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Production Flow Efficiency with Mass Customization in Small-Medium Enterprises

A Case Study Within the Swedish Electronics Industry

Master thesis in Production Engineering

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Abstract

Small-medium enterprises within the electronics industry have experienced large difficulty in retaining production in Sweden. The large focus on customization of products introduces many challenges for the production system. Lean capabilities and tools are a way to help companies retain their competitive edge. Prior research has focused on how larger companies can adapt lean manufacturing. Therefore, this research focuses on flow efficiency in small-medium enterprises. Flow efficiency is a common metric in lean practices which follows a products movement as it moves through the process. In this project flow efficiency is examined with respect to how mass customization impacts the production system.

This research is based on a single case study; investigating the material and information flow along with the sociotechnical system. The research method has been mainly qualitative. The research approach contains value stream mapping, company surveys, interviews, and observations. The empirical data collected form the case study presents a map of the process in its current state. The empirical investigation is then compared to the theoretical framework in the analysis.

The analysis revealed that mass customization is challenging due to the vast number of unknown variables that customized products introduce to the system. The higher upstream customization occurs, the more demanding it is to standardize routes in production and secure desired lead times. Analysis of the material flow revealed that inefficiency is introduced into the production system by utilizing a push mechanism. Proper production planning and control plays a crucial role in the information flow and in the reduction of lead times. Moreover, communication and knowledge management facilitate flow efficiency. Lastly, it is important to that people with different functional expertise work together to produce these complex and customized products. All in all, these are large-scale changes and it takes time and energy to develop a system that can produce these complex and customized products in an efficient manner.

Keywords: Mass customization, production, flow efficiency, lean production, make to order, lean implementation, lead time, SME, sociotechnical system

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Anna Dean and Carl Swanström, Gothenburg, June 2017

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Abbreviations and Terminology

Abbreviations

AOI	Automated Optical Inspection
CONWIP	Constant Work In Progress
AOI	Automated Optical Inspection
CT	Cycle time
FIFO	First In First Out
ERP	Enterprise Resource Planning
HAL	Hot Air Leveling
IL	Inner Layer
KPI	Key Point Indicator
OL	Outer Layer
MIT	Massachusetts Institute of Technology's
ML	Multi-Layer
PCB	Printed Circuit Boards
POLCA	Paired-cell Overlapping Loops of Cards with Authorization
SME	Small and Medium-sized Enterprises
SMED	Single Minute Exchange of Dies
TPS	Toyota Production System
VSM	Value Stream Mapping
WIP	Work in Progress

Lean Terminology

Heijunka	Leveling the load
Kaizen	Small-scale continuous improvement activities
Muda	Waste
Mura	Uneveness
Muri	Overburden

1
Introduction

In this chapter the topic for the master's thesis is introduced. The introduction includes a short presentation of the background in general. Furthermore, the problem definition, purpose, and aim are presented.

1.1 Theoretical Background

The livelihood of small-medium enterprises, SMEs, is essential for a society's financial health due to their flexible and innovative nature (Rymaszewska, 2014). SMEs are characterized by their small size and their financial turnover (Rymaszewska, 2014). An SME plays a key role in providing employment in addition to supporting larger sized companies (Gunasekaran, Forker, & Kobu, 2000). In recent years, global competition has increased pressure on businesses and their production routines (Zhou, 2016).

Mass customization, as a strategical concept, sustains a competitive edge for organizations since the market demands for individualized products has been steadily increasing for years (Blecker & Friedrich, 2006; Hart, 1996). Qiao, Lu, and McLean (2006) state that mass customization is characterized by random and unpredictable manufacturing requirements. In Sweden, production has shifted from mass production to flexible manufacturing in order to produce such complex goods and services (Teknikforetagen, 2013). Flexible manufacturing's objective is cost-efficient production of customized products to a global customer base (Teknikforetagen, 2013). Fast and flexible production becomes essential to deal with external changes such as market development (Teknikforetagen, 2013; Qiao et al., 2006). Production and supply chain management need to become smarter to secure sustainability (Zhou, 2016).

To make companies more efficient, the popularity of lean manufacturing is undeniable. However, the majority of research within implementation of lean is centered around larger companies (Rymaszewska, 2014). For instance, Liker and Meier (2006) base their field book mainly on Toyota and how adding value to the customer through people is the kernel of their lean philosophy. Rymaszewska (2014) expounds on the universal applicability of lean and argues how SMEs can also benefit from the conversion to lean if the process is adjusted accordingly. Some authors argue that SMEs can be even more adept at adopting lean processes in comparison to larger companies. Traditionally, smaller companies are more agile in response to customer's needs and are more open to risk-taking and innovation (Rymaszewska, 2014). This claim arises from that SMEs are typically young companies with more flexible norms and codes of conduct (Rymaszewska, 2014). Moreover, small businesses tend to have an easier time gaining management support and commitment (Rose, Deros, Rahman, & Nordin, 2011). Special attention has to be paid to the difference in resource management and overall premise that SMEs face in comparison to large companies (Rymaszewska, 2014). Although there exists a large range of lean practices that are utilized by industry today, there is some dissension among researchers on which lean practices are adoptable for SMEs (Rose et al., 2011). However, they agree upon the goal of improving the organization's efficiency and competitiveness (Zhou, 2016). Therefore, further research should be aimed at gaining a deeper knowledge of application of lean methodologies in SMEs and the benefits to smaller companies.

For the past 200 years, industrial development has focused on maximizing the resources' value-adding time (Modig & Åhlström, 2012). Modig and Åhlström (2012) describe how many organizations make the mistake of defining their processes with respect to their machines' operations. A common concern within an organization is if the resource is being utilized or is it standing still (Modig & Åhlström, 2012). As exemplified by Modig and Åhlström (2012), strong focus on resource efficiency can lead to long lead time for products. Liker and Meier (2006) argue the importance of utilizing a flow efficiency perspective; flow efficiency focuses on a product's path through the process (King & King, 2015). Value is increased as the product moves continuously through the process steps (Modig & Åhlström, 2012; Stewart, 2011). Flow efficiency is improved by shortening the time it takes a product to flow through the entire process (Modig & Åhlström, 2012). Sustaining flow efficiency, or continuous flow, additionally serves to uncover problems (Liker & Meier, 2006; Rother & Shook, 2003). Moreover, continuous flow aids in identifying issues impeding the flow of products visualizing the value stream (King & King, 2015). Correcting the issues gives an opportunity to build a more robust production system (Liker & Meier, 2006).

1.2 Industry Background

Production of printed circuit boards, PCBs are the mechanical support for electronic components, connected by conductive tracks to achieve desired functionality of electronics. PCBs, in Sweden has during the 21st century been under strenuous pressure due to globalization. A large part of the Swedish PCB manufacturing industry has been sold or moved overseas as a result of competition from emerging markets' efficiency of low-cost production and trading.

The electronic business is a fast moving market suitable for make to order strategies (Holweg & Pil, 2001). The issue of managing lead time and regulating flow requires analysis to adapt lean production methods. This is particularly true for SMEs in markets with increased globalization, such as the Swedish electronic industry. Moreover, machinery adapted for large lot and batch production, as observed in the PCB industry, challenges responsiveness when handling smaller production lots in the production systems. Smaller orders bring difficulties with material utilization and increased order handling. Another weakness is the complexity of the process as orders are highly customized, various processes are put under varying levels of stress.

1.3 Purpose

The production system, as the transformation process between input and output, is often a core function of a business. Production encompasses every part of the production process utilized to create a marketable product (Teknikforetagen, 2013). The design and development of high-performing production systems is therefore often essential for a business' sustainability. Mass customization systems for complex goods and services face a challenging role in attaining the vital goals of reduced lead-time and production cost (Qiao et al., 2006). *The purpose of this project is to gain insight on how mass customization impacts the production system.*

Past research has proven that lean production has been successful in enhancing a company's competitiveness and efficiency. Products that move progressively through the various processes with minimal waiting time between them and the shortest distance traveled, will produce the highest efficiency (Liker & Meier, 2006). Flow efficiency is the concept the describes a product's path through the system (King & King, 2015).

Previous research has placed large focus on how lean production can be adopted and implemented into large organizations, yet the application for SMEs is still largely uncharted (Zhou, 2016). This research project studies flow efficiency in SMEs. In particular, this research considers a case study of an SME with made to order products for a vast span of end customers. This leads to the first research question:

How does mass customization impact the production flow efficiency of an SME?

The creation of flow is a central focus of lean production (Liker & Meier, 2006). Rother and Harris (2001) state that the production flow is comprised of three subsystems: information flow, material flow, and the operator's work. The information flow examines the communication channels, e.g. how the production goals are communicated and how concerns are lifted (Rother & Harris, 2001). The material flow is characterized as the movement of the product from raw material to the customer (Rother & Harris, 2001). This thesis critically reviews how the the material and information flow influenced the production flow efficiency in the context of mass customization in SMEs. This leads to the following research question:

How do the material and information flows impact the production flow efficiency of an SME?

Rother and Harris (2001) also comment on how the operator's work affects the productions flow. The application of the sociotechnical perspective in work organization can lead to increased productivity (Trist et al., 1978). Thus, the sociotechnical system's influence over the production system is also of interest when studying production flow efficiency. This leads to the third research question:

How does the sociotechnical system impact production flow efficiency of an SME?

The project will study how the flow efficiency is affected by the material and information flow and sociotechnical perspective in the current state. With the aid of the theoretical framework, the authors will suggest an improved future state and steps to assist the transformation.

