flow of parts, see figure 17.

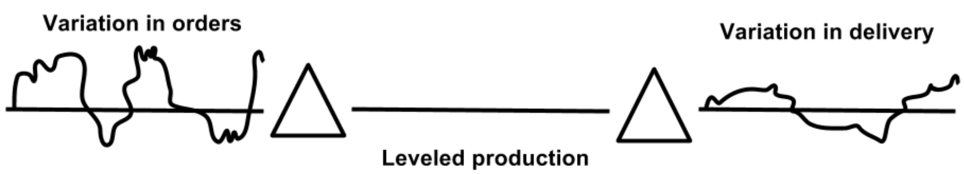

Figure 17: Leveled production (Adapted from Wänström, 2015)

The aim of levelling is to reduce the customer order variability and that can be done by analyzing the orders in a given time period resulting in a pattern which can be fitted to smaller time schedule. Customer orders may seem arriving constantly in the long run but in a short period of time, they are often inconsistent and unpredictable (Lippolt & Furmans, 2008). Those inconsistent environments causes hidden problems and poor quality because of the unbalance use of resources and the uneven demand on the upstream processes will cause the bullwhip effect (Matzka et al., 2012). Further, levelling creates a constant flow of parts and reduces the need for spare capacity (Lippolt & Furmans, 2008). Therefore, the two main goals of heijunka is to supply one or more customer processes with a constant flow of small lots while generating constant demand of parts for upstream processes and to reduce the bullwhip effect (Matzka et al., 2012). That is also connected to what Liker & Meier (2006) describe about what heijunka is, one of the lean tools to make the processes stable in the organization which is important because process stability is the first step of creating a lean process. Heijunka advantages are therefore, reduction in overall inventories, reduction of required productive capacity and reduction of lead times to the customer (Coleman & Vaghefi, 1994). Hence, the final result is then a "production sequence with a continuous flow adjusted to the customer demand and leading to an even utilization of the production stages" (Lippolt & Furmans, 2008, p. 13).

In order to perform heijunka and produce what the customer needs, Matzka et al. (2012) explains that the company needs to adapt their production quantity and produce to takt time (see chapter 2.2.2). Heijunka also requires an effective quality system since the employees are constantly switching from one product to another and then defects and time losses due to errors in work motions is a concern that needs to be taken into account. Parts must be supplied to the assembly process in a very small lot without delays and therefore, heijunka needs a kanban system to supply the needed parts at an appropriate time (see chapter 2.2.1) (Coleman & Vaghefi, 1994). Lastly, heijunka requires setup between items to be extremely simple and quick because otherwise the production would be inefficient because of the small-lot production sequence (Matzka et al., 2012; Coleman & Vaghefi, 1994).

Leveling the production volume and production mix

There are two phases of leveling, the leveling of the production volume and the leveling of the product mix (Lippolt & Furmans, 2008). When leveling the volume, both the type and the quantity of product variants that are produced in a shift needs to be specified. A data analysis of monthly order of each product variant is performed and the quantity of given leveling horizon (week, day, shift) per variant is divided by the number of available manufacturing shifts. By doing that, levelled outputs per shift of each variant and cycle times for all products have been found (Lippolt & Furmans, 2008). Rother & Shook (2003) explain that by levelling the production volume, initial pull is created by releasing and withdrawing small, consistent increments of work at the pacemaker process. They further describe why levelling the volume is important by describing the problems of having large batches. When there are large batches several problems can occur, firstly, there is no sense of takt time and no pull to which the value stream can respond to. Secondly, the volume of work typically occurs unevenly over time that causes extra burden on machines, people and inventories. Thirdly, the situation becomes difficult to monitor since the employees don't know if they are behind or ahead. Fourthly, large amount of work released to the shop floor which leads to increased lead time and finally responding to customer requirements becomes very complicated (Rother & Shook, 2003). Therefore, it is important to level the production volume and determine average demand in given time interval or EPEI (every-part-every-interval) which also indicates the capability of the production process (Lippolt & Furmans, 2008). The leveling needs to be adjusted when needed and continuous improvements are used with the aim of producing every-part every-shift (Lippolt & Furmans, 2008).

Leveling the product mix is however, done by using the same sequence of products for each production shift (Matzka et al., 2012). That means, instead of producing all of the

“Type A” product in the morning and all of the “Type B” production in the afternoon, small batches of products “A” and “B” are produced in an alternating way (Rother & Shook, 2003; Matzka et al., 2012). By leveling the production mix the production system is more able to respond to the different customer needs while still having little inventory of finished goods as well as smaller upstream buffers between processes (Rother & Shook, 2003; Matzka et al., 2012). If products are instead grouped together and produced all at once, it gets difficult to serve customers who want something else than the batch being currently produced (Rother & Shook, 2003). Also, then the bullwhip effect on upstream processes will not decrease as it does when leveling the production mix (Matzka et al., 2012). On the other hand, leveling the production mix, requires setup times between products to be extremely quick and simple (Rother & Shook, 2003; Matzka et al., 2012). Further, when leveling the mix, it is required to be utilizing multi-purpose machinery and equipment on the one hand as well as multi-skilled operators on the other hand (Bohnen et al., 2011).

Heijunka box

There are many ways to practically use heijunka by having paced withdrawal of small consistent quantities. One tool to help level both mix and volume of the production, is load-leveling box (or heijunka box) (Rother & Shook, 2003). The load-leveling box visually presents the leveled schedule (Liker & Burr, 1999). The box has a column of kanban slots for each pitch interval and a row of kanban slots for each product type. The box therefore, indicates both the quantity to be produced and how long it takes to be produced, based on takt time. Kanban are then placed into the leveling box in the desired mix sequence by product type (Rother & Shook, 2003), see figure 18. The material handler then, withdraws the cards at each time period, which sets the assembly schedule (Liker & Burr, 1999).

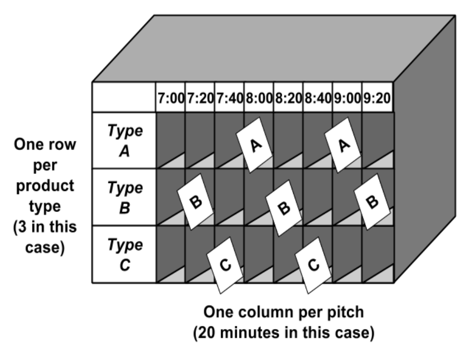

Figure 18: Load Leveling box (Rother & Shook, 2003)

3 Method

This chapter will present the research methods that were used in order to fulfill the purpose of this master thesis. The first section explains the general research strategy that is then followed by explanation of the chosen research design and the conducted literature review. The fourth and fifth section explains the different data collection and data analysis methods used in this study. Finally, two sections about how reliability and validity, and ethical considerations were addressed are presented.

3.1 Research strategy

The main research strategy used in this research was a qualitative strategy but some elements of a quantitative strategy were also used. Qualitative strategy was seen more applicable as the aim of this study was to get a deeper understanding of a specific situation. According to Bryman & Bell (2011) qualitative strategy is more suitable for research focusing on understanding the social world through examination of its participants. Also, qualitative strategy was seen more suitable for this study, in order to be able to fulfill the purpose and research questions. This research started with theory being collected about the subject before the empirical data was collected. Later, toward the middle of the research period, theory and empirical data were collected in an iterative way.

3.2 Case study

The research design used for this master thesis was a single case study design. A case study design allows you to make a detailed and intensive analysis of a single case (Brymann & Bell, 2011). It is a design that focuses on understanding the present dynamics within a single setting (Eisenhardt, 1989). However, case studies can both involve single or multiple cases as well as many levels of analysis (Yin, 2011). Further, Baxter & Jack (2008, p. 545) state “a case study design should be considered when (a) the focus of the study is to answer “how” and “why” questions; (b) you cannot manipulate the behavior of those involved in the study; (c) you want to cover contextual conditions because you believe they are relevant to the phenomenon under study; or (d) the boundaries are not clear between the phenomenon and context”. Since the research questions in this study aim to give a deeper understanding of a specific subject, a single case study approach was found to be appropriate.

For this research, the case study was designed around an organization named Milleteknik, which is a small sized organization working within the protective and security industry. Selecting a case to study is an important aspect, where the concept of population is very important as it defines the set of body from which the research sample is to be drawn (Eisenhardt, 1989). In this research the selected case had to be from a population of a small to medium sized corporations that were interested in lean manufacturing. Milleteknik is a good representative and fits well for this research as it is a Swedish SME with interest in implementing the lean methodology. Milleteknik has already started to implement some of the tools found in the lean toolbox and they have found those tools to be very successful in helping them to improve their operations. In order to succeed in the future, Milleteknik believes that their production flow performance needs to be improved. Therefore, they are interest to see how cellular manufacturing and lean production planning and control techniques can impact their production flow efficiency. When designing the cellular layout and the lean production planning and control, decisions where taken together with Milleteknik where the CEO, the production manager and one operator from the production where mostly involved.

3.3 Literature review

In order to get a thorough and deeper knowledge of the researched subject, a literature study was conducted. Reviewing existing literature shows the researcher what is already known within the area of interest and what concepts and theories are relevant to that area (Bryman & Bell, 2011). In the beginning of this research, the literature study was focused on researching production flows within lean to get a holistic view and an initial understanding of that area within lean. Then, the literature study was conducted within the field of cellular manufacturing and lean production planning and control in SMEs as the research was aimed at that specific area within lean. The literature study was performed in structural way where all potential literature was categorized into specific topics depending on the subject of the literature. This made it easier for the authors to keep track of the different references as well as to increase the variations of reference in order to get as many different points of views as possible.

Literature study can be performed in different ways but using electronic databases is the most popular (Bryman & Bell, 2011). In this research both electronic databases and public libraries were used to gather the different sources of literature. The electronic databases that were mainly used were Google Scholar and Chalmers Library where the keywords used to guide the study were: *SMEs, lean production, production flow efficiency*, *continuous flows, cellular manufacturing, cell layout, lean production planning and control, pull, kanban, takt time* and *heijunka.*

3.4 Data collection

Data collection is the key point of any research project and there are many different methods of data collection that exist. Data collection methods are used in order to answer the research questions (Bryman & Bell, 2015). In order to answer the two previous stated research questions, the data collection methods used in this research were interviews, observation, value stream mapping, time study, benchmarking and secondary data, see figure 19.

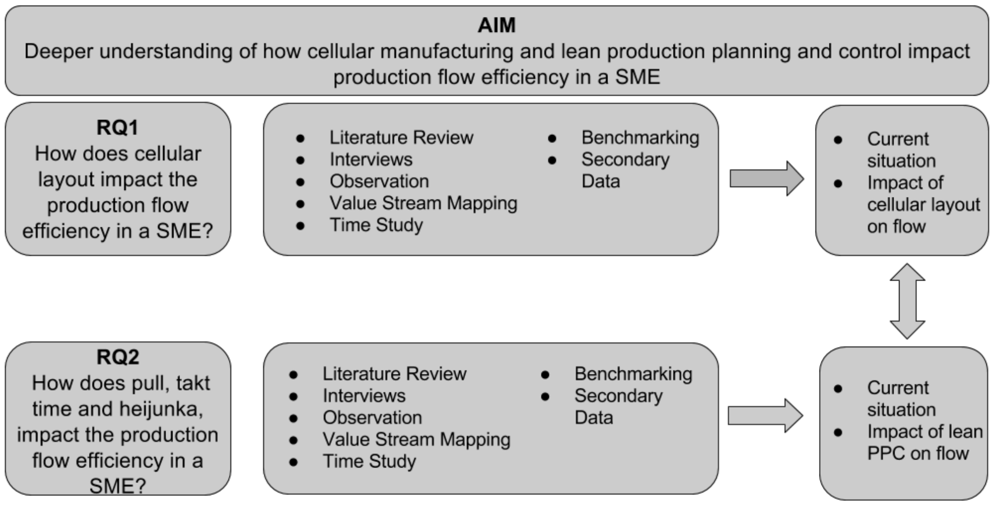

Figure 19: Data collection and analysis process

3.4.1 Interviews

Qualitative face-to-face interviews were used in this study since the focus was on understanding the interviewee. According to Bryman & Bell (2011), qualitative interviews are performed in order to gather information about the interviewee's point of view but quantitative interviews in order to reflect on the researcher's concerns (Bryman & Bell, 2011). Interviews can be conducted through face-to-face meetings where the interviewee is contacted before and time and location are agreed upon (Denscombe, 2014), which was done in this study. Both semi-structured interviews and unstructured interviews were used. Semi structured interviews where used with the Purchasing Manager, Logistics Manager, Sales Manager and Production Manager. Before the semi-structured interviews were conducted, an interview guide was prepared beforehand. The interview guide had a list of questions and topics that the authors wanted to get deeper knowledge of. According to Bryman & Bell (2011) an interview guide is only used as guidance in order for the interviewer to be flexible and focused on how the interviewee frames and understands the issues and events. Unstructured interviews were however, used with employees working in the production and during weekly meetings with the CEO. Unstructured interviews are based on the interviewee thoughts with the aim of letting the interviewees develop their own ideas rather than shaped by questions, which the interviewer already had in mind (Denscombe, 2014). Therefore, the choice of the interview method was dependent on what results was wanted from each interview.

3.4.2 Observation

Over the six months of this research, participant observation was used. According to Bryman & Bell (2011), participant observation is performed in order to focus on cultural norms, expressions of organizational values and patterns of workplace behaviour. By using the participant observation method, the participant observers participate in the daily life of the people under study, observing things that happen, listening to what was said, and questioning people, over some length of time (Becker & Geer, 1957). The observations in this study were mainly gathered by going to gemba and observe the operators. Observation was also conducted during interviews, when performing the time study, during daily control meetings at the company and at other regular meetings the company had (e.g. continuous improvements and deviation meetings). The different observations were categorized under the seven types of waste of lean production where each of them was given a index from 1-5 based on how frequently the waste was observed.

3.4.3 Value stream mapping

Value Stream Mapping (VSM) was used as a data collection method in this master thesis as a focus had to be put on understanding the production flow. According to George et al. (2004) VSM is a good method to use to understand and visualize the process of the organization studied. Further, VSM is a Toyota method and is used as a training method where you “Learn to See”. A current and a future (ideal) state map are developed and from that implementation plans are established to install lean systems (Rother & Shook, 2003). By looking at the value stream, attention is given to establishing flow, eliminating waste and adding value (Rother & Shook, 2003). The process studied in this master thesis was the production process of a battery backup. The focus was put on this one product family, since the battery backups are around 80% of all volumes sold in the company. A current state map was developed to understand the process and the flows. A future state map was not made since future state map did not add value to the project. Therefore, VSM was only developed to the extent that was valuable for this project. By doing the VSM the authors realized that the focus needed to be put on both material flow and information flow of the main assembly process of the battery backups. It was decided to start with material flow and then study the information flow, since the company wanted to start on improving the production. Then, from the current state map, it was decided that a time study was needed to be performed, which is described in next chapter.

3.4.4 Time and commonality study

Stopwatch studies are conducted in order to collect assembly time data on the battery backups (Baudin, 2002). According to Ousnamer (2000), stopwatch studies are traditionally a tool to determine production time standards. The operation need to be broken down to easily measurable tasks, by making observation and knowing how to rate an operator, which, can be difficult. Therefore, Ousnamer (2000) suggest that 15% is made as an allowance to accommodate the worker getting a drink, minor product breakdown, etc. The time study results in a rate that can be applied to an operation or series of operations (Ousnamer, 2000). In this study, the authors documented all the times when the operator preformed an operation, both value adding and non value adding. The time study was performed on 14 products out of 124 battery backups and their optional extras. The products were divided into 14 categories depended on their sizes and similarities. Therefore, the products chosen to time study was one from each category, with the highest sales volume data, where the value adding, non-value adding and total assembly process time for each product was studied. While doing the time study, the authors also took notes on what material and process steps each product had and made a commonality matrix out of that to understand the different parts and process steps for each product.

3.4.5 Benchmarking

The benchmarking method was used to collect ideas and information from a manufacturing SME that has grown and improved really quickly using the tools and methods of lean. According to Talluri (2000) benchmarking is a process that identifies efficient and productive business processes which can then be used as a target for improvements of inefficient processes. In other words, benchmarking is about finding out legally how others do something better than you, which can be used as a guide to improve your own organizational process (Drew, 1997). Benchmarking can either be internal, industry or process related (Talluri, 2000). In this study, the benchmarking was performed at a company that is not within the same industry as the case study. The benchmarking was conducted as a one day visit at an SME that is working within the highway and off highway lighting industry. Even if the company was not within the same industry, the benchmarking was useful since the company is an SME that has recently start using cellular layout as well as the pull, takt time and heijunka techniques. The visit included a tour of their production and a small presentation of their daily operations where both unstructured interviews and observation was used.

3.4.6 Secondary data

According to Bryman & Bell (2011) secondary data is a data that the researchers include in their analysis, but have not collected themselves. Further, secondary data is data that has been collected without any specific research purpose, since it is usually collected for management, claims, administration and planning, control functions and others (Sørensen et al., 1996). There are many advantages of obtaining secondary data in research, for example *more time for data analysis* and *re-analysis may offer new interpretations*. However, there can also be some disadvantages and that can be *lack of familiarity with data* or *complexity of data* (Bryman & Bell, 2011). In this study, secondary data was collected from the company's database, their MPS system, and sent directly from the employees via email. The data was used to get a better knowledge of the company itself, their operations and products. The data consisted of both verbal and numerical data, where the verbal data consisted of brochures and documents and the numerical data consisted of historical data regarding sold volumes and revenue as well as produces product volumes.

3.5 Data analysis

Data analysis is a stage in the research, which incorporates several elements where it is important that the data is managed and reduced (Bryman & Bell, 2015). Further, when managing the data, the data needs to be broken down into component parts so that the data will be manageable. The main objective with reducing the data is to make sense of the data collected (Bryman & Bell, 2015). In this research, the data was collected and analyzed in an iterative process. After each verbal data collection (interview, observation, benchmarking etc.) the authors discussed the results and compared each other's understanding. When the authors reached a common view of the answers or observation, the authors made a summary of the interview or observation that was gathered. In order to make sense of the collected numerical data (time study, secondary data etc.), the appropriate graph or tables was used to present the data in a simple way.

3.6 Reliability and validity

As described in chapter 3.1, both qualitative and some aspects of quantitative strategy was used in this research. It is important to address the trustworthiness and present criteria for assessing the quality of the research (Bryman & Bell, 2011). In a qualitative study the criterion of assessing quality consists of four criteria, which has the equivalent criterion in quantitative research, those are credibility, dependability, conformability and transferability (Bryman & Bell, 2011). Firstly, credibility parallels to internal validity and it entails both ensuring that research is carried out according to good practice and submitting research findings to the studied social world for confirmation that it has been correctly understood (Bryman & Bell, 2011). Secondly, dependability parallels to reliability and entails ensuring that complete records are kept of all phases of the research project. Thirdly, conformability parallels to objectivity and entail the recognition that a complete objectivity is impossible in a business research. Fourthly and lastly, transferability parallels with external validity, which entails the researcher making a description or database of judgment about possible transferability of findings to others (Bryman & Bell, 2011).

In order to construct credibility, the authors discussed the interview-results directly after they were performed with each other in order to compare the interviewer's understanding as well as had regular meetings with the employees at the company. Further, all research findings were submitted and confirmed by an employee in the studied case. To construct dependability, the authors took down notes during the interview and observation that was then directly written into a summary that allowed the authors to always go back and look at the data. Further, the authors conducted this research at the company in order to construct dependability, where over the six month period of the study the authors were present at the company. To construct conformability the analysis was constructed by both authors to reduce bias from the interviewer where the results were also interpreted as objectively as possible. Transferability was however not considered since the data collection was limited to one specific case.

3.7 Ethical considerations

Ethical issues cannot be ignored in research and therefore, the authors considered the four ethical principles provided by Bryman and Bell (2011) in this research. These principles are: *harm to participants*, *lack of informed consistent*, *invasion of privacy* and *deception*. To prevent *lack of informed consistent* and *invasion of privacy* during the case study all persons involved were introduced to the research before data was collected e.g. before the interviews, observation and time studies. All of them were given a choice of being a part of the study and were therefore, not forced to answer any questions. To prevent *harm to participants* the authors did not, intentionally, stress the persons during the data collection and to prevent *deception*, information about the research was clearly stated.

4 Empirical data

This chapter will present the empirical data that was collected in this master thesis. The first section explains Milleteknik´s production and products. The second section then goes more into details and start by explaining their current production flow, that is than followed by chapters explaining their current production layout and their current planning and control techniques.

4.1 Milleteknik's production and products

Milleteknik is a small innovative company that manufactures battery backups and uninterruptable power supplies to the growing Protective and Security Industry in Scandinavia. Milleteknik was founded in 1993 and is one of the leading companies in their niche where Sweden and Norway is their current biggest market. The company has in total 23 employees where 10 are working within the production department. Their production is mostly manual assembly work, where most of their products are assembled in their facilities located in Sweden but few products are outsourced to China and delivered fully assembled to their facilities.

Milleteknik´s production is divided into two areas within their facilities, one on the second floor and one on the first floor. On the second floor the battery backups and other optional extras are produced, but on the first floor the uninterruptable power supplies are produced. The focus of this study was on Milleteknik's battery backup and their optional extras production since they account for 80% of their total production volumes. The uninterruptible power supplies were also seen as too complex products to focus on as many of them can take up to few days to produce. A battery backup is made up from many different components, but the main components of every battery backup, is a cabinet that includes a power supply (PS), a PCBA card and a battery, see figure 20.

Figure 20: The main contents of a battery backup

The battery backups are categorized into several different series based on what type of system they backup. The series studied in this master thesis are the BAS series, which backups large access control systems as well as alarm systems, the ECO series that are for smaller access control systems, the SSF series, which backups burglary alarms or integrated security systems, the EN54 series, which backups fire alarm systems or voice alarm systems and lastly PLU series, which backups emergency light systems. Milleteknik is now introducing new series, called the NEO series, which in the future will replace the BAS and the ECO series. In each series, there are number of different battery backups types, for example BAS has three different product types based on the size of cabinets they are stored in, where further each product type includes several different products that vary in regards to complexity. The most simple battery backups are the ones that are stored in small sized cabinets, which are XXS2 and XS, while the most complex battery backups are the ones stored in big sized cabinets, like XXL and 19S. For the other types of cabinets, the complexity of the battery backup depended a lot on the type of series, where for example the EN54 XM battery backup is a lot more complex than the BAS XM battery backup, that are both stored in XM-sized cabinets.

All of Milleteknik’s different product types can be seen in figure 21, where both how many products are a part of each product type and their sold volumes are visualized. For example, the product type, ECO XS, includes 17 different battery backup products and in 2015 these products accounted for 24% of the total volumes sold. In total, there are 14 main product type categories, which include in total 61 different battery backup variants and 34 different optional extras variants, for more details see appendix I.

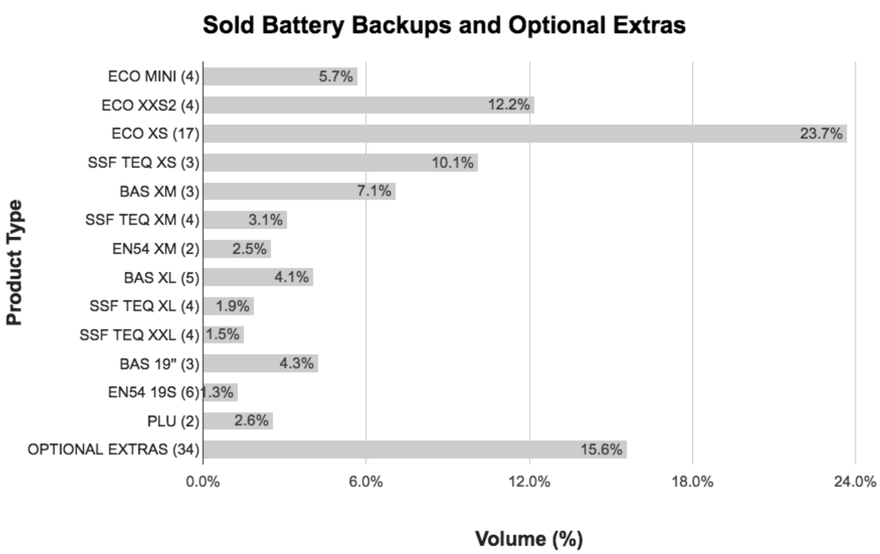

Figure 21: Sold battery backups and optional extras in 2015

Milleteknik´s goal is to grow fast and have within the next 3 years increased the company's turnover by 15 million Swedish kroners. In order to do that, their next step is expanding outside the Scandinavian market and into the European market. In order to succeed in the fierce competition occurring in Europe, Milleteknik entered the Produktionslyftet in 2013 where they were introduced to the principles and practices of lean methodology. Followed by that, they started to implement some of the tools found in the lean toolbox, such as daily control meetings, root cause analysis and kanban. Milleteknik found these tools to be very successful in helping them to improve their operations but despite those improvements Milleteknik believes that in order to really succeed in the future their production flow has to be improved.

Milleteknik is working a lot with continuous improvements and they are constantly developing new concepts, new processes and new products. Also, Milleteknik's main focus is to have short delivery times and therefore, their main focus is flexibility and deliverability. One of the new concepts that Milleteknik is currently working on is reducing the lead time from China by bringing the production to Sweden. In order to be able to do that Milleteknik is currently developing a new concept of modular electrical cabinets. By developing the new concept of the cabinet, they have a strong belief in being able to bring home their production of electrical cabinets from China to Sweden and thus enable shorter lead times and faster impact on product changes. This development will have a great impact on the production flow and therefore, has to be taken into consideration for the redesign of their production.

4.2 Production flow

In order to visualize Milleteknik's current production flow, a value stream map, that consist of visualizing the material and information flow, was conducted and can be seen in figure 22. The material flow of the battery backup production starts with raw material being ordered with the lead time varying from two weeks up to six months, as some of the suppliers are located in Sweden, but others in China and Taiwan. When the raw material arrives, the smaller components are organized into bins and stored in component racks within the inventory area. Then, transferred to the component racks located at each workstation within the production when needed. If a material is missing from the component racks, the operators write the missing material number on the daily control whiteboard so the material handler can see it and can give feedback for why it is missing. The two main reasons for why material is often missing is that the material handler does not notice that the material is missing or the material is not in stock and then, information regarding when it will arrive are given to the operators. The bigger components or the cabinets, on the other hand are stored in their original boxes and transferred from the warehouse to the production area, in pallets, when the inventory in the production is about to finish. The raw material can be seen as the starting point of the production where the following production steps are the *PCBA and the battery backup assembly*.

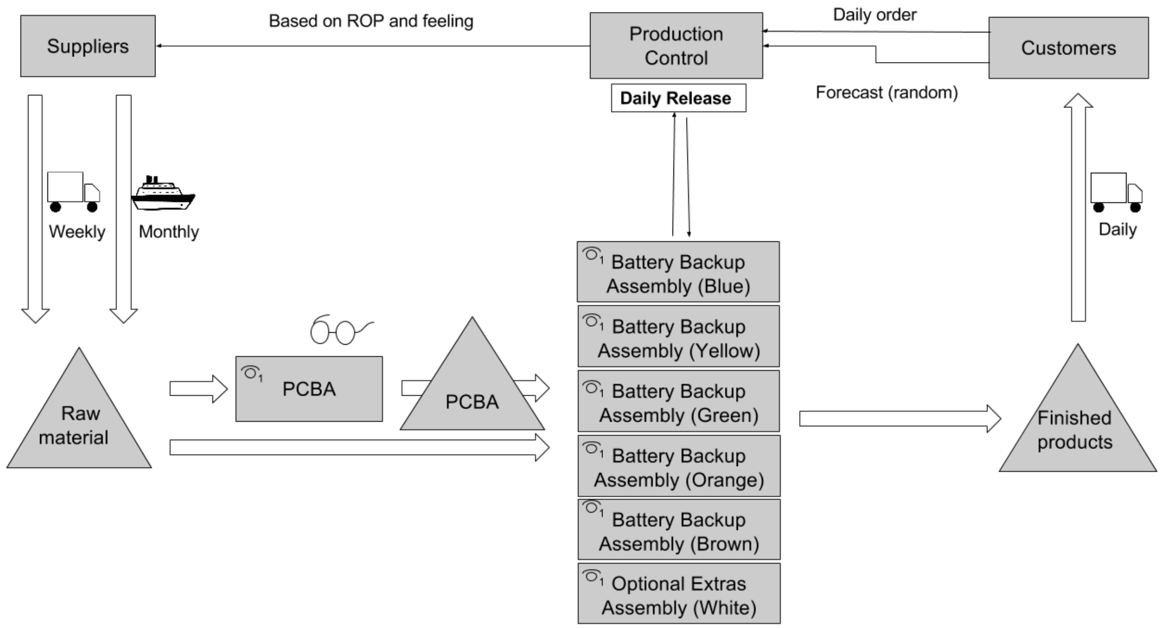

Figure 22: Value stream mapping (VSM)

The first process step, PCBA, can be seen as sub-assembly process but this step is not needed for all of the products. All battery backups need a PCBA, but only battery backups that need a PCBA card that have to be modified, calibrated or programmed go through this first step. The battery backups that only need a PCBA cards that has to unpackaged and assembled go straight from the raw material into the battery backup assembly step as well as all other raw material. The second is the battery backup and optional extras assembly and that can be seen as the main assembly process. This step included six independent workstations, where five of them produce battery backups from start to finish, depending on the series and size of the battery backup, and one of them produces optional extras. The end of material flow process is the finished goods inventory, which includes all products that have not been shipped out to the customer.

Along with the material flow, there is an information flow where the production control is the main function. It involves preparing daily production plan, from their MPS system, for the battery backups and optional extras assembly. These plans are based on daily customer orders and customer forecasts. Due to customer forecast being very seldom received (yearly and unpredictable), the production plan is mainly developed from the daily customer orders. The production control does however, not prepare any plans for the PCBA assembly, the PCBAs are produced by the operators feeling and by going to see what is needed by the main assembly. The MPS system has further, a predetermined reorder point for every component. The system is then used to order raw material from the suppliers on daily bases based on the reorder point. In conjunction with the reorder point, the purchasers feeling and previous experience is also used when material is ordered. Based on this, it can be seen that the main assembly process is the largest element of the production flow. Therefore, it was decided together with the company, that the focus of this study should be on this specific process. Hence, the next chapters will only describe how their current assembly layout and how their current planning and control techniques look like.