1.4 Scope and Delimitations

The project researches improvement of production flow efficiency, using Cogra Pro AB (referred to as Cogra from now on) as a case study. This research considers the investigation of the in-house production flow in a single SME where the focus will be on studying the flow for tree product families, and therefore, other products will be excluded.

The approach is specific to this case but has not been found to impact generalized findings of the research. Studying the customized composition of production panels yield the opportunity to optimize buffers before this flow, these areas are excluded from this project. The thesis examines in depth the production steps where large fluctuations emerge. Furthermore, efforts will be made to identify an appropriate pace of production, TAKT time, with input from the customer demand to aid planning stages, and construct a future state enhancing flow efficiency. The research focused on lead times as the main measurement of improvement. The research also considers motivation to be a measurement of improvement.

The thesis does not include financial analysis or viability of the company's business plan. However, parts of this thesis can be used to serve that aim, as secondary outcomes from flow effectiveness may affect cost scenarios.

In the exploration of the future state, the company's resources and possibilities are restricted which take more variables into account. The research focused on large-scale improvements that aid production flow efficiency for the production system.

1.5 Report Outline

This thesis is organized in different chapters that characterize this research project. This chapter describes the project and industry background along with introducing the project's purpose, scope and delimitations. The fourth chapter presents the theoretical framework. The third chapter describes the method formed and employed to answer the research questions. This chapter includes descriptions concerning the data collection and analysis methods. In addition, research quality and ethical aspects are discussed. Chapter four presents the empirical data regarding the case study. Chapter five integrates the empirical data presented in the previous chapter with the theoretical framework. Chapter six follows the structure of chapter five, however chapter five focuses on analyzing the current state and chapter six focuses on the future state and speculates on how flow efficiency can be improved. Chapter six discusses steps to reach a future state for the case study. The seventh chapter presents a discussion regarding the findings of this research and applies them to a broader scope. Chapter eight presents the conclusion of this research project.

2

Theoretical Framework

The theory chapter presents the theoretical framework relevant to this master's thesis.

2.1 Production Systems

During the 1990's, it was observed that holistic view on production systems were required to regard the system in totality (Bellgran & Säfsten, 2010; Wu, 1994). A holistic perspective implies that the system should be designed so that technical, physical, human interference and work organization is to be considered when viewing the production system (Bellgran & Säfsten, 2010). Bellgran and Säfsten (2010) state several views on the definition of a production system. The most simple is the transformation of a product from input to output (Slack, Brandon-Jones, & Johnston, 2016; Wu, 1994). Wu (1994) exemplifies the transformation of products with the black-box principle, where one block describes the system as a whole. Hubka and Eder's (1988) example of a production system includes executing system, active environment, passive environments and various subsystems (Hubka & Eder, 1988). With respect to identifying factors affecting existing production systems, Bellgran and Säfsten (2010) summarized three categories to shed light on what has shaped the system. The categories are: actual options, external influences & strategies and fundamental attitudes viewed in Figure 2.1.

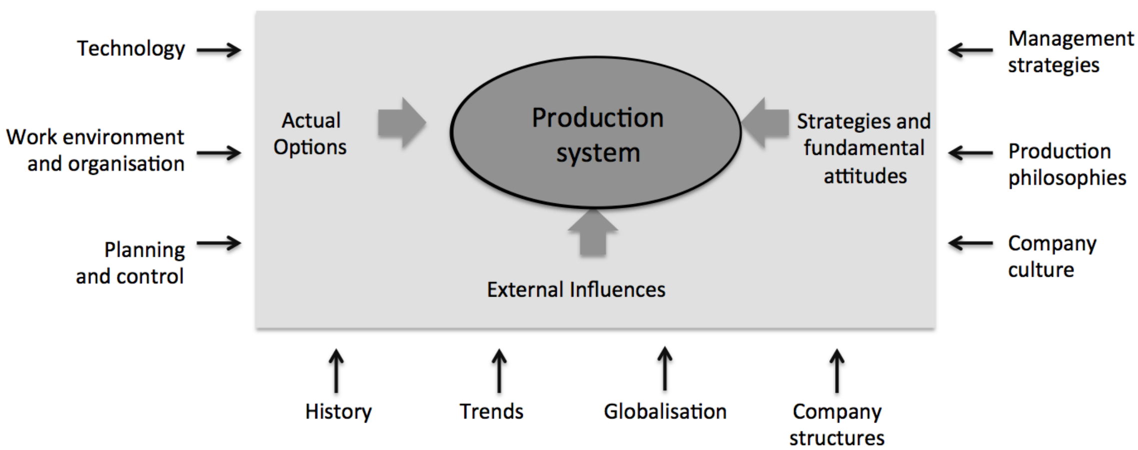


Figure 2.1: Factors affecting the production systems (as viewed in Bellgran and Säfsten, 2010).

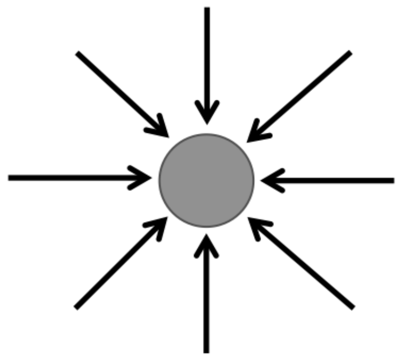
As the production system is shaped by the three categories and corresponding factors, it indicates complexity of production systems and the possible inputs which has during development affected the state. The complexity implies that one production system looks different to the next and is to be considered when looking for improvements of the system.

Strategy and a fundamental attitude among involved people are decisive in the development of production systems and the final result (Bellgran & Säfsten, 2010). Strategies provide boundaries, for instance on capacity, which translates into manufacturing strategy and company culture (Bellgran & Säfsten, 2010; Bruzelius, Skärvad, & Hofvander, 2011). A manufacturing strategy is a plan comprised of the activities that are necessary to reach targets (Bruzelius et al., 2011). Hill (2000) defines the manufacturing strategy as a series of decisions concerning process and infrastructure investments, which, over time, provide the necessary support for the relevant order-winners and qualifiers of the different market segments of a company. Four commonly important competitive factors are considered; quality, deliverability, cost and flexibility (Bellgran & Säfsten, 2010). They are visualized in the Sand-Cone model where competitive factors build on one another (Bellgran & Säfsten, 2010). The model states that for instance in order to compete with flexibility, prior factors need to be met as the factors are classified based on their role in a competitive situation (Bellgran & Säfsten, 2010).

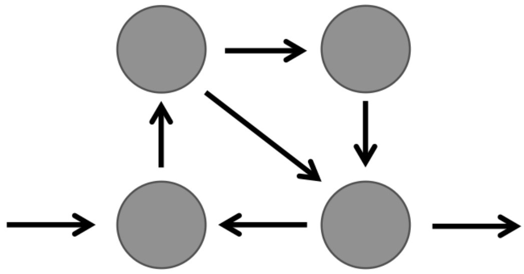
2.1.1 Production Layout

Facility layout is an arrangement of equipment required for production of goods or services (Drira, Pierreval, & Hajri-Gabouj, 2007). Generally there are four main types of layout viewed in Figure 2.2; fixed position, functional layout, batch flow (cells) and line based flow (product oriented) (Bellgran & Säfsten, 2010). Layout type describes the flow of products in the system, if the product is static or how it moves forward. The choice of layout depends on variety of products, production volumes and competitive factors (Bellgran & Säfsten, 2010; Slack et al., 2016) and material handling system chosen (Drira et al., 2007). The choices reflect manufacturing costs, WIP (Work In Progress), lead times, and productivity (Drira et al., 2007).

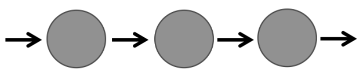
Fixed position layout is appropriate when there is a low volume and high variation (Bellgran & Säfsten, 2010). The product is stationary while resources are moved to perform the operation on the product, seen with large products for instance ships or air-crafts (Drira et al., 2007). Functional layout group processes of similar operations together, which is suited when there is a large variety of products or operations performed in the group (Drira et al., 2007). Pure line based flow has high volumes and a low variety of products having connected sequences of operations (Drira et al., 2007). As products travel the same path, balancing of workstations is essential in maintain continuous flow in line based layouts. In batch flow layout, also called cellular layout, machines are grouped into cells to process similar product families or parts following the same or similar processing steps (Drira et al., 2007).



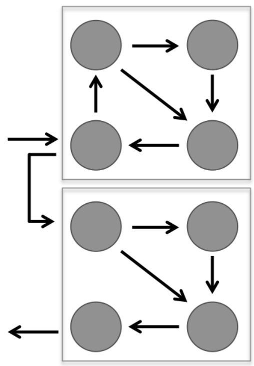
(a) Fixed position layout.



(b) Functional layout.



(c) Line based layout.



(d) Batch flow layout.

Figure 2.2: Main layout types (adapted from Slack, Brandon-Jones, and Johnston, 2016).

2.1.2 Mass Customization

The terminology, mass customization aims, to conjoin mass production with single-piece craft production (Blecker & Friedrich, 2006). Mass customization can be described as the business practice that aspires to provide individualized products to customers and simultaneously practice cost efficiency (Blecker & Friedrich, 2006). Hart (1996) portrays customization as providing the customers with anything they want, anytime, anywhere, and in any way. The manufacturing of individualized products is made economically feasible by the development of flexible production systems (Blecker & Friedrich, 2006; Hart, 1996). Management of additional costs, resulting from the increased degree of product differentiation offered to customers, is paramount for successfully implementing mass customization (van Hoek, Peelen, & Commandeur, 1999). The aim is to design flexible production systems, technologically capable of producing the required level of customization at minimal cost per unit (Hart, 1996).