Before going into more details of the current layout and current planning and control techniques, a time series plot of daily produced battery backups and optional extras, from September 2016 to the mid of February 2016, can be seen in figure 23. The plot shows that the production has been rather unstable, since produced products range from 25 products up to 187 products between days. However, it has to be taken into consideration that their different products vary a lot in size and complexity and therefore, their day to day production volumes will always vary.

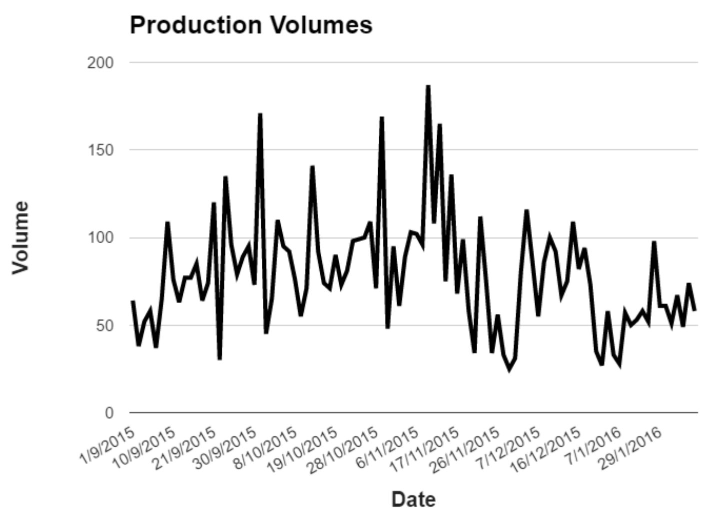

Figure 23: Production volumes time series plot

4.3 Production layout

The main assembly process is the main part of Milletekniks production flow and is currently divided into six independent workstations (Blue, Yellow, Green, Orange, Brown and White). All workstations produce different types of battery backups and optional extras, where the products are divided on workstation based on their type of series and their size. Due to that, the assembly process steps are not the same for all of the different workstations. A breakdown of the observed assembly process steps for all the different workstations can be seen on figure 24. This figure only show a rough picture of the different assembly steps that are included on each station as in what order and how, these steps are conducted is completely up to the operator. Therefore, there are no specific standardized production steps, as each operator creates its own way of working, Further, a list of the different battery backups produced on each workstation can be seen in appendix II.

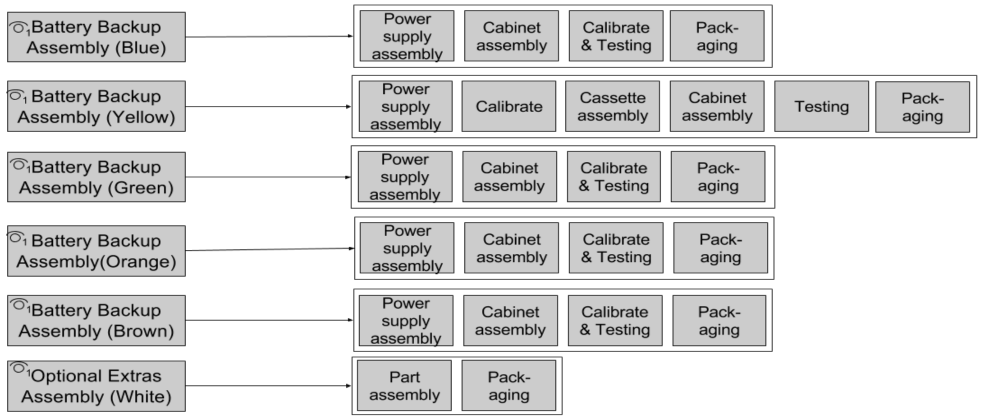

Figure 24: Observed assembly process steps

There are five operators working on these six workstations where there is always one operator working on the Blue, Yellow and Brown workstations but the utilization of the White, Green and Orange workstations depends on the customers orders. At each workstation there should be all tools, material, testing and packaging equipment needed to produce a battery backup from start to finish. Therefore, each battery backup only goes through one workstation and usually one operator when it is being assembled.

The six workstations are spread around a space that is approximately 300 m^2 and is on the second floor of the company's facilities but the raw material stock and finished good warehouse are located on the first floor. Therefore, there are two doors that are for forklifts to take either raw material to the second floor or finished products to the first floor. Both doors are utilized for both raw material and finished products. The current layout of the assembly process can be seen in figure 25, where both the position of the six workstations and the different inventories is shown.

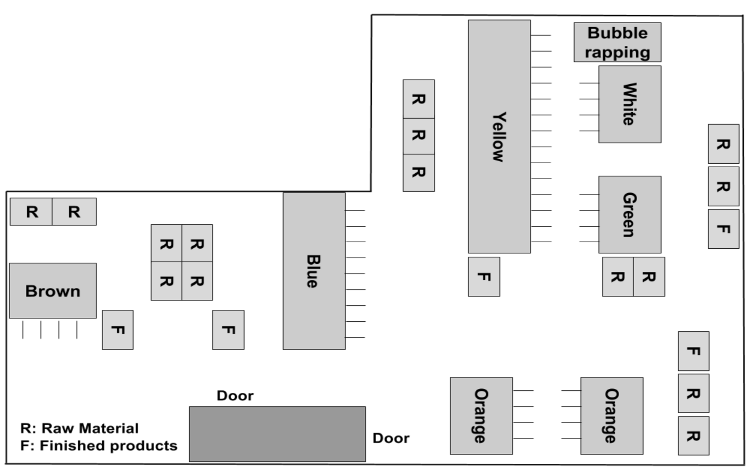

Figure 25: Milleteknik's production layout

As can be seen in figure 25, all stations have a pallet where the operators put finished products on, which is marked with F (finished goods) in the figure. Further, there are also a lot of pallets lying around the production where the cabinets and the packaging material are stored, marked with R (raw material). Other parts needed to assemble the product, are stored in components racks in front of each workstation, which is filled from the warehouse downstairs when needed. Milleteknik's assembly area is quite flexible since there are no heavy machines in the production. The only machines that are utilized are small machines located on each workstation like screwdrivers, drillers etc. The workstations also have all the material needed to assembly all the products that have been assigned to them. Further, the workstations are easy to move, and currently Milleteknik is working on having each workstation on wheels so it will be easy to change the layout if needed. Therefore, the design of the layout is not dependent on any specific machines or the workstations. One of Milleteekniks workstations can be seen in figure 26.

Figure 26: One of Milleteknik's workstation

4.4 Production planning and control

The assembly process is planned and controlled by a production manager, where the current planning and control is mainly based on daily incoming customer orders and their finished good stock. Customer forecast and other project offers are also used but not to a great extent, due to forecast only being sent from their customers once a year when renegotiating contracts. The daily planning process starts with the production manager generating a paper from their MPS system, which shows what products the customers have ordered for the week. The paper shows the customer name, order number, week number, weekday number, delivery date, product type, amount ordered and the amount in stock. If the ordered product needs to be produced the amount of how much is needed is located in the last column but if they already have enough in stock, it says, "OK". The reason for why a new schedule is printed out every day is because new customer orders can come in every day, and Milleteknik promises short delivery times, or 2-5 days lead time. Based on that paper, the production manager creates a plan of what should be produced each day. The production manger then color codes the plan to show what workstation each ordered product should be produced on and distributes it to the operators. Each operator does not get specific information about what he or she is supposed to produce every day, they only know what workstation they should cover and what products needs to be produced. The operators thus, determine the sequence of what is produced and when. The operators also have a list at each workstation of how much safety stock should be in inventory for each product. The operators use that list when they are not able to produce what the customer ordered, due to missing material that happens around once a week, or when they have finished producing everything on the plan. Along with the daily release of a production plan, daily control meetings are held by the production manager every morning. There, the operators tell the manager what they have been producing, if it was for the storage or for a specific customer order, and if they have encountered any problems. At this meeting, representatives from the sales, service and logistics department are also present in order to be able to discuss problems and information that every department needs to have knowledge and be aware of.

4.4.1 Milletekniks kanban system

Currently, Milleteknik has a kanban system that they use to supply material to the different workstations. Their kanban system starts when new raw material comes into the warehouse. Then, the material handler categorizes the material into bins, where each bin has a special color, a special number and other relevant information. The color shows which workstation the bin should be put into and the number say where the bin should be stored in the warehouse and in the prodcution. Other relevant information is also presented on the bin, for example how many components should be in the bin and name of the component. The material handler tries to go once a day to check if some bins are empty and fills them up before placing them in the component racks at each workstation. When the bins are empty in the production, the operators put the empty bins in a special box so the material handler can easily see when material is needed. If material has not been refilled when needed, the operators write what component is missing on the daily control board, which is discussed on the daily control meetings. Both the bin and the components rack, that is a part of their kanban system, can be seen in figure 27.

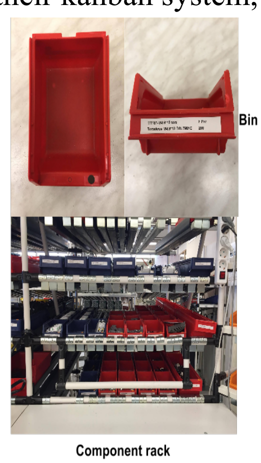

Figure 27: Milleteknik's kanban system

5 Analysis and design of a new system

This chapter will present the analysis that was performed in this master thesis. The first section presents the analysis, the design and the implementation of cellular manufacturing, that is then followed by a chapter on how it impacts the production flow efficiency. The second section presents the analysis and the design of the lean production planning and control, that is also followed by a chapter on how it impacts the production flow efficiency.

5.1 Cellular manufacturing

Comparing Milleteknik's current production layout with the four main types of layout design described in theory, their layout design does not match any of these four types. Their current production layout consists of six independent workstation where each station produces different products based on their type of series and size. Each station produces a battery backup from start to finish. Choosing the appropriate production layout is a complex decision that according to theory depends on various factors. One of these factors is that the decision should be based on the product variety and the product volumes. According to the empirical data Milleteknik produces battery backups and optional extras in 124 variants, where production volumes vary from 25-187 products a day. From that, it can be seen that using a cellular layout within their production is the appropriate choice, since according to Bulgak & Bektas (2009), cellular manufacturing is appropriate when both volume and product variety are medium. Further, cellular layout is appropriate for Milleteknik, due to their requirement of having high level of flexibility within their production, and according to Abdul-Hamid et al. (1999), cellular manufacturing is the only layout option that can cover all the four types of flexibility, which are wide range of products, design changes, changes in capacity and process flexibility. Therefore, by implementing cellular manufacturing to Milleteknik's production, both the flexibility requirement and the layout option, that fits best for companies working within the medium volume and medium variety production environment, is fulfilled. With that said, the next chapters will present the analysis and design of a cellular layout for a SME.

5.1.1 Analysing the current state

In order to redesign their production layout, a more thorough analysis of Milleteknik´s current production was conducted. Where the main focus was on studying the different product parts and how they were assembled by conducting a communality study, a time study and a waste analysis.

Communality study

The commonality study revealed that many of the battery backups had a lot of common parts despite not being a part of the same product series. These common parts were not necessarily assembled in the same way. The products that have the same type of parts did not necessarily have the same process steps. Therefore, the process step of the battery backups depend a lot on their series type, but also on size of the cabinet they are stored in. Currently, Milleteknik has divided the different battery backups into families on six different workstations based on their type of series and sizes but not based on their process steps. The series and the size have the biggest effect on the process steps and therefore, most of the battery backups are divided up into families as Kandiller (1994) recommends. However, even though the product have been divided into families, the operators on the workstations do not have any standardized way of assembling the products and each operator creates his own way of working. It is important to have standardized process steps as Black & Hunter (2003) state that standardized steps are important in order to make the flow smoother. Further, Kandiller (1994) describes the importance of taking the associated machines of the products into consideration when categorizing products into families. Currently at Milleteknik, there are no heavy machines needed to assembly the products but on the other hand, there are a lot of different small machines needed. Milleteknik has already taken this into consideration as most of the machines needed to assembly a battery backup are included on each workstation but where they should be located on the workstation has however not been taken into consideration.

Time study

The time study revealed that the total time that takes to produce a product varies from 5 minutes up to 170 minutes, see table 1 and appendix III. The production time of 5 minutes can though only be found for the simplest products, which are the optional extras. The high production time, 170 minutes, can also just be found for their most complex product type, the EN54 19S. For all of the others product types, the total time varies from 16 minutes to 55 minutes in production. This high variety of total production time can be explained due to the different sizes and complexity that the different battery backups have, where also products that are produced on the same workstation have high variety of production time. For example the products on the yellow station vary from 23-55 minutes in total production time. This is due to the fact that even though the products are being produced on the same workstation, the time each process step takes depends on the product. This high variety of production time has to be taken into consideration since according to Greene & Sadowski (1983) it is important when designing a cellular layout to know the precise start time and completion time of each job.

Table 1: Time study results

Product Type	Workstation	Value Adding Time [min]	Non-Value Adding Time [min]	Total Time [min]
ECO MINI	Green	11	7	18
ECO XXS2	Blue	10	6	16
ECO XS	Blue	13	5	18
SSF TEQ XS	Blue	13	3	16
BAS XM	Brown	13	4	17
SSF TEQ XM	Blue	16	8	24
EN54 XM	Brown	19	2	21
BAS XL	Yellow	19	5	23
SSF TEQ XL	Yellow	33	5	38
SSF TEQ XXL	Yellow	50	5	55
BAS 19"	Yellow	32	3	35
EN54 19S	Orange	149	21	170
PLU	Orange	22	8	30
OPTIONAL EXTRA	White	4	1	5

The calculated total time of the products is comprised of value adding and non-value adding time. The value adding time was defined as the time where value was being added to the product, or when the different parts of the battery backup or the battery backup itself was being assembled. The non-value adding time was defined as the time when operators were not assembling the product or the time that went into, setting up the computer and production, fetching tools and parts from other workstations, unpackaging of parts, waiting time and rework. For most of the products the non-value adding time varied from 2-8 minutes where in most cases the waiting time was the biggest part, where the operators were taking extra coffee breaks and being interrupted by others around them. The second largest part of the non-value adding time was the time when operators needed to fetch tools and parts from other stations. The ratio between the value adding and the non-value adding time for all of the products can be seen in figure 28, where the non-value adding time varies from 7-42% of the total time for all of the products studied. The reason for why the non-value adding time was not higher can be explained by the definition of the non-value adding time in this report. For example, when operators were fetching parts that were on the workstation, or did not need to walk away or leave the workstation, that time was not considered as a non-value adding time.