A flexible manufacturing system is designed to manage mass and individual production, process modularity, centralized production & logistics planning, organizational learning, and continuous improvement (Stump & Badurdeen, 2009). As stated previously, the core of flexible manufacturing is the ability to make individualized products economically feasible (Hart, 1996). Process modularity establishes a commonality between products by allowing the use of interchangeable components thus enabling higher efficiency in the manufacturing process (Stump & Badurdeen, 2009). Improved transparency and handling of the customer order information is essential to centralized production and logistics planning (Stump & Badurdeen, 2009). Mass customized products are characterized by their short life-cycles (Stump & Badurdeen, 2009). Customization demands highly skilled workers adept to dynamic work content in decentralized and cross-functional teams (Holweg & Pil, 2001). Organizational learning and continuous improvement support this (Stump & Badurdeen, 2009).

Delaying activities in the value chain so that they are not performed until a customer's order is received, provides a practical solution for mass customization by combining push and pull forces in an operating system (Brun & Zorzini, 2009). Traditional production systems for customized products are designed to satisfy the needs of the immediate customer, as opposed to the final customer (Stump & Badurdeen, 2009). In essence, a made to order item, does not exist in the system until the end customer submits their request (Holweg & Pil, 2001; Stump & Badurdeen, 2009). To make products to order, one needs to understand the customer and know what they desire (Holweg & Pil, 2001). If not, to compensate for customers' perspective, producers must increase production volumes and variants relying on forecasts (Holweg & Pil, 2001). Thus the focus shifts from minimizing stock to offsetting the cost to manage it, making it increasingly difficult to produce the product the customer wants (Holweg & Pil, 2001).

The manufacturer receives pull signals from individual customers; the effect of the multiple pull signals is dependent on the extent and type of mass customization used by the organization (Stump & Badurdeen, 2009). The level of variety achieved through mass customization leads to a high complexity both from a customer's and manufacturer's standpoint (Blecker & Friedrich, 2006). The manufacturer can experience internal complexity, which prompts additional costs, while customers can experience external complexity, which can disorientate the decision making process (Blecker & Friedrich, 2006). Internal complexity describes the complexity that is experienced inside operations and manufacturing-related tasks (Blecker & Friedrich, 2006). Blecker and Friedrich (2006) exemplifies external complexity as the difficulties encountered by customers when they have to select adequate variants out of a large range of product alternatives. Holweg and Pil (2001) describe three dimensions to successful make to order strategies:

- Process Flexibility
- Product Flexibility
- Volume Flexibility

The first is process flexibility, which enables linking customer requirements directly to production so decisions are based on actual customer demand rather than forecasting (Holweg & Pil, 2001). Process flexibility relates to the speed at which the company makes decisions, alter schedules, changes existing orders to meet customer needs. Thus, an indication of how quickly information from the customer is translated to organizational decisions and operations (Holweg & Pil, 2001). Process flexibility takes into account the entire value chain. It therefore requires cooperation with suppliers and distributors, and links the customer directly to production. Stump and Badurdeen (2009) comment that mass customization production systems not only need to be flexible and comparable in terms of cost to mass produced items but also highly responsive to customer demands. Distortion in demand, complexity of products and geographic distances are issues to overcome which hinder process flexibility (Holweg & Pil, 2001).

Second is product flexibility, which relates to how well the company adapts production of multiple products on the same capacity, and ability to relocate capacity based on customers' specification (Goyal & Netessine, 2011). It weighs a company's ability to delay or reduce the degree of tailoring (Holweg & Pil, 2001). By customizing late in the process, companies better respond to orders and stabilize production (Stump & Badurdeen, 2009). Difficulties concern managing product variety. This is due to the fact that wide product range can be viewed as customer value, while reducing the options customers do not deem critical to enhance customer-perceived value (Holweg & Pil, 2001).

Thirdly, volume flexibility indicates how well production responds to changes in demand, altering production volume (Holweg & Pil, 2001). It enables a company to produce above or below capacity, at a cost, in response to demand (Goyal & Netessine, 2011). Seasonal products for instance can be a concern for the production system with large customer fluctuation (Holweg & Pil, 2001). Handling volume flexibility becomes especially important for make to order strategies (Holweg & Pil, 2001). Holweg and Pil (2001) state the importance of reducing dependency of full capacity utilization. Naturally, abundant capacity gives margins for last minute changes. Which allows for the possibility to better adapt to volume flexibility. Processes with close to capacity utilization will not be able to react as quickly to changes in production planning, without causing increased lead times of the individual order (Holweg & Pil, 2001). Focus should be aimed at managing the short

term variability, either by making the factory more responsive or managing demand flow (Holweg & Pil, 2001). One piece of the puzzle is to handle labour flexibility, as labour often is seen as the largest proportion of operating cost (Holweg & Pil, 2001). Holweg and Pil (2001) state negotiating flexible working hours, for instance agreement on total amount of worked hours per year could be a solution. Labour could then be focused on high intensity periods and instead of overtime pay, receive shorter days when demand is less critical. This strategy reduces costly over-time or utilization of untrained temporary workers who may compromise quality.

Make to order gets quick results in fast moving markets, where fixed costs are low and rapid response is more important than production cost (Holweg & Pil, 2001). Holweg and Pil (2001) further add that a hybrid make-to-order strategy paired with forecasting for high-volume and stable product assists in creating stable base production. A possible approach is to produce larger series on forecasts while introducing make to order on the smaller series and gradually phasing out the high volume products (Holweg & Pil, 2001).

Mass customization is classified into four types with respect to two criteria; point of customer involvement and type of modularity (Duray, Ward, Milligan, & Berry, 2000; Stump & Badurdeen, 2009). Modularity or postponement, delays the customer's point of involvement to later stages in the value chain dividing complex products to simpler portions (Brun & Zorzini, 2009). It pertains to when in the manufacturing process the customer is involved. Modularity pertains to providing variety and speed in delivering the made to order item (Duray et al., 2000). Stump and Badurdeen (2009) list Fabricators, Involvers, Modularizers, and Assemblers as the four types under mass customization; the groups can be viewed in Figure 2.3. Fabricators require the highest degree of mass customization since they involve customers in early processes, i.e. fabrication and design, and utilize modularity in the earlier stages in the production process (Stump & Badurdeen, 2009). Customers are directly involved in creating the design and modularity in the early stages giving them flexibility in the design (Stump & Badurdeen, 2009). The customers for Involvers are active in the design and fabrication stages (Stump & Badurdeen, 2009). Modularity for Involvers is associated with assembly and delivery stages (Stump & Badurdeen, 2009). Involvers are considered to have a high degree of mass customization however not as high as fabricators (Stump & Badurdeen, 2009). Modularizers are defined by their involvement of customers in the later production stages, assembly and delivery, and utilization of modularity in the design and fabrication stages (Stump & Badurdeen, 2009). Modularizers work by producing standard elements to the base model that can then be assembled and delivered according to the customers' needs (Stump & Badurdeen, 2009). Assemblers have the lowest level of mass customization since they involve and use modularity in the later production stages (Stump & Badurdeen, 2009).

Stump and Badurdeen (2009) categorize Assemblers and Modularizers as types requiring only a low degree of mass customization. The explanation is that both Assemblers and Modularizers engage the customer in the later production stages thus simplifying the value chain for the design and fabrication stages (Stump & Badurdeen, 2009). Stump and Badurdeen (2009) categorize Involvers and Fabricators as types requiring a high degree of mass customization. Both Involvers and Fabricators involve customers at an early stage of the value chain and impose pull signals several times during the earlier production stages (Stump & Badurdeen, 2009). Complexity is increased by the difficultly to forecast magnitude and variety of customer demand (Blecker & Friedrich, 2006; Stump & Badurdeen, 2009).

Mass customization is characterized by the low levels of standardization which leads to low stability (Stump & Badurdeen, 2009). The applicability of lean manufacturing processes is directly related to the degree of mass customization (Stump & Badurdeen, 2009). A wider span of lean practices are applicable to low levels of mass customization, as those found in Assemblers and Modularizers, due to the ability to

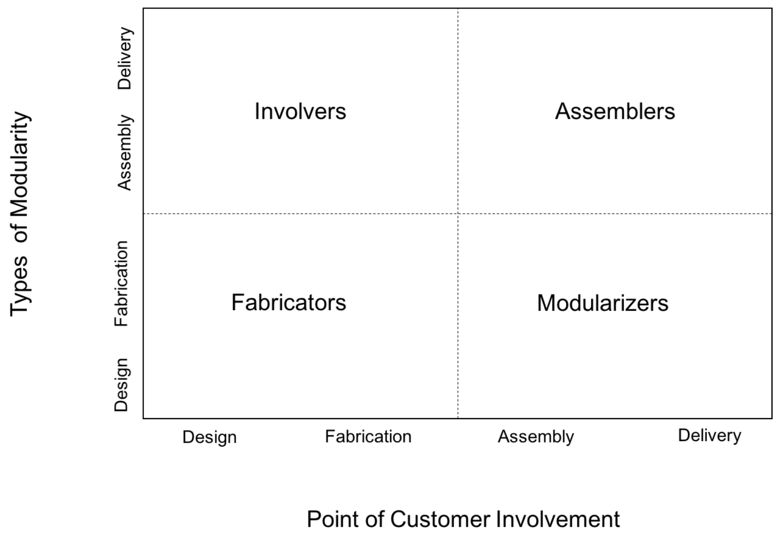


Figure 2.3: Mass customization classification matrix (adaption from Stump and Badurdeen, 2009).

forecast demand through standardized modules (Stump & Badurdeen, 2009). Modularity provide basis for repetitiveness in mass customization, limiting the degree of customization (Duray et al., 2000). In contrast, higher levels mass customization, as found in Involvers and Fabricators, have a more difficult time applying lean practices due to the difficulty in standardizing upstream processes (Stump & Badurdeen, 2009). Stump and Badurdeen (2009) go as far as to say that the use of lean practices in the earlier stages of production are very abstract and limited research has been done on the subject.

2.1.3 Small and Medium-sized Enterprises

SMEs play a critical role in a nation's business ecology since they compose a substantial percentage of the national economy and are a key element of governmental strategies (Achanga, Shehab, Roy, & Nelder, 2006). For instance, many SMEs are a vital link in large supply chain networks (Zhou, 2016). SMEs face different conditions than large companies (Achanga et al., 2006; Rymaszewska, 2014). Due to an SME's limited influence over suppliers and the openness for new entrants in the sectors they operate, SMEs are very exposed (Achanga et al., 2006). The size, between 10 and 250 employees, and financial turnover, € 50 million or less, lead to SMEs being constrained (Achanga et al., 2006). Thus, leading European SMEs tend to have a short-term orientation (Rymaszewska, 2014). Rymaszewska (2014) believes that European SMEs are hindered in their competitiveness by their lack of adequate innovation and their restricted financial support from the government.

Rymaszewska (2014) highlights a few of the characteristics in SMEs including: a clear source of responsibility for the organization, employee empowerment, reduced complexity of interactions, streamlined communication, rapid decision making, clear vision, and the ability to consider every opinion. Centralized power, a clear source of responsibility, in small businesses stems from the fact that there is generally a single owner or small group of executive management (Seitz, 2003). There is potential for high employee empowerment, as upper management is familiar with employees' strengths and weaknesses they can delegate responsibility and autonomy for work tasks (Seitz, 2003). Simpler interactions stem from the flatness and small size of the infrastructure (Seitz, 2003). Reduced complexity of interactions leads to increased speed of information transfer, streamlining communication (Seitz, 2003). Rapid communication facilitates and accelerates decision-making (Seitz, 2003). Clarity in vision is the result of the simplified management. This allows small businesses to communicate, monitor, and enforce their vision (Seitz, 2003). Since there are a limited number of employees, management has the chance to consider every opinion thus even the minority opinion is prevalent (Seitz, 2003).

2.2 Overview of Lean Production

Twice in the 20th century the automobile industry has changed the view of production (Womack, Jones, Roos, & of Technology, 1990). First, during the rise of the model T-Ford and mass production. Ford re-introduced interchangeable standardized parts, effectively reducing non-value adding processes, together with the moving production line creating the mass-production system (Bellgran & Säfsten, 2010). They were able to reduce the price of automobiles by solely producing the model Ford-T from 1908 through 1928, making them available to consumers by increased production numbers with price as the sole selling point (Nicholas, 2011). Quality was an issue with the T-Ford as cars were rarely inspected (Nicholas, 2011). As T-Ford sales went into decline, consumers were looking elsewhere for new interesting products seeking higher quality and more innovative products (Nicholas, 2011).

Secondly, Toyota Production System (TPS) changed the view on production having brought inspiration from the Ford plants to Japan. Post WWII Japan did not have the resources to invest in modern equipment and technology (Nicholas, 2011). Toyota chief production engineer at the time, Taiichi Ohno, concluded that in order to handle a variety of cars to better supply the Japanese market they would need to design their system to be less costly, less wasteful, while more efficient and flexible (Nicholas, 2011). Nicholas (2011) describes eight early features of TPS which distinguishes it from traditional mass production:

- Reduced setup times
- Small lot production and one-piece flow
- Employee involvement and empowerment
- Quality at the source
- Equipment maintenance
- Pull production
- Standardized work
- Supplier partnerships

Lean production and TPS received minimal interest until studies during the 1980's pointed out performance gaps compared to other automobile manufacturers, and coined the expression "Lean Production" (Hines, Holwe, & Rich, 2004; Krafcik, 1988; Bellgran & Säfsten, 2010). Former quality engineer at Toyota and researcher at MIT, Krafcik (1988), wrote the article *The Triumph of Lean Production* which studied performance of various car producers. He concluded that companies inspired by TPS can operate outside of Japan and that lean production was not tied to Japanese culture and success. Showing results at plants in Europe and North America, Krafcik (1988) together with the later release of *The Machine That Changed the World* (Womack et al., 1990), sparked the interest of producers of various products and heritage to build their lean production systems based on TPS. Thus, engaging lean transformations and familiarity with the term lean while adopting its general philosophies (Coleman & Vaghefi, 1994; Hines et al., 2004). Prior to the 1990's, implementations were entirely tool-focused neglecting human aspects of the high-performance work system (Hines et al., 2004).

Table 2.1: The evolution of lean (adaption from Hines, Holwe, and Rich, 2004).

Phases	**1980-1990 Awareness**	**1990-mid 1990 Quality**	**Mid 1990-2000 Quality, cost and delivery**	**2000+ Value system**
Litterature theme	Disseminiation of shop-floor practises	Best practise movement, benchmarking leading to emulation	Value stream thinking, lean enterprise, collaboration in the supply chain	Capability at system level
Focus	JIT techniques, cost	Cost, training and promotion, TQM, process reengineering	Cost, process-based to support flow	Value and cost, tactical to strategic, to supply chain
Key business process	Manufacturing, shop-floor only	Manufacturing and materials management	Order fulfilment	Integrated processes, such order fulfilment and new product development
Industry sector	Automotive - Vehicle assembly	Automotive - vehicle and component assembly	Manufacturing in general - often focused on repetitive manufacturing	High and low volume manufacturing, extension into service sectors
Key gaps	Outside shop-floor, inter company aspects, systematic thinking, auto assembly only	Mainly auto, human resources, exploitation of workers, supply chain aspects, system dynamic aspects	Coping with variability, integration of process, inter-company relations, still mainly auto, integrating industries	Global aspects, understanding customer value, low volume industries, strategic integration, e-business

As viewed in Table 2.1, Hines et al. (2004) point out that the focus and spread of lean has changed during the last decades, with acceptation lagging in western industry adaptation. Liker and Meier (2006) state that TPS should be kept separate from the way of thinking as both the production system and the way of thinking need to be emphasized.

2.2.1 Lean Principles

TPS is a system that searches for the best method to gain continuous improvements, small ideas and innovations are expected of everyone, from the top floor to the shop floor (Stewart, 2011). Through *The Toyota Way*, Liker and Meier (2006) identified 14 management principles for guidance to understand the build of TPS. Liker and Meier (2006) organized the principles into four categories as a hierarchical pyramid with higher levels building on the lower. Simplified in Table 2.2, long-term philosophy is required for companies to do as the other P's imply. Technical processes provide a setting to develop people, and people is most important when becoming a learning organization, focused on continuous improvement by solving problems (Liker & Meier, 2006). Coetzee, van der Merwe, and van Dyk (2016) state that the Toyota Way is a mindset explaining how thoughts and actions guide people to interact with each other on a daily basis, or even as a organizational culture.

Table 2.2: The Toyota Way, Philosophy, Process, People and partners, and Problem solving (inspired by Bellgran and Säfsten, 2010).

Category	Content of Toyota way principles
Philosophy	Management decisions on long-term philosophy
Process	Create continuous flow, pull-systems, leveled production workload, Build culture for quality right from the first time, base kaizen and employee empowerment by standardized tasks, use visual control, use of reliable and tested technology
People and partners	Grow leaders, develop exceptional people and teams, respect network of partners and suppliers by challenging them
Problem solving	Go and see, make decisions slowly but implement rapidly, become a learning organization

Just in time and jidoka are the driving principles behind everything that Toyota does (Stewart, 2011). Understanding of the center core principles, provide a better understanding of the outlying principles as well (Stewart, 2011). Learning the meaning of the principals is as important as knowing how they are applied. Often too much focus is spent on understanding certain tools within lean rather the principle they enable. Stewart (2011) states that the focus on lean manufacturing is the tools, in contrast TPS's focus lies in the system. There are many tools that can be utilized, but not all are mandatory and TPS should not be seen as a toolkit. TPS focuses on supporting and encouraging people to continually improve the process they are working on (Coetzee et al., 2016). That is why the epicenter of the lean system is considered to be people and how they work together to obtain continuous improvement. Viewed in Figure 2.4 is the relationship of the principles in comparison with the lean values, 4P model, continuous improvement and respect for people.

The Toyota Way	Philosophy	1. Long-term philosophy
	Process	2. Create flow
		3. Use a pull system
		4. Level out the workload
		5. Stop and fix the problem
		6. Standardize tasks
		7. Use visual control
		8. Use reliable, tested technology
	People	9. Grow leaders who live the philosophy
		10. Respect, develop, and challenge your people
		11. Respect, challenge and help your suppliers
	Problem solving	12. Goo see for yourself to understand
		13. Make decisions slowly by consensus
		14. Continual organizational learning through Kaizen

Figure 2.4: Scaling the Toyota Way sorting the 14 management principles (inspired by Liker and Meier, 2006).