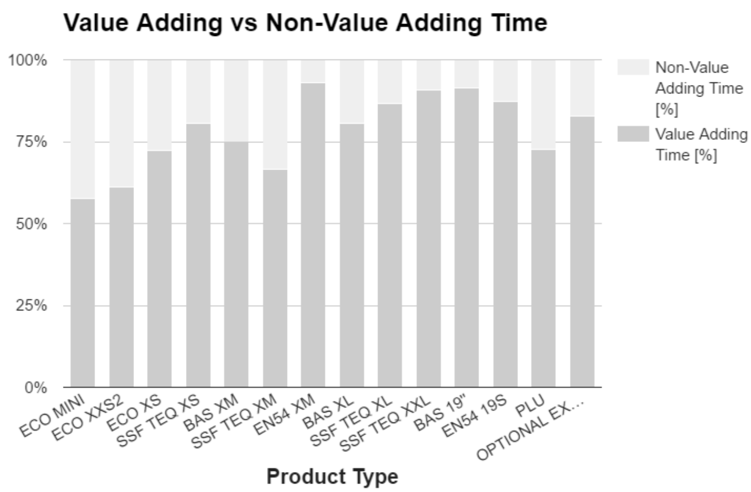

Figure 28: Value adding vs non-value adding time

By looking closer at this ratio the smallest and the most simple products, or the ECO MINI, ECO XXS2, ECO XS, BAS XM and SSF TEQ XM, have the highest amount of non-value adding time in comparison to total time or 25-42% or more than ¼ of their total production time. PLU also has a high ratio of non-value adding time or 28% but that ratio can be explained due to the printer at the orange workstation being broken when the study was conducted that led to the worker having to fetch parts to other stations more than he would have under normal circumstances. This high amount of non-value adding time for the other products is however related to the design of the workstations since they are not designed properly or not according to the production steps for the products. That can be explained by the fact that they don't have any standardized steps. That then, leads to operators needing to fetch parts and tools more often from other stations that create more distraction for the operators that can then lead to them making more mistakes. This high amount of non-value adding time can also be related to the high level of disruption created by others that make the product wait while discussion is going on.

Waste analysis

Along with the different types of waste observed during the product assembly itself, other types of waste, for the production as a whole, were also observed, see table 2. The most frequent wastes, observed hourly, were the high raw material stocks located in the production and the waiting time of the product due to operators being interrupted while working. Regardless of these wastes being the most frequent, all of the seven wastes were observed on a daily basis in the production, except for the over processing waste that occurred on a weekly basis. When the operators were asked about improvements regarding the different waste, the operators did not feel that many of the wastes needed to be improved. That can be explained by the fact that even though the company has started working with lean, the operators have not reached the mindset needed when working with lean. By looking back at the value adding and non-value adding ratio, the value adding time varied from 58 - 93%. This shows that there is existing waste that needs to be reduced to utilize the operator times more. The current existing waste will therefore be taken into consideration when designing the cell, since according to Black & Hunter (2003) it is important to eliminate the waste, since the cell is suppose to be designed to utilize people and all assets fully.

Table 2: Waste observation

Waste	Description	How frequently
Overproduction	Prodcuts prodcued before they are needed by the customer	4
Inventory	High raw material stock within the production	5
	Large safety stock of finished goods	3
Waiting	Interupted by others while working	5
	Long times identifying what to prodcue	4
Motion	Fetching parts and tools from other stations	4
	Moving component boxes	4
Transportation	Moving half empty pallets	4
	Different prodcuts put on the same pallet	4
Rework/Defects	Parts broken	3
	Problems with PCB	2
	Wrongly identified problem	2
	Operators fix problems outside of their work responsibilites	4
Over processing	Old assembly material used	3

5	Hourly
4	Daily
3	Weekly
2	Monthly
1	Yearly

5.1.2 Designing the cellular layout

The design and the implementation of a cellular layout was done by going through the four steps of cellular design, cell formation, group layout, group scheduling and resource allocation (Wu et al., 2007). The cell design was however, only conducted for one test cell and not the entire production at Milleteknik. The data and knowledge that will be gathered from this test cell can then be used to design a cellular layout for the rest of Milleteknik's production.

Cell formation

The first step when designing a cell according to Wu et al. (2007), is the cell formation, where products are divided into families based on their process steps, as was described in chapter 2.1.5. Based on the knowledge obtained analyzing Milleteknik´s current production, the required process steps and total production time for most of their products was known and therefore, few different cell formation scenarios were able to be created, see table 3. In order to categorize the different products, the types of the cabinets were used to demonstrate which battery backups would be included in which cell. All of the designed scenarios are based on going from their current production layout, six independent workstations, to cellular layout with two, three or four cells.

Table 3: Cell formation, different options of dividing the products into families

No of cells:	2 cells	3 cells	4 cells
Families:	**1.** Products with PS (15 - 170 min) (*MINI, XXS, XS, XM, XL, XXL 19", 19S*) **2.** Products without PS (5-30 min) (*OPTIONAL EXTRAS, PLU*)	**1.** Small products with PS (15 - 25 min) (*MINI, XXS, XS, XM*) **2.** Large products with PS (25 - 150 min) (XL, XXL, 19", 19S) **3.** Products without PS (5 -30 min) (OPTIONAL EXTRAS, PLU)	**1.** High volume, small products with PS (15 - 25 min) (XXS, XS, XM) **2.** High volume, large products, with PS (25 - 55 min) (XL, XXL, 19") **3.** Low volume, small products, mixed (5-15 min) (MINI,OPTIONAL EXTRAS) **4.** Low volume, large products, mixed (30-170 min) (PLU,19S)

The first scenario was creating a cellular layout with only two cells. Then all their products would be divided into two product families or two cells, one with products that have power supply (a part in the product that they have in common), and one family with products that do not include power supply. The second scenario was creating a cellular layout with three cells, where the production would be divided into three families based on sizes, small products with power supply, large products with power supply and lastly, products without power supply. The final scenario was creating a cellular layout with four cells. The products would then be divided into four families based on sizes and volumes. The first family would include small, high volume products with power supply, the second family would include large, high volume products with power supply, the third family would include small, low volume products, with or without power supply and the fourth family would include large, low volume products with or without power supply. The reason for only considering those three scenarios was because the goal was to create a cellular layout with as few cells as possible to make the production simple and visual. Therefore, having more than four cells was not considered in this research. Further, creating only one cell for all of the products was also not considered because the cell would then not be efficient due to the capacity utilization would be low when the products have so high variety in total production time.

These three scenarios all have different benefits and challenges that have to be evaluated before choosing the most suitable one for Milleteknik. The benefit of having only two production cells, is that it will be easier to plan and control the production the less cells there are. On the other hand, it will be more difficult to design the cells due to the difficulty of designing the process steps within the cell that are fitting for all products. Further, there will be a challenge to balance the different steps between the operators within each cell since the total time to process the products varies from 15 minutes to 170 minutes. Furthermore, having only two cells will decrease the level of flexibility in relation to capacity. The less amount of work stations there are, the less flexible the production will be in regards to meeting a wide range of production demand volumes. The products have such high variety in total production time that makes it difficult to utilize the capacity of these two cells efficiently. The benefits of adding more cells or having three or four cells, is that it will be more easier to design the process steps within the cells as well as to balance the steps due to the less time variation the products will have. Further, the benefit of adding more cells is that is creates more flexibility in regards to capacity, but decrease the flexibility in regards to wide range of products, design changes and process flexibility, compared to having fewer cells. By having more cells, the wide range of products flexibility factor will lower because there are fewer products in each cell. Therefore, it will also be more difficult to change the design of the products because of standardized steps. The process flexibility will be less because the ability to change products within a given mix and with low set-up times does not need to be is as high as when having fewer cells. The challenges on the other hand, of adding more cells, is that it makes it harder to plan and control the production as well as it increases the cost of machine and tools and the space needed to build these different cells.

These three scenarios were presented to workers and managers at Milleteknik and the different benefits and challenges discussed. Due to the importance for Milleteknik to be flexible in regards to capacity, as they have high variation in customer demand and have short delivery times, the three or the four cell scenario were seen as the most applicable options. By changing to fewer workstations or cells, Milleteknik will also enhance their flexibility in regards to wide range of product, design changes and process flexibility and therefore, it is important for them to reduce the amount of workstations that they currently have but still maintain the flexibility in regards to capacity. However, instead of choosing to implement one scenario, a decision was made to create a test cell or a pilot study before taking a final decision on what cell formation scenario should be implemented. This was done due to the fact that the first step in cell design is so important and according to Kandiller (1994) it affects all other steps in the cell design. As well as that some employees were being skeptical if a cellular layout would work for these different types of products. The first cell in the final scenario or the small high volume products that include power supply (XXS, XS and XM products) was chosen as a representative for the test cell. Hence, next steps in the cell design will not be presented for the whole production, but only the parts affected by the pilot study. Designing a cell for only part of the products is also something that is seen applicable as according to Green & Sadowski (1984) converting an entire production into a production cell in order for it to work is not something that is necessary. They stress that products that can´t be associated with the specific product family should not be pushed on the cell.

Group layout

The next step of cell design is the group layout, where inter cell layout and intra cell layout is created (Wu et al., 2007). First, the intra-cell layout was designed, which included designing and positioning the workstation and the process steps within the cell. The first step was designing standardized production steps within the cell for all the different products as according to Pan (2014), a cell has to be designed in a way that all it´s products can be produced from start to finish in a correct sequence. The process steps design was based on knowledge gained in analyzing their current production layout and then presented for the operators in order to get feedback on how the steps could be improved. Further, these steps were categorized into smaller units as Pan (2014) talks about, which would work together to finish the tasks of the production process. This was done in order to separate the different type of procedures from each other and create units that would have different responsibilities. The cell would then be more visual for the different operators and easy to see where the handover of work would be located. In total three units or subcells, were created that would be positioned in a U-layout, since the U-layout, according to Miltenburg (2001), is the cell layout that is most often used in lean production systems. The reason for why three subcells were created was because three main processes were needed in order to make a battery backup, sub assembly, main assembly and testing. The first subcell would cover all the subassembly, the second one all main assemly and the third one the testing and the packaging of all the different battery backups. This was seen the most appropriate way to divide the cell in order to be able to use as many parts as possible of the company's current workstations setup. The designed standardized production steps within the three subcells can be seen in appendix IV.

Secondly, the inter-cell layout was designed where three different scenarios were listed up with different ways on how to position the subcells and the operators within a cellular U-layout, see figure 29, 30 and 31. All of these layouts have the same level of flexibility in regards to wide range of products, design changes and process, since all of these layouts are designed in regards to the same product types that have the same process steps. However, the layouts differ in regards to capacity. The first scenario can be seen in figure 29, where the operators are all positioned inside the cell. The production starts on CELL3 where an order is started in the computer system. After that the actual assembly starts on CELL 1 where an operator has a component racks in front of him with all parts needed to subassembly the power supply and the PCBA card, that are parts needed for the main assembly of the battery backup. The operator therefore, performs steps number two, three and four and then hands over the assembled parts from CELL 1 to CELL 2. The operator at CELL 2 then starts by walking to pick up an empty cabinet located on pallets beside CELL 2. He then, starts performing steps five to nine that include assembling the battery backup itself by both using the sub assembled parts from CELL 1 and other parts kept in component racks in front of him. When the operator finishes step number 9 the battery backup is fully assembled. The operator at CELL 3 then takes the assembled cabinet, tests it, packages it and performs administrative work that are steps 10, 11 and 12 and finally starts a new order, step 1. Lastly the battery backup is put on a pallet at the end of CELL 3 that is ready to go down to next floor into the finished good stock.

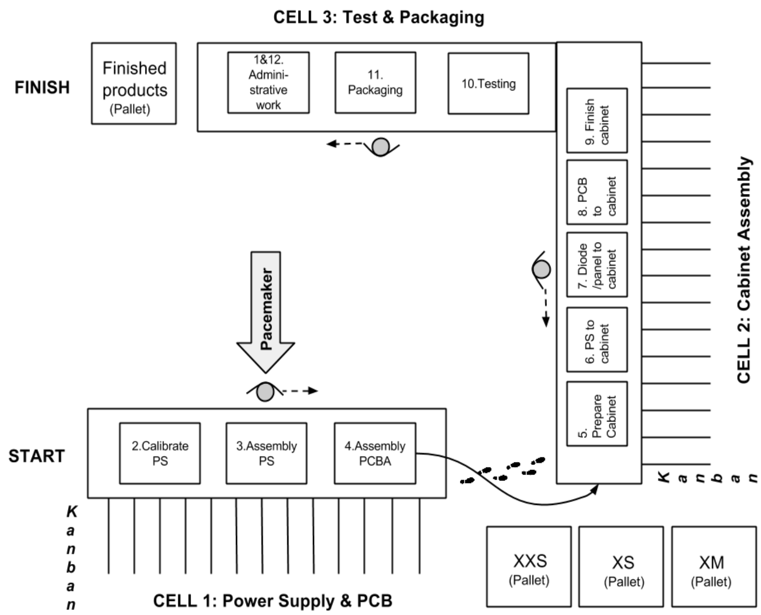

Figure 29: Scenario one, all operators inside the U-layout

The benefits with this setup of the subcells is that it makes the cell very flexible in regards to capacity since it allows different number of operators working on the cell, one or multiple, depending on how many products are needed and how many operators are available per day. Therefore, all of the cell systems Pan (2014) describes, subcell, shared cell, rabbit chasing and expanded rabbit chasing, are possible to be used with this type of setup of the cell. This way of positioning the cells also makes the WIP very visual for all of the operators. Further, it forces the operators to work close together due to them being so dependent on each other that create a team feeling among the operator's. Furthermore, this type of setup makes it easy to balance the workload of the cell if needed between the operators. However, the challenge of this set up is that the three subcell cannot to be all interconnected due to the gap that has to be in between CELL 1 and CELL 2 in order for an operator to be able to pick up a cabinet for the pallets in the beginning of CELL 2.

The second scenario can be seen in figure 30 where the operators are all positioned outside the cell. The concept is the same as in scenario one but the cells are all positioned in opposite direction and are interconnected with conveyor belts in order to have more smooth flow meaning, no necessary walking between the cells. The benefits with scenario two is that the cells can now all be interconnected that makes the cell have less waste compared to previous scenario, as there is no need of walking and having a gap between CELL 1 and CELL 2 and therefore, it is easier to access the pallets. Suciu et al. (2011) describes that by having interconnection the cell should be more flexible but in this case the cell is not very flexible in regards capacity, due to only multiple operators, or three operators, being able to work on the cell without having high losses. Other challenges with this type of setup is that it has less visualization and creates less team feeling since the operators cannot see the WIP despite being dependent on each other. Further, this setup has more difficulties when trying to balance the work between the operators without having high losses. That is because, if there are two operators working on the cell, one working on CELL 1 and CELL 3, and one working on CELL 2, the operator working on CELL 1 and CELL 3 would need to walk from the first cell to the third instead of just being able to turn around as it was in scenario one, and therefore, losses are created.