2.2.2 Customer Focus

The foundation of TPS is adding value to the customer through people (Liker & Meier, 2006). The customer requirements or "voice of the customer" define requirements including production rate (takt time), volume (quantity), model mix, and sequence of production (Liker & Meier, 2006). Liker and Meier (2006) emphasize the importance of a production system's ability to deliver the required variety and meet the customer's needs. Takt time is based on the rate of customer and influences the material flow (Liker & Meier, 2006). Incorrect production volumes and model mixes stem from not synchronizing the actual customer demand. Producing items in greater quantities or earlier than the customer desires leads to overproduction (Liker & Meier, 2006). In many cases the customer requirements are not clearly defined, thus thwarting the lean process (Liker & Meier, 2006).

Hart (1996) utilizes the concept "customer customization sensitivity" to evaluate the actual customer needs for customized products. The concept is based on the uniqueness of customers' needs and level of customer sacrifice (Hart, 1996). Blecker and Friedrich (2006) describe the uniqueness of customers' needs as dependent on the type of product. The level of customer sacrifice as the gap between what the customer desires and what the customer finds acceptable (Blecker & Friedrich, 2006). Customer sacrifices includes the unavailability of quality goods and the unavailability of low priced goods in quantity (Hart, 1996). Hart (1996) summarizes customer value in an equation:

$$\text{customer value} = \frac{\text{perceived benefits} - \text{customer sacrifice}}{\text{price}} \tag{2.1}$$

Quality for the customer is a driver in the value proposition of lean production (Liker & Meier, 2006). As a competitive factor, quality refers to the success factor when meeting customer needs and expectations (Bellgran & Säfsten, 2010). Quality is a subjective term. Generally, quality refers to the experienced value and meeting of specifications, i.e. less defects (Bellgran & Säfsten, 2010). Quality gaps materialize when customer expects higher quality that the producer built in (Tersine & Hummingbird, 1995).

Bennett (1986) counsels that quality can be achieved by designing better production systems rather than by merely exercising greater control over existing ones. This can be exemplified in Toyota's excellence in quality (Liker & Meier, 2006). Toyota's philosophical stance according to Liker and Meier (2006) is that the right process gets the right results. Furthermore, Toyota promotes a culture of stopping to fix problems directly in order to get the quality right the first time (Liker & Meier, 2006).

2.3 Production Flow

Modig and Åhlström (2012) describe flow efficiency as being focused on how a product flows through a system and how value is added to the product through various activities. Flow describes the transfer between activities (Bellgran & Säfsten, 2010). The transfer must be conducted in such a way that transfer reaches the correct receiver, to the appropriate extent at the appropriate time (Bellgran & Säfsten, 2010). Value-adding activities are activities that increase the product's worth from the customer perspective (Modig & Åhlström, 2012; Rother & Shook, 2003). Increasing flow efficiency by eliminating non-value adding activities leads to cost reduction (Rahani & Al-Ashraf, 2012). In contrast to flow efficiency, resource efficiency centers on resource utilization. Figure 2.5 expresses the difference.

Flow efficiency is the sum of value added time in relation to total lead time (Liker & Meier, 2006). The larger the variation the longer the lead time (Modig & Åhlström, 2012). Resources, products, and external factors all contribute to variation (Modig & Åhlström, 2012). Higher variation in processes impact lead time and increase resource utilization (Modig & Åhlström, 2012). In addition, bottlenecks increase lead time (Modig & Åhlström, 2012). Lead time and cycle times increase with more products in the system (Modig & Åhlström, 2012). External factors such as irregular timing of customer demands also contribute to higher variation (Modig & Åhlström, 2012).

To achieve flow efficiency, Liker and Meier (2006) state the importance of stable processes in the phase of creating of initial stability to gain consistent performance to meet the costumers demands. Table 2.3 display indicators of instability as seen

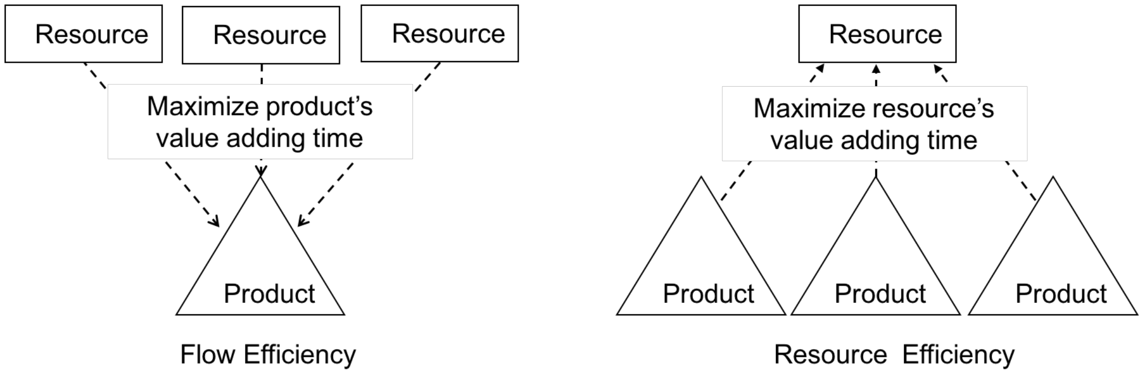


Figure 2.5: Flow efficiency vs Resource efficiency (adapted from Modig and Åhlström, 2012).

in Liker and Meier (2006). Liker and Meier (2006) argue that the process will not ever reach a perfect level of stability, and in some degree several of these conditions will always exist. Development and flow and approaches to reach stability go hand in hand. There is no clear indicator for how stable a process needs to be, the main consideration is how unstable the process is and what stability is required to be to meet the demands of flow (Liker & Meier, 2006).

Table 2.3: Eight indicators of instability (as seen in Liker and Meier, 2006)

Liker & Meier's 8 Indicators of Instability
A high degree of variation in performance measures.
Changing the "plan" often when a problem occurs. Relocating labor or leaving a position vacant when an absence occurs and stopping work in the middle of an order to change to another order.
It is not possible to observe a consistent pattern or method to the work.
Batches or piles of work in process (WIP) that are random sometimes more, sometimes less.
Sequential operations that operate independently (island processes).
Inconsistent or nonexistent flow, indicated by random WIP.
Frequent use of the words usually, basically, normally, typically, generally, most of the time, when describing the operation, followed by except when, as in: "Normally we do this... except when... happens, then we do this...."
Statements such as, "We trust the operators to make decisions about how the work is done" (misguided employee empowerment).

2.3.1 Lead Time

One of the main goals of lean production is to reduce waste by improving material flow (King & King, 2015). Tersine and Hummingbird (1995) argue that time is a critical resource and high speed does not necessarily convert to a better use of time in production. Tersine and Hummingbird (1995) explain speed as the ability to deliver products faster than other competitors. Lead time is considered to be directly connected to the flow of material and information; including time to implement, time to market, time to produce, time to respond, and time to deliver (Tersine & Hummingbird, 1995). Liker and Meier (2006) concur that flow adheres to minimizing the amount of time a product is idle.

Bellgran and Säfsten (2010) comment that short delivery lead times can either be achieved through the production system or through delivery from finished stock. As summarized in a simple and short definition, a lean process is the result of reducing time between customer order and delivery through decreasing non-value adding time (Hines et al., 2004; Liker & Meier, 2006). Due to the context of which products are produced, different product stages give way to different opportunities for reducing lead times (Tersine & Hummingbird, 1995). Tersine and Hummingbird (1995) list four product environments including engineering to order, make to order, assemble to order and make to stock. The various product environments are defined by how the customer order decoupling point divides the flow; the customer order decoupling point strongly influences the coordinating between planned deliveries and sufficient capacity (Bellgran & Säfsten, 2010). The product stages correlating with the different product environments is displayed in Figure 2.6; lead times related to the different product environments is displayed in Figure 2.7.

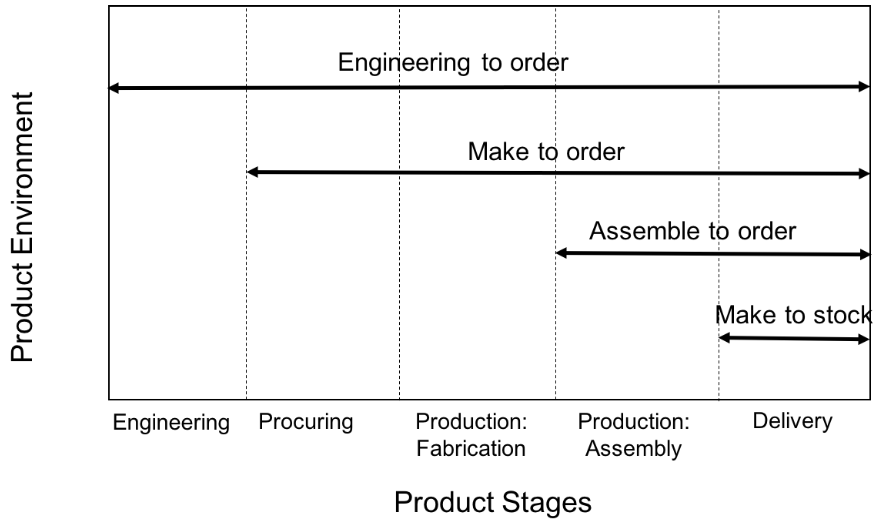


Figure 2.6: Product environments and product stages (adapted from Tersine and Hummingbird, 1995).