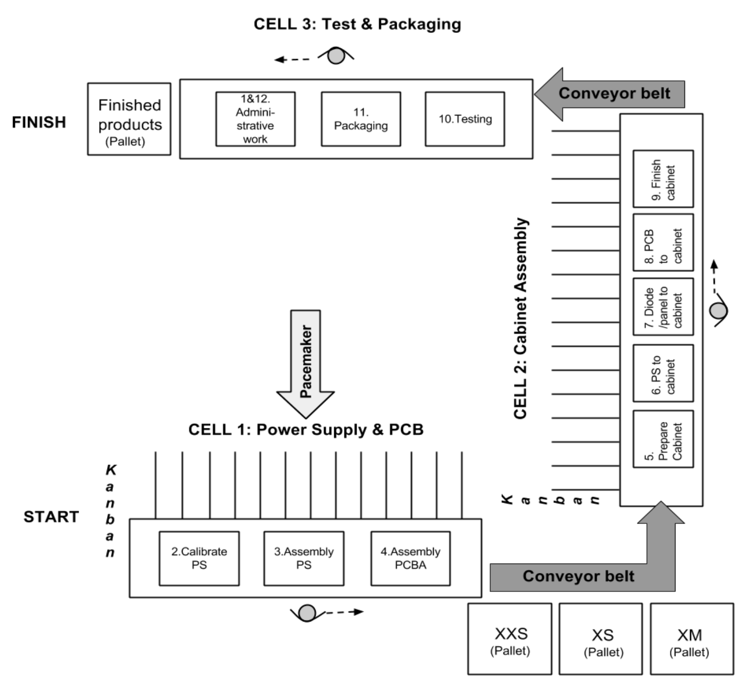

Figure 30: Scenario two, all operators outside the U-layout

The third, and the last, scenario can be seen in figure 31 where the operators on CELL 1 and CELL 3 are located inside the cell but the operator on CELL 2, is located outside the cell. The benefits with scenario three is that it allows the workload to be balanced more easily than in scenario two between CELL 1 and CELL 3. Further, this type of setup allows the component racks to be used as a kanban system, where the operator on CELL

1 sub assemblies the needed parts and puts them in the racks at CELL 2. Then, a predetermined volume can be agreed upon about how many parts can be in the component racks and then operator on CELL 1 knows what and when to produce according to what operator on CELL 2 takes from the racks. That leads to third benefit, which is that the pacemaker is now closer to the customer than in the previous two scenarios because now, CELL 2 controls the pace of the production. Whereas, in the other two scenarios, CELL 1 controls the pace of the production. However, the challenge with this third scenario, is that it is also not as flexible in regards to capacity as scenario one since this setup is not seen appropriate for one operator working on all the cells and therefore, this setup does not allow the cell to use the rabbit chasing and the expanded rabbit chasing cell systems. Since this setup is not appropriate for one operator the flexibility in relation to capacity will be less. That is because at least one operator needs to work CELL 1 and CELL 3, and one needs to be at CELL 2, due to otherwise having too much losses by having one operator going between CELL 1 and CELL 2 and then between CELL 2 and CELL 3.

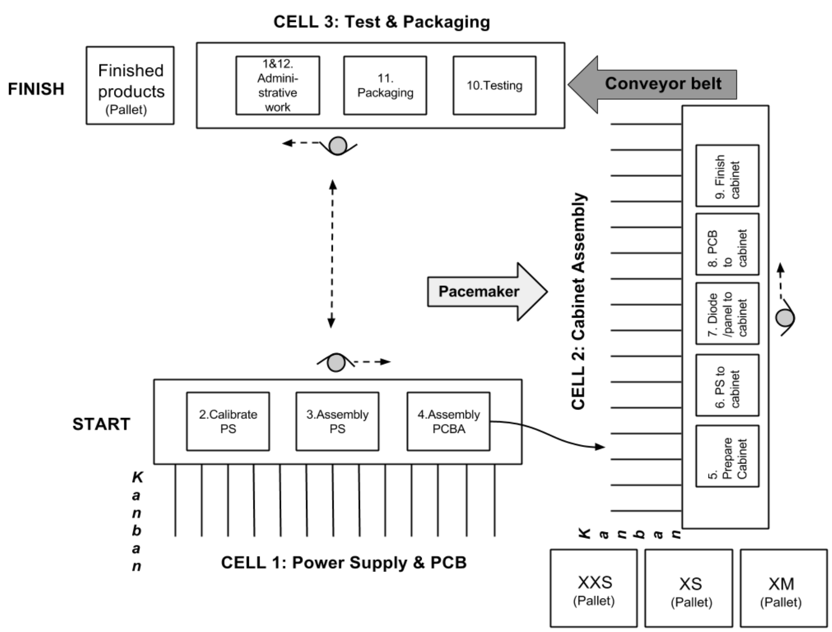

Figure 31: Scenario three, two operators inside and one outside the U-layout

From those three scenarios a decision was taken together with the company about what scenario would be the best option based on the different benefits and challenges. Due to the company's main focus of having high flexibility in regards capacity and being interested in increasing the team feeling mindset among the operators, scenario one was seen as the best option and was implemented at the Milleteknik.

Group scheduling

The third stage when designing a cell is group scheduling (Wu et al., 2007). This stage is closely related to production planning and control since it is about scheduling products for production. Therefore, see chapter 5.2 for more details.

Resource allocation

The fourth and the final stage of cellular design is the resource allocation stage (Wu et al., 2007). This last stage was designed parallel to the implementation of the test cell and was about assigning all tools, material and personnel to the right place of the cell. First, all the material needed for the different products, were placed in the component racks at the cell according to the previously designed production steps, which can be seen in appendix IV. All material needed was available at old workstations and therefore, transferred from them to the cell. Secondly, all tools needed to assembly, test and package the battery backups were placed on the cell according to the process steps. As mentioned before there are no heavy or expensive machines being used in their production and therefore, all tools needed were available at old workstations and transferred from there to the cell. Further, many of the process steps include using the same set of tools and therefore some of the tools are shared between process steps. This resulted in few extra tools needed to be purchased for the design of the cell. All tools and material were then, changed iteratively according the operators when they tested the cell by producing different products. This was done, in order for all the different tools and material to be in correct position within each process step of the cell.

The personnel assigned to the test cell were predetermined by the company and ranged from one to three operators. Therefore, the next step, was understanding how the cell would function using one, two or three operators. From the time study, the cycle time of each cell could be estimated, see table 4,5 and 6. From the table, it can be seen that for all the products, CELL 1 and CELL 3 take a similar amount of time, ranging from two to four minutes but CELL 2 however, takes longer time, ranging from five to 13 minutes. Therefore, assigning two operators to the cell, where one would operate on CELL 1 and CELL 3 and the other one on CELL 2 would be ideal in order to balance the work efficiently without high losses. For example, ECO XXS takes three minutes on CELL 1, five minutes on CELL 2, and two minutes on CELL 3, and by having two operators, one could work on CELL 2 (five minutes) when the other operator could work on CELL 1 and CELL 3 (together five minutes), see table 5. The workload for the two operators would then be balanced. This arrangement would work like Pan (2014) describes as a sub cell system. The cell would also function utilizing only one employee by using a rabbit chasing system like Pan (2014) recommends. Then, one operator would work the cell from start to finish, from CELL 1, to CELL 2 and finish the cabinet on CELL 3, before starting again, see the cycle time in table 6. If the cell is utilized on the other hand, with three operators, the challenge of balancing the cell without high losses becomes more difficult than before due to CELL 2 having such high cycle time in comparison to CELL

1 and CELL 3 also because of the fact that CELL 2 has high variation of cycle time between different products. In order to make the cell function with three operators, the different operators could be placed in one position on the cell that they would be responsible for. In order to compensate for the time losses between the operations, the operators would not hand over work at the buffer areas that are between the sub cells. The handover would than take place when the neighboring operator is available. By having that kind of system, each operator would have to be able to complete the beginning steps of the other cells similar to the shared cell or the expanded rabbit chasing systems that Pan (2014) suggests.

Table 4: Estimated cycle time of each cell by having three operators

Product Type	Cell 1 [min]	Cell 2 [min]	Cell 3 [min]
ECO XXS2	3	5	2
ECO XS	4	7	2
SSF-TEQ XS	4	6	2
BAS XM	4	6	3
SSF-TEQ XM	4	10	3
EN54 XM	3	13	3

Table 5: Estimated cycle time of each cell by having two operators

Product Type	Cell 1&3 [min]	Cell 2 [min]
ECO XXS2	5	5
ECO XS	6	7
SSF-TEQ XS	7	6
BAS XM	7	6
SSF-TEQ XM	7	10
EN54 XM	6	13

Table 6: Estimated cycle time of the cell by having one operator

Product Type	Cell 1, 2 & 3 [min]
ECO XXS2	10
ECO XS	13
SSF-TEQ XS	13
BAS XM	13
SSF-TEQ XM	16
EN54 XM	19

5.1.3 Impact of cellular layout on the production flow efficiency

After having analyzed the current production flow and designed and implemented a cellular layout into Milleteknik´s production, several changes were identified that affected the production flow efficiency, see table 7. Firstly, the *standardized steps* were created for the cell since Black & Hunter (2003) stresses how important it is to create the standard steps in order to maintain a smooth flow of work. The steps are seen to improve the flow since the operators are always working the same way and therefore, fluctuations of different ways of working, that take different amount of times, will decrease. This will make the production more predictable because the time every process steps takes within the cell can easily be revealed, that makes it easy to match the capacity with the demand. The standardized step will also reduce the changeover time since it will always be done in the same way and not like before where operators chose how to work. Secondly, the *waste* in the cell will be less, as some of the previously observed waste was eliminated with the design of the cell. All parts and tools are designed exactly where they need to be in the cell. Then, the waste of fetching parts and tools from other stations and moving component boxes around the workstation will be reduced and therefore, the flow will be better. Also, by both having the standardized steps with less changeover time and the less waste, the throughput time will be reduced which matches what Suresh & Meredith (1985) describe as benefits for cellular manufacturing. The reduced changeover time and throughput time further matches what Boughton & Arokiam (2000) identified as benefits of using cellular manufacturing in SMEs. Thirdly, *everything inside the cell will become more visual* which can affect the flow because then the operators know more about the status of the production, for example if WIP are building up and another worker needs help and so on. That also matches what both Suresh & Meredith (1985) and Wemmerlov & Johnson (1997) describe as they say that one of the benefits of implementing cellular manufacturing is reduction of WIP. Fourthly, in connection to visuality, the *teamwork* will also be better since the operators will be dependent on each other, which was not present in their previous layout and that will have positive effect on the flow. By being dependent on each other also helps the operators to take decisions on what to produce since they need to talk together more and build up the team spirit. Therefore, when decisions take shorter time, waste like deciding what to produce will be shortened. Further, according to Miyake (2006), one benefit of cellular manufacturing is improved workers morale and motivation, which is something that the authors think the teamwork factor, will have affect on. The cell is though flexible in relation capacity because of how many operators can be positioned in the cell so the teamwork factor will be different depending on the number of operators working on the cell. The flexibility in relation to capacity is considered good for Milleteknik since they aim to be as flexible as possible. Miyake (2006) also points out that companies describe that one of the main benefit of cellular manufacturing is increased flexibility and therefore, faster responsiveness, which is exactly what Milleteknik needs. Fifthly and lastly, by implementing cellular layout, *hidden problems will be revealed* that Milleteknik should be aware of because according to Matzka et al. (2012) unstable environments have hidden problems that need to be resolved when they come up in the production and by resolving them the flow will become even better. As said before, Milleteknik has regular continuous improvement meetings that can be utilized for when the hidden problems come up.

Table 7: Identified impacts on the production flow by adopting cellular layout

What (What impact was identified?)	How (How did it impact the flow?)	Why (Why does it impact the flow?)
Standardized steps	From choosing how to work → To steps performed in the same way	Fluctuations in regards to e.g. process times and changeover time will decrease
Waste reduction	From fetching parts and tools when needed → To parts and tools positions where needed to be	Higher value adding time and therefore, less time that goes to work not related to adding value to the product in the flow
Visual inside the cell	From operators not knowing what other products are being produced → To operators seeing more clearly what is being produced	Reduced WIP because operators have more knowledge of what is being produced and can identify quickly if someone needs help
Teamwork	From operators working independently → To operators dependent on each other	Positive effect on the flow since workers are more dependent on each other
Hidden problems will be revealed	From problems being hidden → To hidden problems being revealed	By resolving hidden problems, the flow will be smoother

5.2 Lean production planning and control techniques

The production process at Milleteknik, has high variation of production volumes, or from 25 - 187 produced products on a day to day basis. This high variability indicates that their production is not being planned and controlled in the correct way, and according to Stevenson et al. (2005) choosing the appropriate production planning and control system is a crucial decision. The implementation of lean production planning and control techniques has been popular, as they have shown to be successful in eliminating sources of variability in the production system (Slomp et al., 2009), which is exactly what Milleteknik needs. Further, these techniques according to Matt & Rauch (2013) are equally as applicable for large and small enterprises if adopted correctly. Currently, Milleteknik has already implemented a kanban system into their production to try to control their inventories but a structured way of controlling what, how much and in what order, the operators need to produce is on the other hand not present. That can be explained by the fact that the operators tell the manager what they have been producing the day before on the daily control meetings. This should be the other way around that the manager or a system tells the operators what to do and when to do it. In order to understand how to reach a structured way of working, the next chapter will analyze and design how lean production planning and control techniques can be used in a SME.

5.2.1 Analysis of the current state

As described in theory, the lean production planning and control techniques are pull, takt time and heijunka according to Slomp et al. (2009). In order to design how these techniques could be used in a SME, a more thorough analysis of Milleteknik´s current production planning and control within these three areas was conducted.

Pull system

As described in chapter 4.4.1, Milleteknik has a system that they call a kanban system. However, this system is not used as according to theory. Milleteknik has some kind of one card system where they use containers to signal when material is needed in the production. The container holds all the necessary information. Therefore, Milleteknik has a part of a kanban system where the containers are used as the withdrawal card that gives them their base for the kanban system where the container has the same purpose as a withdrawal card. However, according to Monden (2011) a kanban system is about controlling the production by providing the necessary products and quantities at the right time. The system at Milleteknik is not used in that way, as there is no standardized quantity of how many bins can be at one place nor any standardized time when the material handler should fill on the material. Therefore, the controlling of the production gets lost, since material is often missing due to the material handler has not checked if it is needed and sometimes there are too many bins that are not needed in the production. This analysis shows that Milleteknik’s kanban system is not used as a pull system but rather as an inventory system.

Takt time

Currently, Milleteknik does not use takt time control in their production. However, the takt time was calculated and based on the customer demand (sold products) in 2015. The calculations show that the takt time between different products types as well as the takt time between different workstations, varies a lot, see table 8 and 9. For example, the product type ECO XS has the takt time of 36 minutes while the product type BAS XM has the takt time of 119 minutes, see table 8. Further, if we look at the different takt time of the workstations then the blue station has the lowest takt time, 16 minutes and the orange the highest, 217 minutes, see table 9. By comparing the takt time of the workstations with the total time it takes to produce a product from the time study, then all stations should be able to meet the customer demand except the blue station as few of its products take longer time to produce than the calculated takt time. However, by comparing the takt time with the value added time from the time study, the blue station should also be able to meet the customer demand if all non-value added actives would be eliminated. Hence, the cycle time of the different workstations is lower than the takt time in most circumstances. Therefore, Milleteknik should be able to meet the customer demand in most situations but that is not the case and customer orders are often being delivered late. This analysis shows that takt time control is something that Milleteknik could use. The takt time control helps companies to know what the pace of the production needs to be in order to keep up with the customer demand (Slomp et al. 2009). That will further result in improved delivery performance to their customers.