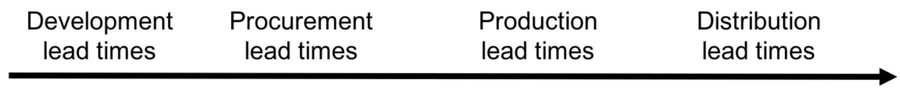


Figure 2.7: Lead times applicable to different product stages (adapted from Tersine and Hummingbird, 1995).

Excessive lead times can lead to expensive repercussions, e.g. expediting and scheduling problems (Tersine & Hummingbird, 1995). Therefore, management of lead time can be a competitive advantage (Tersine & Hummingbird, 1995). A method of time reduction is to combine activities into a simultaneous or parallel manner instead of performing them in a series (Tersine & Hummingbird, 1995). Tersine and Hummingbird's (1995) strategy to reduce lead-time consists of:

1. Survey the entire flow from an efficiency perspective
2. Identify and react to bottlenecks
3. Monitor the system for continuous improvements

Maximum effectiveness is achieved when effort is placed on improving the performance constraints of the system (Tersine & Hummingbird, 1995).

2.3.2 Lean Production Planning and Control

It is essential that a harmony exist between *muda* (waste), *muri* (overburden), and *mura* (unevenness) (Smith, 2014). Smith (2014) promotes addressing mura and muri first. Mura refers to unevenness or inconsistency in a system (Smith, 2014). Heijunka works at smoothing the daily peaks and valleys thus facilitating mixed model assembly, as opposed to batch production (Stump & Badurdeen, 2009). Lippolt and Furmans (2008) describe leveling as the concept of balancing a production system by flattening the peaks and valleys created by customer order fluctuations and batch processing. Muri refers to the overburdening of people and processes (Smith, 2014). Standardization of tasks can ease muri by providing all employees with an efficient way of working (Smith, 2014). Reduction of muri is an important factor in decreasing muda, waste, in the system (Smith, 2014). Elimination of muda is one of the primary objectives in lean production (Liker & Meier, 2006). Seven plus one wastes typify muda including:

- Overproduction
- Waiting
- Transportation
- Overprocessing
- Excess inventory
- Unnecessary movement
- Defects
- Unutilized employee creativity

Reduction of internal waste leads to increased value (Hines et al., 2004). As wasteful activities and associated costs are reduced, the overall value proposition for the customer increases, resulting higher competitive potential (Hines et al., 2004). Development of a production system needs to consider the flows of material, information, and people (Bellgran & Säfsten, 2010). In lean production, the information flow is of equal importance to the material flow (Rother & Shook, 2003). In today's highly competitive manufacturing environment, production planning and control systems are essential tools for dealing with increasingly high customer demand and expectations (Stevenson, Hendry, & Kingsman, 2005). Customers rarely order products in specific batch sizes, hence the need for production systems to synchronize production volumes and mixes with actual customer needs (Liker & Meier, 2006). Production planning and control system's main objectives are to reduce WIP, shorten shop floor throughput times, manage lead times, minimize inventory costs, improve responsiveness to changes in demand and improve delivery performance (Stevenson et al., 2005).

The choice of an appropriate production planning and control system is of high importance, however it is also complex (Stevenson et al., 2005). Complexity is increased as small businesses tend to have limited formal infrastructure (Seitz, 2003). As well as limited control over their supply chain (Rymaszewska, 2014). Due to lack of adequate funding, SMEs are especially at high risk for implementing improper, hence not effective, production planning and control systems (Stevenson et al., 2005). Furthermore, dual resource constrained production is characterized by high variability in demand, high product variety, low volumes in orders, and variable processing times (Slomp, Bokhorst, & Germs, 2009). The non-standard product routing in production is a direct consequence of customization (Stevenson et al., 2005). Mass customization often leads to operations issues including capacity planning, order acceptance, order rejection and attaining high due date adherence (Stevenson et al., 2005). Slomp et al. (2009) suggest three lean manufacturing control techniques to successfully identify and eradicate unneeded sources of variability including:

- Production leveling
- Pull mechanisms
- Takt time control

Heijunka

Heijunka is a method for production planning (Coleman & Vaghefi, 1994). Toyota defines heijunka as "distributing the production of different types evenly over the course of a day, a week, and a month" (Coleman & Vaghefi, 1994). The direct translation is to level or to make smooth (Liker & Meier, 2006; Smith, 2014). Though, as customers do not typically order in specific batches, that is often how products are made (Liker & Meier, 2006). Efforts are made to match production sequences to actual demand (Coleman & Vaghefi, 1994). The aim is to handle demand while avoiding the peaks and valleys in production (Grimaud, Dolgui, & Korytkowski, 2014). Furthermore, heijunka incorporates balancing of workstations and lines to match sequential processes workloads to one another. Adapted from Rother and Harris (2001), Figure 2.8 illustrates a practical example where a supermarket in combination with a heijunka box aids in smoothing variety in customer demand. A supermarket is a controlled buffer containing a small number of products to a downstream process or end customer (Lippolt & Furmans, 2008). As products are used, a signal for replenishment is sent creating a pull- effect of process (Liker & Meier, 2006). The heijunka box is a schedule with predetermined slots of product variations, which shows in what order products are to be produced aids in maintaining continuous flow.

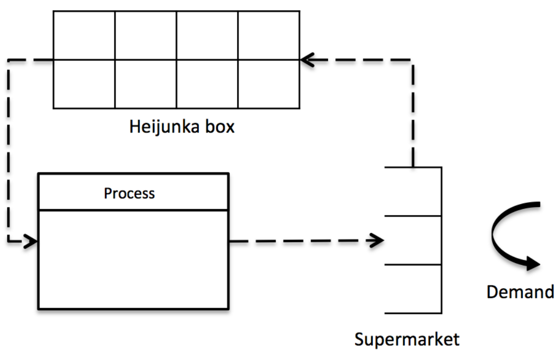


Figure 2.8: Visualization of Heijunka box (inspired by Rother and Harris, 2001).

In this simplified example, defining standardized volumes of production creates repeatability which enables continuous improvements (Liker & Meier, 2006). Achieving true heijunka by hourly time pitched scheduling requires advanced lean practice and consider the trade-off between variability in the production line and inventory levels (Grimaud et al., 2014). To achieve the benefits of continuous flow, leveled production is required (Liker, 2004). For the Heijunka box, Liker and Meier (2006) adds that all elements needs to be identified: The time pitch, product volume of the batch, product mix of product variations during the time period and product sequence of the different types (i.e. that production in sequence A A B C C is viable). Obtaining the objective of single piece flow is the final goal, though depending on the conditions at hand first implementations of heijunka is to achieve initial stability and ground for improvements (Liker & Meier, 2006). Liker and Meier (2006) further adds that a common trap is analysis paralysis when aiming to create the ultimate system in regard to all details will be virtually impossible. A basic leveling schedule enables adjustments and tuning in later stages (Liker & Meier, 2006).

Introducing different types of products into one production line increases the number of setups, which is one of the biggest challenges for mixed production (Coleman & Vaghefi, 1994). As a result, reduction of setup times through single minute exchange of dies, SMED, becomes an important tool. SMED aims to remove supportive non value activities and perform activities offline while the equipment is still under use (Liker & Meier, 2006). Product variations mandate cross-trained and flexible employees as well as flexible machinery and equipment (Coleman & Vaghefi, 1994).

Pull Mechanism

TPS strives to create an uninterrupted and smooth flow that is perfectly coordinated with the customer demand, the pull (Jones, Hines, & Rich, 1997), as seen in Figure 2.9. Rother and Shook (2003) emphasize that the most efficient way to produce is in continuous flow, also known as single-piece flow. The concept, continuous flow, refers to producing a single piece at a time and the items are immediately passed along the value chain, eradicating the waste between process steps (Rother & Shook, 2003). However, Liker and Meier (2006) remark that achieving a continuous flow is immensely difficult and requires a very well-developed process with specific conditions. Processes with very slow or fast cycle times and that serve multiple product families are not well-equipped for single-piece flow (Rother & Shook, 2003). Also processes that have very long lead times or lack stability in their processes are not appropriate to conjoin with other processes for this type of flow (Rother & Shook, 2003). Furthermore, proximity to customer can be a constraint and single-piece flow can make shipping demands unrealistic (Rother & Shook, 2003).

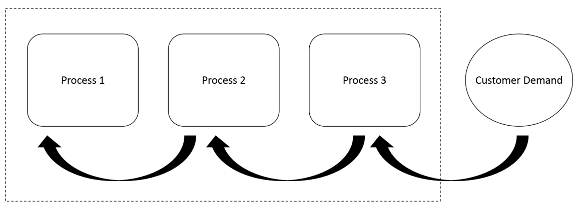


Figure 2.9: The concept of pull.

Liker and Meier (2006) emphasize that not adapting a single-piece flow does not equate with not being lean; it is better to view flow on a continuum, as seen in

Figure 2.10. The spectrum spans from the traditional batch and queue with push to the ideal state of lean with continuous flow (Liker & Meier, 2006). Rother and Shook (2003) propose implementing a pull system between processes in order to exercise control over the system when continuous flow is not possible. The aim of the pull system is to focus on waste elimination (Liker & Meier, 2006). Hence controlling the production flow by securing up-to-date production instructions to the upstream process and avoiding forecasting downstream demand (Rother & Shook, 2003).

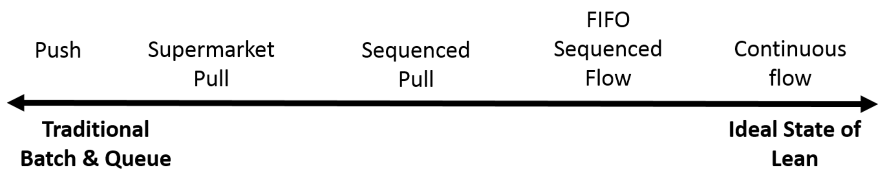


Figure 2.10: State of lean with respect to pull mechanism (inspired by Liker and Meier, 2006).

Liker and Meier (2006) highlight a predictable and repeatable process as the foundation for flow and pull. Liker and Meier (2006) describe flow as the state of material as it moves through processes. Pull dictates the timing of material movement; the customer's need is the reason that the material is moved (Liker & Meier, 2006). Pull is derived from the point in the value stream where the actual customer demand meets the forecast-driven push (Hines et al., 2004; Jones et al., 1997). A push system lacks a defined agreement between the supplier and the customer concerning the quantity of work to be supplied and the timing (Liker & Meier, 2006). Thus, a push system does not take into account of the actual needs of the downstream customer (Rother & Shook, 2003). A pulled system differentiates from a push system by having a defined agreement between the customer and supplier, sharing dedicated factors and control methods (Liker & Meier, 2006). The defined agreement contains details considering the volume, model mix, and sequence (Liker & Meier, 2006). The shared, dedicated factors between the customer and supplier should include dedicated resources and takt time (Liker & Meier, 2006). Controlled yet simple methods that visualize the agreement are key in a pull system (Liker & Meier, 2006). The system becomes more complex the wider the variety of product mix (Liker & Meier, 2006).

Sequenced pull lanes aid in maintaining the flow between and upstream and downstream process (Liker & Meier, 2006). The sequence pull works as an agreement between the upstream and downstream processes since a fixed quantity in a fixed sequence is passed down through the process (Rother & Shook, 2003). Hence the sequence pull works as a technique to control WIP since it deters overproduction (Rother & Shook, 2003).

The sequence pull works as a visual arrangement (Liker & Meier, 2006). Stump and Badurdeen (2009) expound on the ability of visual management of information to provide up-to-date conditions in application. However, neither the kanban pull system nor the classic takt time control principle is considered to be appropriate when handling dual resource constrained production (Slomp et al., 2009). However, CONWIP, Constant Work-In-Process, and POLCA, Paired Cell Overlapping Loops of Cards with Authorization (similar to the kanban system), are continuous shop floor release methods (Stevenson et al., 2005). These methods utilize cards to limit the number of orders on the production floor (Stevenson et al., 2005) limiting WIP thus limiting overproduction. Nonetheless, CONWIP and POLCA systems do not ordinate cards to a specific part number and sequence through production (Slomp et al., 2009). Figure 2.11 illustrates the difference between a regular pull mechanism and the various sequence pull mechanisms.

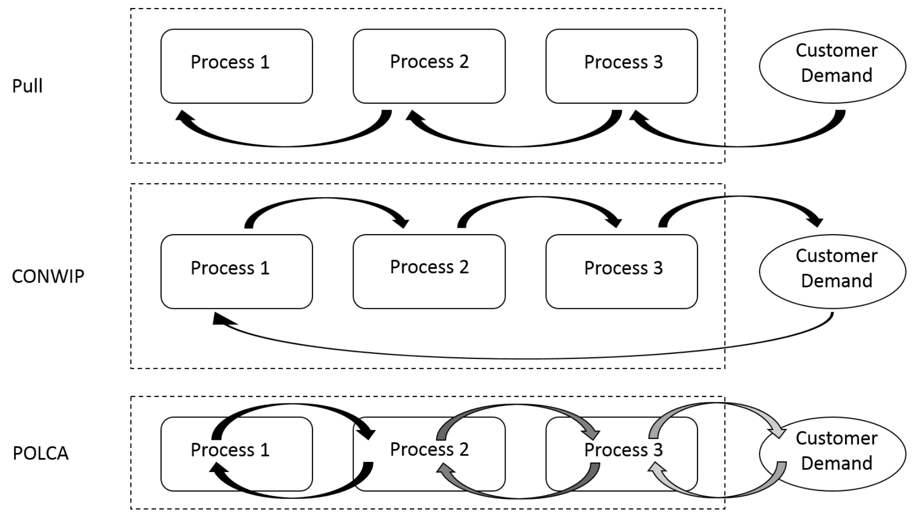


Figure 2.11: Pull, CONWIP and POLCA systems.

In CONWIP, the cards are "job number specific" and accompany the product through the entire production process (Stevenson et al., 2005). The focus is on maintaining a constant WIP in comparison to kanban that aims to control throughput (Stevenson et al., 2005). A single level of WIP is set for the entire production system (Stevenson et al., 2005). In a CONWIP system, an order is allowed to enter production only if there exist a free card; when an order is finished the card is set aside until there is another order is supplied by a customer (Slomp et al., 2009). In order to be efficient, some standardization of products should be implemented in order to promote that each card has a similar workload (Stevenson et al., 2005).

POLCA is a variation of the kanban method. CONWIP's cards are specified by job number while POLCA's are specified to cells, as they operate between two cells by accompanying a job on its route through production (Stevenson et al., 2005). The POLCA card is attached to the item upon entering the first cell and disunited upon leaving the second cell, thus coordinating the inventory levels between the two cells and across production (Stump & Badurdeen, 2009). Moreover, the POLCA cards work in pairings, allowing the jobs to travel in one direction and the information returns in the other (Stevenson et al., 2005). Stevenson et al. (2005) describe POLCA as a hybrid push-pull card based signaling system and that works well for highly engineered production with small batches and high product variety. Organizations can utilize POLCA to manage routing and inventory between cells. In comparison to CONWIP, POLCA requires the aid of higher planning levels to determine delivery dates based on workloads and capacities at the customer interaction point (Stevenson et al., 2005). Also, POLCA requires other methods to address the issues of job entry and job release (Stevenson et al., 2005).

2.3.3 Takt time

Takt time is an important technique in lean production control principles (Slomp et al., 2009). The concept takt time serves as a common time reference when designing work (Liker & Meier, 2006). Slomp et al. (2009) describe takt time control as setting a fixed production pace that is equivalent to the rate of customer demand. Rother and Shook (2003) characterize takt time in the following equation:

$$\text{Takt time} = \frac{\text{Available working time}}{\text{Customer Demand}} \tag{2.2}$$

Slomp et al. (2009) define flow time as the product of takt time and WIP. In order to achieve continuous flow, operation cycle times must be balanced to the takt time (Liker & Meier, 2006). Unbalanced work times will lead to waiting time and overproduction (Liker & Meier, 2006). Takt time applies pressure to reduce variability in the system generated by work preferences in work task decisions (Slomp et al., 2009). Hence, generalized takt time control supports workers by providing incentive and guidance to work on the right order at the right time (Slomp et al., 2009).

2.3.4 Value Stream Mapping

Value stream mapping, VSM, is a tool used to describe both current and future states of a production system (Bellgran & Säfsten, 2010). It is one of the most important tools within lean production (Vinodh, Somanaathan, & Arvind, 2013). The VSM is used to identify, create understanding, and communicate improvement areas of processes needed creating value for the customer (King & King, 2015; Rother & Shook, 2003). A value stream consists of all the actions, value adding and supportive, to carry a product through the main flow (Rother & Shook, 2003). More than just the processes, the map lifts barriers hindering flow, including the eight types of waste, and understanding of interactions between various steps (King & King, 2015). A holistic approach does not just view individual processes but improves the system at whole (Rother & Shook, 2003). To reduce the first four types of waste, overproduction, inventory, defects and transportation are readily seen in a well performed value stream map (King & King, 2015) and targeted for improvement transforming the current state into the future state.

The process of generating the value stream map is educating, as the participants gets to view the larger picture (Rother & Shook, 2003). The level of detail is high enough to address production control issues (Baudin, 2002). As the level of detail is contained users should have the future state completed in two days (Rother & Shook, 2003). King and King (2015) state that if the VSM is created by a cross-functional team representing all process areas and functions it builds strong inter-functional understanding of overall process and interconnectedness. Involvement from managers, technicians and operators is seen as important to create consensus around the map before moving on to improvement plans (Liker & Meier, 2006). The 25 original icons used in the VSM according to Rother and Shook (2003) are categorized into material flow, information flow and general icons. A selection is viewed in Figure 2.12 and the full list of icons can be found in Appendix D. Baudin (2002) state that complexity of the VSM can make it difficult to read and requires experience. Large quantity of icons, relations and rules are needed to describe a system makes it difficult for the inexperienced user to make use or even read the map (Baudin, 2002).

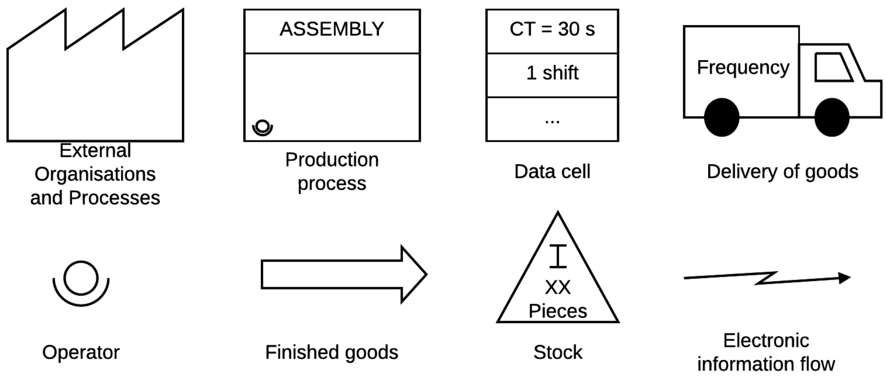


Figure 2.12: Selection of VSM figures.