Table 8: Product type takt time vs total time

Product Type	Product Number	Workstation	Value Adding Time [min]	Non-Value Adding Time [min]	Total Time [min]	Takt Time [min]
ECO MINI	ECO 1315 MINI	Green	11	7	18	149
ECO XXS2	ECO 2730 XXS	Blue	10	6	16	69
ECO XS	ECO 2750 XS	Blue	13	5	18	36
SSF TEQ XS	BT - 8A COM	Blue	13	3	16	84
BAS XM	BAS 27100 XM	Brown	13	4	17	119
SSF TEQ XM	SSF-TEQ XM/B	Blue	16	8	24	282
EN54 XM	EN54-2760-XM	Brown	19	2	21	384
BAS XL	BAS 27100 XL	Yellow	19	4	23	209
SSF TEQ XL	SSF-TEQ-XL/B	Yellow	33	5	38	542
SSF TEQ XXL	SSF-TEQ-XXL/	Yellow	50	5	55	555
BAS 19"	BAS 27300 19"	Yellow	32	3	35	198
EN54 19S	EN54 5465 19S	Orange	149	21	170	647
PLU	PLU 1270 - STS	Orange	22	8	30	327
OPTIONAL EXTRA	T/BAS-SDX 24	White	4	1	5	60

Table 9: Workstations takt time

Workstation	Takt Time [min]
Blue	16
Yellow	72
Green	149
White	54
Orange	217
Brown	88

Heijunka

Currently, Milleteknik does not use any type of leveling within their production. That can be seen by looking back at the production volumes plot presented in chapter 4.2, which shows how unstable they day to day production is, varying from 25 - 187 products produced. However, it has to be taken into consideration that the time it takes to produce a product, battery backup or optional extras, varies from 5 minutes up to 170 minutes in total production time. Therefore, their day to day production volumes will always vary. In order to know if the variation is within normal limits, the production capacity was calculated. The production capacity was found out by calculating how much each workstation could produce on a daily bases, based on having one operator full time on each station except for the white and green where one operator would work 50/50, as their production only has 5 working operators and 6 workstations. By calculating the capacity in that way is a realistic example as the blue, yellow, brown and the orange station are always in use while the green and the white are not utilized every day, see figure 32.

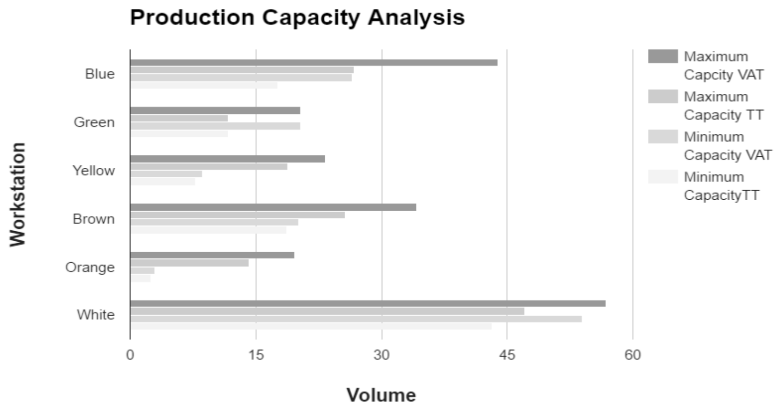

Figure 32: Production capacity analysis on each workstation

Due to each workstation producing products that have different total time the maximum and minimum production capacity had to be calculated. The maximum and minimum production capacity was both calculated based on the total time (TT) it takes to assembly the products and also based on the value added time (VAT). This was done in order to compare how much Milleteknik can produce and how much they could produce by eliminating all the non-value added activities. The production capacity of each workstation was then summed up in order to know their total production capacity. Their minimum capacity is 103 products a day and their maximum capacity is 198 products a day. That is due to their high variation of different production total time between their products, their day to day production volumes can vary between 103-198 products depending on what products are produced each day. Their total production capacity was then compared with their production volumes were normal limits of production volumes were defined between 103-198 products a day.

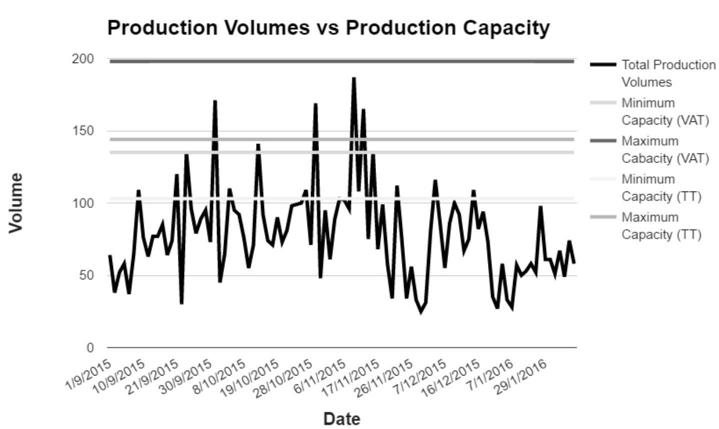

Figure 33: Production volumes compared with production capacity

Figure 33 shows that Milleteknik has overcapacity that they are not utilizing, where capacity is how much a process can produce over a given time period. Based on the time study, Milleteknik is able to produce minimum 103 products per day and by reducing the current waste or the non-value adding activities they are able to produce minimum 135 products a day. By comparing their daily production volumes and their minimum production capacity it was seen that 85% of the time from September 2015 - February 2016, their production volumes were lower than their minimum production capacity. Therefore, figure 33 shows that currently, the production at Milleteknik is unstable and they can produce more than what they are currently producing. This analysis shows that balancing the workload to the capacity of the process is needed at Milleteknik in order to help them utilize the capacity of the their production better.

As explained in the empirical data, Milleteknik is sometimes not able to meet the customer demand and therefore, products are delivered late. That can be explained by the fact that the operators are given control of what needs to be produced. The production manager gives guidance, by giving the operators information about customer orders and numbers of what products is currently ready in stock. Then the operators decide what to produce based on the information from the production manager. From the data collection, it was observed that the operators sometimes produced a product to stock that was not needed, instead of producing a product that was needed by the customer. The operators however, did not have enough information to know what product was needed the most. That led to a problem in the warehouse that some products had been overproduced and there was a lot of inventory of unneeded products, and no inventory of other products needed.

5.2.2 Designing the lean production planning and control techniques

The design of the lean production planning and control techniques was focused on the test cell described in the last chapter, or chapter 5.1.2. The data and knowledge generated could then be used to design the techniques around the rest of Milleteknik´s production.

Pull system

The first step of designing a pull system is understanding where continuous flow can be introduced as according to Rother & Shook (2003), the need for pull system is only necessary at places where continuous flow cannot be reached. Therefore, a study of where continuous flow could be reached was conducted, both between the subcells of the test cell and between the cell itself and the incoming raw material. Firstly, the test cell has three different sub cells with different process steps and includes 37 products that vary both in size and complexity. The cells do not include any type of heavy machines or tools that make it more efficient to produce batches. Therefore, producing one product from start to finish, without generating any inventory, is something that is possible. The time it takes to produce these products, on the other hand, varies from 10 - 24 minutes and therefore, the time each product stays at each cell varies. The cell that has the biggest variation in time is cell number two where the estimated cycle time varies from five to 13 minutes but for CELL 1 and CELL 3 the process time only varies around one minute. Having this different cycle times, will cause difficulties in balancing the cells and lead to inventories building up between the cells. Therefore, reaching a continuous flow between the cells for all of the different types of products is hard to achieve. When continuous flow cannot be reached, a pull system should be used to keep control of the system (Rother & Shook, 2003). Due to the fact that so many different products will be produced at the cell, keeping inventory of all possible parts between the cells is not seen practical. Therefore, choosing between the pull systems Sequenced Pull or FIFO Sequenced Flow as Rother & Shook (2003) recommend in that type of situation is seen as the appropriate solution for Milleteknik to keep control of the inventory between the cells. The benefits with these pull systems is that they have good control of the WIP, both in regards to limiting the WIP itself and limiting the variability of the WIP which matches what Huang & Kusiak (1996) describe. These systems include having defined maximum amounts of WIP that makes the downstream process, stop producing when they have reached that limit and therefore, make sure that they don't overproduce. These pull systems have further proven to be successful according to Araújo & Alves (2012), even in situations where processes have different cycle times and instability. Therefore, those systems is something that Milleteknik can use, despite them having different cycle times in the production.

Secondly, a study of reaching continuous flow between the cell itself and the incoming raw material was performed. Having continuous flow between the cell and the raw material in the production can be a problem, due to of the fact that the lead time of products varies and can be up to six months to arrive, therefore, there is often missing material in the production. Further, the material handler at Milleteknik does not have standardized times on when to fill the bins of raw material in the production that further leads to problems reaching a continuous flow between these two processes. Hence, continuous flow cannot be reached between the cell and the incoming raw material. In order to cope with that, a supermarket pull or a kanban system would be suitable for Milleteknik to adopt into their production, because according to Coleman & Vaghefi (1994) a kanban system helps to supply the parts needed on an appropriate time. As said before, in chapter four, Milleteknik has currently some type of a kanban system, where they have bins or containers, that Schonberger (1983) describes that should have small quantity, for all of their material, they also have component racks for the bins and have a material handler that fills up the missing material. However, what is missing, are the kanban cards and having a standardized time for the material handler to take care of the cards. Between the raw material (the warehouse) and the cell should be incorporated a withdrawal card, see figure 34. Then when an operator takes a card from the bin in the supermarket, the card goes to a pile of cards that the material handler takes to the warehouse to know what is needed. In the warehouse he fetches the needed material and brings it to the supermarket.

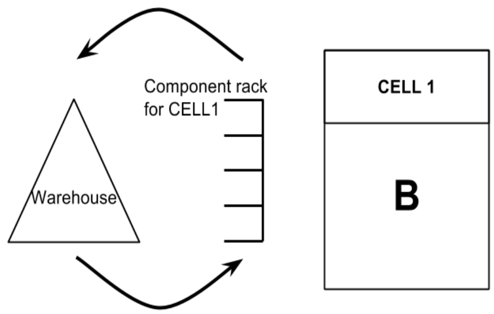

Figure 34: Kanban between warehouse and the cell

One part in the battery backups, the PCBA, does not go directly from the warehouse to the cell. Then both a withdrawal and a production card is needed in order for the PCBA process to know what to produce. Then, the process would start the same, the operator at CELL 1, takes a card from the bin in the supermarket, the card goes to a pile of cards that the material handler takes to the PCBA supermarket. From the PCBA supermarket, the material handler takes a production kanban to the PCBA and then takes the ready products and put it into the ready PCBA supermarket, see figure 35.

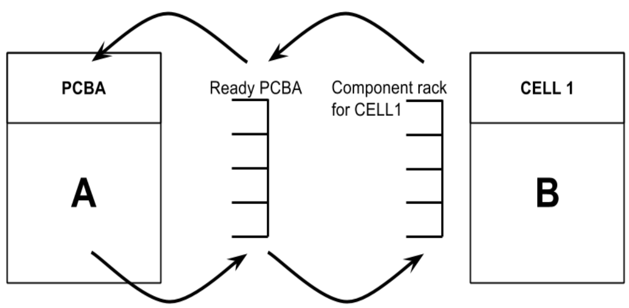

Figure 35: Kanban between the PCBA process and the cell

As described in chapter two, the most common kanban systems are one card kanban and two card kanban systems. Since Milleteknik is having problems with both materials missing in the production as well as problems with the planning of what should be produced, a two card kanban is seen as a better option for Milleteknik to incorporate into their whole production system. Firstly, a withdrawal card kanban should be implemented where needed, like described above for the warehouse. After the withdrawal kanban has been implemented the production kanban together with a heijunka box should be implemented for controlling both the production at PCBA production and the production in the cell itself, more information about the heijunka box can be seen later in this chapter. The benefits of implementing this kind of a pull system is that the fluctuations in the production should decrease and therefore, the production will become more predictable that further leads to the control of the flows becoming more clearer as Rother & Shook (2003) describe. However, the challenge for Milleteknik is fulfilling the requirements for having a two card kanban system for the PCBA process. Huang & Kusiak (1996) describe that one of the challenge of having a two card kanban system is having a fast turnover of kanbans which, could be a challenge for Milleteknik. In order to cope with that challenge, Milleteknik should use takt time control, which is described in next chapter.

Takt time

Milleteknik's current production is put together with six different independent workstations that all have their own production process steps. None of these workstations or the different production steps are currently being takt time controlled due to the different products at Milleteknik have different customer demand rate as shown in table 8. Also the different products have different process steps that lead to high variation in total process time, that further lead to difficulties of using takt time control. However, according to Slomp et al. (2009), using takt time control in this type of environment is difficult but not impossible. Instead of having takt time controlled process steps, the production system itself can be takt time controlled, and according to Slomp et al. (2009) that is called generalized takt time control.

As previously described, the focus is on how the new cell system can be efficiently planned and controlled and therefore, the focus was on creating a generalized takt time control for the cell as the different process steps on the cell have have different cycle times for different products, see figure 36. Customer demand, from the year 2015 for all the product types included in the cell, was used to calculate the takt time for the new cell system, which was 12 minutes, see table 10. That means that a product has to leave the cell or the system every 12 minutes in order to meet the customer demand. Therefore, all the different subcells designed in the test cell cannot have higher cycle times than 12 minutes in order for Milleteknik to be able to deliver customer orders on time. That is further explained by Yassine et al. (2014) as they state that if the rate of the production is higher than the takt, the process is unable to deliver and fulfill the customer need.

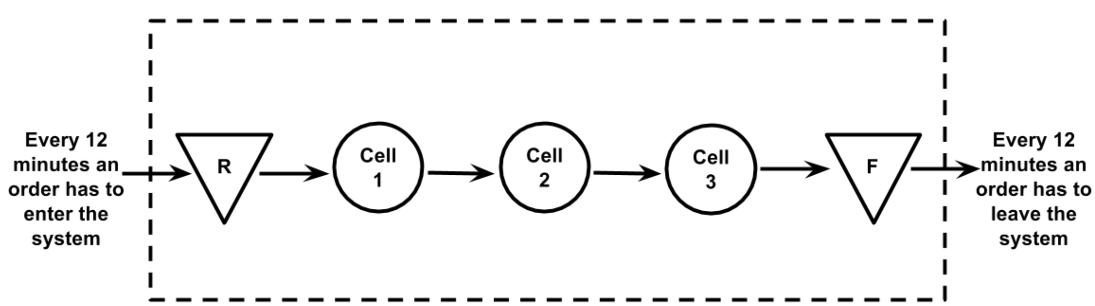

Figure 36: Generalized takt time control for the cell

Table 10: Cell takt time

Product Type	Product Type Takt Time [min]	Cell Takt Time [min]
ECO MINI	149	12
ECO XXS2	69	
ECO XS	36	
SSF TEQ XS	84	
BAS XM	119	
SSF TEQ XM	282	
EN54 XM	384	

By comparing the takt time of the test cell with the estimated cycle times of the different subcells, see table 4, all of them, except for one product type at cell 2, are under the takt time of 12 minutes and therefore, all products should be able to meet customer demands. On the other hand, due to the cycle time of the cells, in many cases, being lower than the calculated takt time, using only takt time control for the cell will make the cell overproduce. That is also further explained by Nutti & Lindström (2008) where they say that when the cycle time is faster than the takt time the risk of overproducing increases. Therefore, using other methods, like a pull system that was described here above and heijunka that will be described below, is important to use to control the cell and make sure that the resources are utilized efficiently.

Further, it is important to match the capacity with the demand and with the current customer demand the cell has high overcapacity due to its cycle times being a lot lower than the calculated takt time. This is however, only the case if two or three operators are working on the cell. If one operator is put on the cell, the total cycle time of the three cells is more or less always higher than the takt time. Therefore, a mix of having, one, two or three operators working on the cell depending on the needed output is important in order to match the capacity with the demand. With that said, it is important to reevaluate or recalculate the takt time over time in order to match the capacity with the takt time, in order to prevent the cell from both overproducing and producing too little, like Yassine et al. (2014) explained.

Heijunka

In order to balance the inventory levels and be ready with products when the customer needs it, heijunka could be used in Milleteknik. When the takt time and pull have been implemented, the production will be more predictable and stable than before. Therefore, the production manager could have more control of the production by leveling the information he has (customer orders and inventory numbers). According to Liker & Burr (1999) a load leveling box or heijunka box can be used to level the schedule. Since the takt time of the test cell is 12 minutes, it could be planned to produce products so that every 12 minutes a product come out of the cell. By using the takt time analysis, it can also be seen what products needs to be produced at what time, which matches what Rother & Shook (2003) say, that the takt time can be used to organize the heijunka box. Table 11 shows an example of how heijunka box could look like for Milleteknik in the beginning of the day. For example, the product type ECO XS has a takt time of 36 minutes and therefore, a new production needs to start every 24 minutes to match the takt time. In order to know what product to produce of the product type ECO XS, the takt time of each product needs to be studied. When the takt time is further studied, the product ECO 2750-XS (BT12) has the highest takt time and therefore, should be produced most often. Then other product needs to be produced along with that product and is determined according to their takt time. The same logic goes to the all other product types in this cell. When designing the heijunka box, it is not enough to only think about the takt time, but the time it takes to assembly a product also needs to be taken into consideration. That time determines how many operators should be working on the cell in order for it to function, therefore the production manager needs to think of that as well when planning the heijunka box. Table 11 was organized as if two operators would be working on the cell and therefore, the time it takes to produce (cycle time) should not exceed the takt time because then the customer orders cannot be met as Schneder et al (2015) describe. However, having the heijunka box controlled by the takt time of 12 minutes is only appropriate for this test cell and if the heijunka box is located besides that cell. The takt time needs to be recalculated if the heijunka box should be used for the whole production and be located centrally in the production.

Table 11: Example of heijunka box

Product Type	7:00	7:12	7:24	7:36	7:48	8:00	8:12	8:24
ECO MINI		ECO 2730 XXS2					ECO 2730 XXS2	
ECO XXS2								
ECO XS	ECO 2750-XS (BT12) & ECO 27100-XS		ECO 2750-XS (BT12) & TRIO 27100 PS		ECO 2750-XS (BT12) & ECO 27100-XS		ECO 2750-XS (BT12) & ASSA 2750 PS	
SSF TEQ XS				BT 16 COM				
BAS XM						BAS 2750-XM		
SSF TEQ XM								SFF TEQ XM/BT40
EN54 XM		EN54 2730-XM						

When the heijunka box time slots are 12 minutes, there is going to be at least one product coming out of the system every 12 minutes. However, not every product on the cell take 12 minutes to go through the system, depending on how many operators are working on the cell. In order for Milleteknik to utilize their operators fully, the production manager must plan the heijunka box according to how many operators are working on the cell. If there is one operator, the production manager can plan to have one product in each time slot, however if there are three operators, the production manager must plan more products in each time slots because then the product is faster through the system. By planning to produce more products in each time slot according to the number of operators, the operators will be utilized fully. However, the production manager must plan according to customer needs and level the plan out by having the operators utilized fully without overproducing. The cell was designed to cope with overcapacity so it will be easy to increase the volume produced on the cell. That is because Milleteknik is growing and therefore, the cell was designed to be flexible in relation to capacity and the heijunka box compliments that flexibility factor.

As can be seen in table 11, the EPEI (every part, every interval) has been determined as Lippolt & Furmans (2008) describe as an important step in leveling. When having two operators working on the cell, the EPEI should not be more than two parts every interval because of the takt time that the cell has and because of how long each part takes. But, Lippolt & Furmans (2008) also say that the leveling need to be adjusted when needed by using continuous improvements. Milleteknik needs to be aware of that, and strive for producing every part every shift by reevaluating and changing the leveling when needed. Further, Liker & Burr (1999) describe that the heijunka box is so visual and Milleteknik could use the visuallity to know when to adjust the leveling. For example, if a card has not been taken from the heijunka box on the right time, or several cards, the production manager knows that something needs to be changed.

Lastly, the planning and control techniques are often used together and not individually as they all connect to each other. The heijunka box needs a kanban system to supply parts at the time needed as Coleman & Vaghefi (1994) describe. Therefore, it would be good to connect the heijunka with the kanban as well as the takt time as Rother & Shook (2003) explain. The heijunka box will then have a column of kanban slots for each interval and both quantity and how long it takes to produce will be based on the takt time. When all three techniques, pull, takt time and heijunka, have been implemented, the production at Milleteknik should become more stable and not as fluctuating as before.

5.2.3 Impact of lean production planning and control on the production flow efficiency

After having analyzed the current production flow and designed how the lean production planning and control techniques can be used, it was seen that many of the changes towards using these techniques affect the production flow efficiency, see table 12. Firstly, by using a pull system the *material should not be missing as often as before*. That is because according to Rother & Shook (2003) pull system controls the flow in the production. Further, Coleman & Vaghefi (1994) describe that kanban supplies parts when needed so the situation at Milleteknik should be improved by incorporating the cards and standardize the material handlers times to check the material. Therefore, implementing pull should improve the production flow. Secondly, by introducing takt time, previously observed *waste will be reduced,* like interruption from others should not occur as often as before. That is because then, the operators have more clear instructions and they all work towards a goal that both they and others know about and therefore, the operators would not want to be interrupted as well as others don't want to affect the visual goal of the production. Hence, a smoother flow will be created. Also, by introducing kanban, waste like high raw material stock will be reduced as the system prevents inventory from growing beyond adjusted limits (Hopp & Spearman, 2004).

Thirdly, the *production will be more stable* by introducing heijunka. The problem of overproducing and producing what is not needed should be eliminated by using a heijunka box. Milleteknik has overcapacity in their production and by leveling out what needs to be produced, it is believed that Milleteknik should be able to make the production more stable and utilize the existing capacity to a greater extent. By doing that, the flow of products will be more efficient because the requirements of having efficient flow is having a stable production according to Liker & Meier (2006). Fourthly, in relation to the stableness, by introducing all three of the lean production planning and control techniques the production will be more *predictable*. The pull helps the material to be in place, the takt time helps the waste to be reduced as well as make sure that knowledge of customer requirements are in place and the heijunka helps to balance the production and make it stable. With this predictability, information to other departments will be easier which affect the production flow. For example, the purchasing department gets better knowledge of when to order material, which improves the missing material problem as well. This further allows them to plan more in advance and therefore, there will be less bullwhip effect and more predictability from the suppliers. That also matches what Matzka et al. (2012) say, that when a process supplies one or more customer processes with a constant flow of small lots while generating constant demand of parts for upstream processes reduces the bullwhip effect.

Fifthly, the techniques make the flow more *visual in regards to what to produce*. If the production is behind schedule, it can easily be seen in the heijunka box. The operators are then, not only aware of the behind schedule but also everybody else who look at the heijunka box. The one who plans it, can then easily identify that something is wrong and change it. By having it so visual, the operators and other departments will become more aligned with how the flow should be scheduled. By having the operators and other departments (for example the planner) so aligned the flow should be better since mismatch should not occur. Sixthly and lastly, with heijunka, takt time and pull, there should also be *less WIP* since the production will be more controlled which matches one of the objectives of production planning and control that Stevenson et al. (2005) elaborates on. Huang & Kusiak (1996) also state that both low WIP and fast turnover of WIP are requirements for having the kanban work efficiently and therefore, low WIP need to be in place to make the flow efficient.

Table 12: Identified impact to the production flow by adopting lean production planning and control

What (What impact was identified?)	How (How will it impact the flow?)	Why (Why does it impact the flow?)
Missing material reduction	From material often missing → To material flow controlled by kanban	The needed material will be in place at the time needed
Waste reduction	From operators often be interrupted and having high inventory → To introducing takt time where operators do not want to be interrupted and others don't want to affect the visual goal of the production. Also to introducing kanban where inventory will reduce.	Higher value adding time and therefore, less time that goes to work not related to adding value to the product in the flow
Stable production	From unstable production with overcapacity → To the production and capacity being balanced, using a heijunka box	The requirement of efficient flow is a stable production
Predictable production	From unpredictable production → To the techniques making the production predictable	Reduces the bullwhip effect by having constant flow of small lots while generating constant demand of parts for upstream processes
Visual what to produce	From operators not knowing what products to produce → To operators seeing more clearly what is needs to be produced	Operators and other departments will become more aligned with how the flow should be scheduled
Less WIP	From having different amounts of WIP in the production → To having WIP more controlled	Low WIP and fast turnover of WIP are requirements for having efficient kanban and therefore, low WIP need to be in place to make the flow efficient.

6 Discussion

This chapter will present the discussions about the findings of this master thesis. The chapter will present the discussions about the learning and difficulties in this research along with findings that were out of the scope relation to lean and SMEs.

6.1 Cellular manufacturing

The design of the cellular layout was only focused on creating one test cell and therefore, only part of the production layout was changed. Due to that, the complete process of designing a cell was only conducted on part of the products or only one product family. By creating a test cell before changing the whole production layout, was seen as a really good decision in this case and something that can be seen as a benefit of implementing a cellular layout as the cell can fully operate despite the rest of the production using another type of layout. Also, because then you get the opportunity to learn about how to design the cell and change if something was not done correctly the first time. When that has been understood, cellular layout can be implemented to the rest of the production with better knowledge on how to do it.

Taking a decision on how many cells are applicable to implement and how the products should be divided was found to be the most complex part of designing a cellular system and something that has to thoroughly thought about. One of the biggest decision was deciding how flexible a cell needs to be, where the fewer cells you have the flexibility in relation wider range of products, design changes and process flexibility increase but the capacity flexibility decreases. This has a big impact of the design of a cellular layout, where the amount of cells you want to have and what product should be put together in a production family, controls the rest of design. Therefore, if the first step would have been conducted differently in this study, the design of the system could have been different. These findings strengthen what theory explains where they say that this first step of cell design controls the rest of decisions taken in the design process. Further, the design of the system conducted in this case study was done by using as much of their existing workstations as possible that could have affected the findings of this study. If the cell would have been designed with newer technology or other different material, both the lead time of the implementation could have been longer as well as the design of cell could have further been different that could have affected the results.

Lastly, the findings of this study show that most of the benefits of cellular manufacturing that are presented in theory were also identified in this study. However, in theory many challenges of using cellular manufacturing in an SME environment are presented but in this case study, these challenges were not identified. These challenges are lack of sufficient space, duplication of resources, introduction of new products, sharing of key resources, difficulty of moving machines, under utilization of resources and demand variability. The designed cellular layout rather seemed to help reduce these challenges. The cellular layout increased the space available in the production, created less duplication of resource, had better utilization of resources and made introduction of new products more easier than before. These findings can mainly be connected to the previous layout of the production area in the case study, as the cellular layout helped reduce the amount of previous workstations in the production. Further, there were no expensive or heavy machines needed to be thought of when designing the layout. These findings do therefore, not correspond to what theory explains and is something that needs to be researched further. A challenge that was however, faced in this research, when implementing cellular layout to an SME, and is also described in theory, were disruption to production and therefore, the test cell was not tested as much as planned.

6.2 Lean production planning and control

The impact of the lean production planning and control techniques on the production flow efficiency was only studied in relation to cellular manufacturing and therefore, these results could differ for other type of production environments. Further, this research was conducted only in relation to one production cell without taken into consideration the whole production. It is though believed that these results would have been the same if the whole production would have been studied. However, the design of the system itself could have been different, where for example the heijunka box could be positioned in the center of the production instead of besides the cell. That would further lead to the takt time needed to be recalculated, in regards to the demand of the products involved in the system. Establishing takt time control can be difficult since it needs to be re-evaluated regularly and changing the production pace regularly in connection to the demand can be difficult. The need of changing the production pace regularly makes it difficult to use resources efficiently and balance the capacity with the productivity. Therefore, to be able to cope with demand variation, the system designed in this study was made flexible in relation to capacity. When a system is flexible in relation to capacity, the operators need to be utilized fully but still not overproduce and only produce according to the customer needs. The takt time control may seem easy to adopt, but in reality it is difficult to plan and control the production according to customer needs without having any waste. Therefore, it is believed that both pull and heijunka, complement the takt time control in relation to having less waste when pull reduces waiting time by supplying the right material at the right time and heijunka reduces overproduction by leveling out the production volumes. But even when all those three techniques are used, there still need to be thought of doing things efficiently and re evaluating regularly because customer needs change over time.

6.3 Lean production and SMEs

Lean tools in general are all about simplicity. The system cannot be too complex and it would be best, if everything is visual and everyone understands what is going on, but that is not always the case. As has been discussed before, knowledge about the tools is often missing in SMEs, which can lead to that the employees think that they are implementing lean, but maybe do not have the right knowledge to know that they are only halfway there. For example, with cellular manufacturing, it is not enough to rearrange the workstation into cells and then you have cellular manufacturing. There is so much more behind every lean practices and tools. Also, in this case study, the company studied had a kanban system but did not use it to control the production, only as an inventory system. The kanban system was also more complex than it needed to be but that can be related to the lack of knowledge of kanban systems in the company. One of the factors that can explain the complexity of their kanban system is that the component boxes are used as the signal. The component boxes had a lot of good information but it made it complex, different colors, signs, instructions etc. The company did not use cards as a signal, which made changes and improvements more difficult because then, all the bins would need to be changed as well. It would have been easier to have cards and then just print out new ones if changes needed to be made. By making the tools of lean too complex or wrongly implemented, it can make a lot of constraints for the production, which happened in this case study. It was problematic to change the layout to cellular layout because the kanban system was really difficult to change. Lean is all about improvement and therefore, there system may not hinder changes like was in this case. It should be the other way around, where the lean tools should support the production and help them improve by being flexible and having the possibility to cope with changes, not make constraints on the improvement suggestions.

Other interesting aspects of lean that was found in this study, is that lean tools cannot stand by themselves, they need people in order for them to work. When designing both cellular layout and lean production planning and control techniques, the designing itself was not the main challenge was rather getting employees involved and motivated to use it as well as understand the tools. For example, after designing the cell, it was implemented in the production, which was challenging, but it was more challenging to inspire the operators that this cell layout is better when they like their old way of working. Therefore, you need the people to use the lean tools. Also, in the case study, daily control meetings were held, where a big daily control whiteboard was utilized, which seemed really good in the beginning of the project but when attending the meetings, they were not utilized as should. It was more of an information meeting where operators gave the information to the manager about production volume numbers, which should have been exactly the opposite. The whiteboard was there, the meeting was there, but the people were the main reason for why the meeting was not working as it should. Therefore, people in lean tools are important factor, which need to be thought of when implementing lean tools. Those findings were outside the scope of the purpose but still an interesting and a valuable learning.

As described in chapter one, previous research has not put high focus on researching cellular manufacturing nor lean production planning and control in SMEs. However, this research indicates that cellular manufacturing and lean production planning and control techniques impact the production flow in SMEs in a positive way and therefore, it is beneficial for SMEs efficiency and competitiveness. Theory further describes that the lean concepts and methodology can be equally applicable for SMEs as large companies if adopted correctly and this research revealed that these two concepts, cellular manufacturing and lean production planning and control are no exception. This research therefore, strengthens previous research that lean concepts can be successfully implemented into a SME if adapted to their specific situation. However, the required knowledge needed to implement the cellular layout and the lean planning and control techniques is a big challenge because it is often missing in SMEs. That was no exception in this case study as the needed knowledge was not present at the company. Therefore, when SMEs are adopting lean, it is important to take care of the knowledge gap before starting to implement the tools.

7 Conclusion

This chapter will present the conclusions of this master thesis. The chapter concludes the findings of what impacted the flow efficiency both in relation to cellular manufacturing and lean production planning and control. Lastly, the chapter will conclude how the findings are connected to previous theory.

The conclusion of this master thesis is that both cellular layout and lean production planning and control techniques impact the production flow efficiency in SMEs. Using cellular layout involves creating more *standardized production steps* that impacts the changeover time and the throughput time. Also, it creates *less waste* within the production as all tools and material are positioned exactly where they need to be. Further, it *increases visuallity* of the production, *increases teamwork* and lastly *helps to reveal hidden problems*. All these identified findings, were seen to impact the production flow, both within the cell itself as well as other parts of the production, and therefore, answer the first research question: *How does cellular layout impact the production flow efficiency in a SME?* Lean production planning and control techniques, pull, takt time and heijunka, also impact the production flow efficiency, since they help resolving obstacles that can be in the way of reaching a smooth flow. By introducing pull, *the inventory control improves*, in regards to having the right raw material and finished products at the right time. By having takt time the *waste will be reduced*. Using heijunka, helps the *production to become more stable* by balancing the capacity in the production to the customer need. These techniques further help the production to become *more predictable* and therefore, reduce the bullwhip effect. The production will also become more *visual in regards to what needs to be produced* and lastly, the *WIP will be reduced*. All these identified findings were seen to impact the production flow and therefore, answer the first research question: *How does pull, takt time and heijunka, impact the production flow efficiency in a SME?*

These conclusions can all be connected to what theory explains are the impacts of cellular manufacturing and lean production planning and control. The increased visuallity and increased teamwork are however an exception as they don't seem to be the main benefits of using cellular manufacturing in previous research. The reason for that can be related to previous research being more focused on revealing the quantitative benefits of using cellular layout instead of the qualitative benefits. With that said, this research both confirms as well as adds new findings to previous research. Further, this study has revealed that there is a direct connection between those two areas and production flow efficiency in a SME production environment that has not been the focus in previous research. Therefore, this research is believed to be addition to literature of flow efficiency.

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Appendices

Appendix I - List of products

Battery Backups and Optional Extras Products														
Quantity	ECO MINI	ECO XXS2	ECO XS	SSF TEQ XS	BAS XM	SSF TEQ XM	EN54 XM	BAS XL	SSF TEQ XL	SSF TEQ XXL	BAS 19"	EN54 19S	PLU	OPTIONAL EXTRAS
1	ECO 1315-Mini	ECO 2730-XXS2	ECO 2730-XS	BT 8A COM	BAS 2730-XM	SFF TEQ XM	EN54 2730-XM	BAS 2750-XL_A	SFF TEQ XL	SSF TEQ XXL	BAS 27100-19"	EN54 2765-19S	PLU-1270	T-SPD L
2	ECO 2710-Mini	ECO 2750-XXS2	ECO 2750-XS (BT12)	BT 16 COM	BAS 2750-XM	SFF TEQ XM/BT40	EN54 2760-XM	BAS 27100 XL 24V	SFF TEQ XL/BT80+	SFF TEQ XXL/BT80+	BAS 27200/19"_A H	EN54 2765-19S TUL	PLU-1270-STS	T-4UT L
3	ASSA 1315 PS	ECO 2730-XXS2/N	ECO 2750-XS/NO	BT 32 COM	BAS 27100-XM	SFF TEQ XM/S3		BAS 27100-XL/Integr	SFF TEQ XL/S3	SFF TEQ XXL/S3	BAS 27300/19"_A H	EN54 27130-19S		T-4UT -19" M
4	ASSA 2710 PS	ECO 2750-XXS2/N	ECO 27100-XS			SFF TEQ XM-AA		BAS 27200-XL_A HS	SFF TEQ XL -AA	SFF TEQ XXL/AA		EN54 27130-19S TUL		T-4UT -XL M
5			ECO 27100-XS/NO					BAS 27300-XL_A HS				EN54 5465 19S TUL		T-4UT -XM M
6			ASSA 2730 PS									EN54 5465-19S TUL(SAC)		T-4UT -XS M
7			ASSA 2750 PS											T-4UT -XXS M
8			ASSA 2750 PSC											T/BAS-10UT L
9			ASSA 27100 PS											T/BAS-10UT XL M
10			ASSA 27100 PSC											T/BAS-10UT XM M
11			ASSA 271040 PSC											T/BAS-10UT 19" M
12			RUKO 2730-PS											T/BAS-10UT 19R M
13			RUKO 2750 PS											T/BAS-JFI L
14			RUKO 27100 PS											T/BAS-JFI - 19" M
15			TRIO 2730 PS											T/BAS - XST-XM M
16			TRIO 2750 PS											T/BAS - XST-XL M
17			TRIO 27100 PS											T/BAS - XST-19" M
18														T/BAS - XST L
19														T/BAS - SlingX XM M
20														T/BAS - SlingX 19R M
21														T/BAS - SlingX XL M
22														T/BAS - SlingX L
23														T/BAS LKAL
24														T/BAS - SDX24V-19" 1H L
25														T/BAS - SDX24V-19" 1H M
26														T/BAS - SDX24V-19" 2H L
27														T/BAS - SDX24V-19" 2H M
28														T/BAS - SDX24V-XL L
29														T/BAS - SDX24V-XL M
30														T/BAS - SDX24V-XM L
31														T/BAS - SDX24V-XM M
32														T DCDC 12V1A L
33														T DCDC 12V5A L
34														T DCDC 12V5A M

Appendix II - Division of products produced on workstations

Products divided on workstations						
Quantity	**Blue**	**Yellow**	**Green**	**White**	**Orange**	**Brown**
1	ECO 2730-XXS2	BAS 2750-XL_A	ECO 1315-Mini	T-SPD L	EN54 2765-19S	BAS 2730-XM
2	ECO 2750-XXS2	BAS 27100 XL 24V	ECO 2710-Mini	T-4UT L	EN54 2765-19S TUL	BAS 2750-XM
3	ECO 2730-XXS2/NO	BAS 27100-XL/integra	ASSA 1315 PS	T-4UT -19" M	EN54 27130-19S	BAS 27100-XM
4	ECO 2750-XXS2/NO	BAS 27200-XL_A HS	ASSA 2710 PS	T-4UT -XL M	EN54 27130-19S TUL	EN54 2730-XM
5	ECO 2730-XS	BAS 27300-XL_A HS		T-4UT -XM M	EN54 5465 19S TUL	EN54 2760-XM
6	ECO 2750-XS (BT12)	SFF TEQ XL		T-4UT -XS M	EN54 5465-19S TUL(SAC)	
7	ECO 2750-XS/NO	SFF TEQ XL/BT80++		T-4UT -XXS M	PLU-1270	
8	ECO 27100-XS	SFF TEQ XL/S3		T/BAS-10UT L	PLU-1270-STS	
9	ECO 27100-XS/NO	SFF TEQ XL -AA		T/BAS-10UT XL M		
10	ASSA 2730 PS	SSF TEQ XXL		T/BAS-10UT XM M		
11	ASSA 2750 PS	SFF TEQ XXL/BT80++		T/BAS-10UT 19" M		
12	ASSA 2750 PSC	SFF TEQ XXL/S3		T/BAS-10UT 19R M		
13	ASSA 27100 PS	SFF TEQ XXL/AA		T/BAS-JFI L		
14	ASSA 27100 PSC	BAS 27100-19"		T/BAS-JFI - 19" M		
15	ASSA 271040 PSC	BAS 27200/19"_A HS		T/BAS - XST-XM M		
16	RUKO 2730-PS	BAS 27300/19"_A HS		T/BAS - XST-XL M		
17	RUKO 2750 PS			T/BAS - XST-19" M		
18	RUKO 27100 PS			T/BAS - XST L		
19	TRIO 2730 PS			T/BAS - SlingX XM M		
20	TRIO 2750 PS			T/BAS - SlingX 19R M		
21	TRIO 27100 PS			T/BAS - SlingX XL M		
22	BT 8A COM			T/BAS - SlingX L		
23	BT 16 COM			T/BAS LKAL		
24	BT 32 COM			T/BAS - SDX24V-19" 1H L		
25	SFF TEQ XM			T/BAS - SDX24V-19" 1H M		
26	SFF TEQ XM/BT40			T/BAS - SDX24V-19" 2H L		
27	SFF TEQ XM/S3			T/BAS - SDX24V-19" 2H M		
28	SFF TEQ XM-AA			T/BAS - SDX24V-XL L		
29				T/BAS - SDX24V-XL M		
30				T/BAS - SDX24V-XM L		
31				T/BAS - SDX24V-XM M		
32				T DCDC 12V1A L		
33				T DCDC 12V5A L		
34				T DCDC 12V5A M		

Appendix III - Time study

Products	Type	Assembly Station	Date	Operators [sec]	Batch [sec]	Look at prodcuction plan for the week [sec]	Computer work/ Admini-strative work [sec]	Fetching Parts [sec]	Fetching Tools [sec]	Un-packaging [sec]	PCB Assembly [sec]	Power Supply Assembly [sec]	PS Calibrate [sec]	Casett Assembly [sec]	Cabinet Assembly [sec]	Cabinet Calibrate & Testing [sec]	Docu-mentation [sec]	Packaging [sec]	Waiting (Coffeebrake, interuption from others) [sec]	Rework and correcting mistakes [sec]	Value Adding Time [min]	Non-Value Adding Time [min]	Total time [min]	Value Adding Time [%]	Non-Value Adding Time [%]
ECO MINI	ECO 1315 MINI 2,4	Green	17/2/2016	1	5	0	100	141	59	0	-	41	27	-	480	15	12	60	169	0	**11**	**8**	**18**	**58%**	**42%**
ECO XXS2	ECO 2730 XXS2	Blue	17/2/2016	2	10	0	130	33	0	33	26	63	-	-	300	88	29	85	120	60	**10**	**6**	**16**	**61%**	**39%**
ECO XS	ECO 2750 XS	Blue	15/2/2016	2	10	0	100	4	0	51	33	80	-	-	400	164	47	42	140	0	**13**	**5**	**18**	**72%**	**28%**
SSF TEQ XS	BT - 8A COM	Blue	18/2/2016	2	8	0	100	4	0	20	50	90	-	-	366	180	39	40	61	0	**13**	**3**	**16**	**81%**	**19%**
BAS XM	BAS 27100 XM	Brown	16/2/2016	2	6	0	145	12	0	19	33	80	-	-	345	155	80	64	77	0	**13**	**4**	**17**	**75%**	**25%**
SSF TEQ XM	SSF-TEQ XM/BT40	Blue	18/2/2016	2	4	0	192	12	50	25	32	80	-	-	582	175	80	30	212	0	**16**	**8**	**24**	**67%**	**33%**
EN54 XM	EN54-2760-XM	Brown	23/02/201	1	1	0	25	8	10	13	-	98	-	-	903	139	32	115	43	0	**21**	**2**	**23**	**93%**	**7%**
BAS XL	BAS 27100 XL 24V	Yellow	18/02/201	1	1	0	190	20	20	0	-	55	60	235	600	55	45	60	40		**19**	**5**	**23**	**80%**	**20%**
SSF TEQ XL	SSF-TEQ-XL/BT80	Yellow	23/02/201	2	1	0	7	268	0	6	-	90	65	840	730	113	64	74	0	28	**33**	**5**	**38**	**86%**	**14%**
SSF TEQ XXL	SSF-TEQ-XXL/BT80	Yellow	19/02/201	2	1	0	50	40	0	0	-	73	76	1164	1391	182	50	61	213	0	**50**	**5**	**55**	**91%**	**9%**
BAS 19"	BAS 27300 19"	Yellow	16/2/2016	2	3	0	100	20	0	0	-	-	219	1282	333	31	21	55	60	0	**32**	**3**	**35**	**92%**	**8%**
EN54 19S	EN54 5465 19S TUL	Orange	16/2/2016	2	2	0	96	144	158	0	-	108	453	-	7102	1080	120	50	472	420	**149**	**22**	**170**	**87%**	**13%**
PLU	PLU 1270 - STS	Orange	21/3/2016	1	5	0	289	100	27	0	0	0	0	299	741	65	3	213.8	86.4	0	**22**	**8**	**30**	**72%**	**28%**
OPTIONAL EXTRAS	T/BAS-SDX 24V - XM	White	22/3/2016	1	1	0	47	0	0	0	-	-	-	-	-	-	10	218	0	0	**4**	**1**	**5**	**83%**	**17%**

Appendix IV - Designed production steps for cellular layout

<table>
<tr><th>Sub cell:</th><th>Power supply & PCBA:</th><th>Cabinet Assembly</th><th>Test & Packaging</th></tr>
<tr><td rowspan="5">Process steps:</td><td>2. Calibrate PS</td><td>5. Prepare Cabinet
5.1 Pick up cabinet
5.2 Take cabinet from box
5.3 Put in effect mobtan
(EN54, TEQ XM, ASSA)
5.4 Put door on cabinet (XM)
5.5 Put panel
5.6 Put door security
(TEQ XS, XM, ASSA)</td><td>10. Test the cabinet</td></tr>
<tr><td>3. Assembly PS
2.1 Put cable on PS
2.2 Put fan on PS (*)</td><td>6. PS to Cabinet
6.1 Fasten PS to cabinet
6.2 Fasten fan to cabinet
6.3 Fasten cassette to cabinet (XM)</td><td>11. Packaging
11.1 Pick up packaging box
11.2 But sticker on cabinet and box
11.3 Prepare documentation and “extra bag”
11.4 Package the cabinet</td></tr>
<tr><td rowspan="3">4. Assembly PCBA
3.1 Take out from bag (*)
3.2 Put fuses (*)
3.3 Move jumpers (*)
3.4 Put BAS black box (*)
3.5 Put black plastic pin (*)
3.6 Put white plastic (*)
3.7 Move PCBA and PS to the correct Kanban line (*)</td><td>7. Diode to Cabinet (Panel to cabinet in EN54)
7.1 Put diode in diode box and in cabinet (Put display + panel + button in cabinet)
7.2 Put earth cable in cabinet
7.3 Put diode cable + white hangers in cabinet
7.4 (Put ribbon cable + heat sensor for EN54)</td><td>12. Administrative Work
12.1 Stop production in the computer
12.2 Put on a pallet</td></tr>
<tr><td>8. PCBA to Cabinet
8.1 Fasten PCBA to cabinet
8.2 Connect cable and PCBA
8.3 Add additional PCBA and cable if needed
8.4 Put black stripps</td><td rowspan="2">1. Administrative Work
1.1 Start production in computer</td></tr>
<tr><td>9. Finish Cabinet
9.1 Put white rubber circles
9.2 Put key + hook</td></tr>
</table>