The top half of the map depicts information flow determining what is to be made and when (King & King, 2015). Starting from customer order, tracing back through planning and scheduling processes, ending in schedules and control signals to the production floor (King & King, 2015). Material flow shows material of the product as it progresses from raw material received from supplier through major processing steps, to finished goods moving toward the customer (King & King, 2015). This includes data-boxes with high level performance of each piece (King & King, 2015). Between processes, drawing the type of buffer and number of products in buffers is to help understand the flow and regulating systems (King & King, 2015; Liker & Meier, 2006).

Below the processes, a time line is drawn (Rother & Shook, 2003). It contrasts value adding and non-value adding time (King & King, 2015). As a key indicator of the process, the timeline shows actual effects of waste, enabling the cause to be diagnosed (King & King, 2015). The other two components, material and information flow, describe the process, indicating where the effects hindering flow lies (King & King, 2015).

After creating the current state map of actual process operations, the value stream mapping process has completed the first of three steps in the value stream method

(Rahani & Al-Ashraf, 2012; Rother & Shook, 2003). Secondly, a future state map is produced to identify root causes of waste, a vision of the value stream (Liker & Meier, 2006; Rahani & Al-Ashraf, 2012). Prior to developing the second map, Rother and Shook (2003) facilitate eight future state questions to be answered aiding the process of value stream development:

1. *What is the real customer demand? What is the takt time?*
2. *Will the organization produce for direct delivery or to finished goods stock?*
3. *Where can the organization produce in continuous flow? Where can the organization reduce waste? What activities can be eliminated, combined or simplified?*
4. *Where is supermarket pull systems (buffers) placed to regulate flow?*
5. *Where in the flow does the pacemaker plan production?*
6. *How is production mix leveled?*
7. *In which batch size should we produce?*
8. *Which process improvements are needed?*

Lastly forming the implementation plan is the last step by performing the actions needed to gain project objectives (Liker & Meier, 2006; Rahani & Al-Ashraf, 2012). Action plans are organized around information and material loops (Liker & Meier, 2006). Rother and Shook (2003) state improvements of the value stream are often overlooked as the responsibility for the entire value stream is often divided by several roles or functions. Pointing out the importance of the value stream manager. They are responsible for initiating VSM activities, scheduling, making an action plan, communicating wins and improvements the value stream. Essentially, keeping track of how system improvements impact respective value stream, while other kaizen activities are pursued within individual processes (Rother & Shook, 2003).

In general, there are three loops: supplier loop, intermediate process loop, and pace setter loop (Liker & Meier, 2006). The idea is to facilitate lean implementation by selecting one loop at a time to implement tools to stabilize, create flow, standardize and slowly level the system (Liker & Meier, 2006). This method is perceived to have a wide applicability range and results are typically well-quantified and tangible (Liker & Meier, 2006). In addition, it works with lean as system integrating often a larger view and a "learn to see" method (Liker & Meier, 2006).

2.4 Sociotechnical System

The development of sociotechnical theory stems from the principle that the employee's psychological needs in a work situation had to be considered from a holistic perspective (Bellgran & Säfsten, 2010). The movement was started as a reaction to division of labor and top-down management styles that embodied Taylorism and Ford's assembly line (Bellgran & Säfsten, 2010; Trist et al., 1978). Work organization was characterized by relatively autonomous groups, interchanging roles and shifts, and regulating affairs with a minimum of administration (Trist et al., 1978). Trist et al. (1978) comment that the application of sociotechnical perspective in work organizations lead to better cooperation between task groups, heightened personal commitment, lowered absenteeism, decreased accidents, and increased productivity.

Technology is a crucial element in modern society in particular pertaining to production (Geels, 2004). However, sociotechnical systems are not autonomous but the outcome of human interactions with the technical system (Geels, 2004; Trist et al., 1978). Figure 2.13 visualizes the various components of a sociotechnical system. Geels (2004) considers a sociotechnical production system to consist of labor, raw materials, tools and equipment, capital, and technological knowledge; transfer of knowledge and scientific research are viewed as subsystems and indirectly impact the production system (Geels, 2004). The components and subsystems are interdependent thus giving the sociotechnical system certain durability towards change (Geels, 2004). Regulations, norms, and laws and distribution networks also effect the production. The sociotechnical system is characterized of a holistic view of the entire work system in which focus is placed the functioning whole rather than the single jobs (Trist et al., 1978).

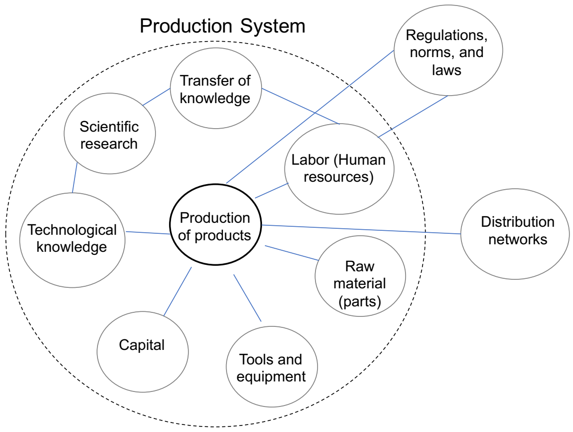


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Figure 2.13: Components of a sociotechnical production system (inspired by Geels, 2004).

Under the sociotechnical system, the work group is given a more central role in comparison to the individual job-holder (Trist et al., 1978). An organization should develop people in harmony with the technical system (Bellgran & Säfsten, 2010). Work rotation, work enlargement, and work enrichment are all tools in the sociotechnical system (Bellgran & Säfsten, 2010). The collective work organization has developed further towards an increased decentralization, reduced division of labor, and reduced dependence on the need for a predetermined work rate (Trist et al., 1978). Flexibility for operators can be increased by incorporating parallel flows and several buffers (Bellgran & Säfsten, 2010).

(Trist et al., 1978) list the following intrinsic requirements with respect to the employee's psychological needs in a work situation:

1. Variety and challenge: The content of the work need to vary and be fairly demanding in terms other than sheer endurance

2. Continuous learning: The ability to learn and continue to improve
3. Discretion, autonomy: The authority to make decisions concerning their own work.
4. Recognition and support: Social support and recognition for the work contributed
5. Meaningful social contribution: To be able to proud of the work done
6. Desirable future: To feel that job leads to a desirable future

Moreover, Bellgran and Säfsten (2010) emphasize the importance in considering technical requirements, prerequisites, restrictions, and possibilities, and social and psychological requirements, needs, and conditions when designing a work organization. Development of knowledge plays a central role in employee development. Knowledge is characterized as tacit or explicit (Shin, Holden, & Schmidt, 2001). Tacit knowledge stems from an individual's experience and actions and is difficult to articulate (Shin et al., 2001). Explicit knowledge is described as objectified, formal, and easier to communicate. Knowledge management is characterized by identifying and facilitating the utilization of applicable and valuable tacit knowledge, transforming it to explicit knowledge (Shin et al., 2001). Bellgran and Säfsten (2010) stress this further in claiming how a universal language facilitates information and communication.

2.4.1 Developing the Work System

A sociotechnical system is characterized by designing a process that focuses upon the interdependence between and among employees, technology, and environment (Cummings, 1978). Cummings (1978) recognizes that the process for the development of certain key aspects, e.g. autonomous work groups, cannot be created in a single step, mechanical approach. On the contrary, these key aspects in the sociotechnical system require time and diagnosis to implement fully (Cummings, 1978).

In reality, transformation efforts are never straight-forward and full of surprises (Kotter, 1995). Beer and Nohria (2000) propose two main theories of handling change, Theory E and Theory O. Theory E is based on economic value and creating a legitimate measure of corporate success (Beer & Nohria, 2000). Theory O focuses on the development of corporate culture and human capability (Beer & Nohria, 2000). Both theories have considerable drawbacks (Beer & Nohria, 2000). Theory E, in pure form, fails to invest in the development of their human resources thus draining the capacity for sustainable performance (Beer & Nohria, 2000). In Theory O, in pure form, leaders can be hindered in making tough decisions by their loyalty and commitment to their employees. An organization must apply and resolve the inherent tensions between the two theories to be sustainable in their transformation; increasing the economic value, the essence of theory E, and transforming culture, the essence of theory O, must be harmonized (Beer & Nohria, 2000).

Beer and Nohria (2000) claim that 70% of organizations attempting change initiatives fail. Fundamental change finds often resistance thus leading change is essential and difficult (Kotter, 1995). No single person is the driver of change; responsibility must be dispersed among local leaders (Beer & Nohria, 2000). Leadership is defined as the ability to motivate others to get things done (Bruzelius et al., 2011). Although it is necessary to communicate the proposal of change so employees can understand and support it, more than top-down communication is required (Levasseur, 2001). Success requires involving a large number of employees in the transformation process (Kotter, 1995). Employees should be actively involved, encouraged to develop new ideas, try new approaches, and further act as leaders and communicators of the transformation (Kotter, 1995; Levasseur, 2001). For example, autonomous groups promote experimentation, trust, and collaboration between white and blue collar (Cummings, 1978). A vision of the goal with adjustable parameters is the guiding coalition thus facilitating the communication of the new direction (Kotter, 1995).

A comprehensive and pedagogical plan of action encourages the internal ordination and inspires confidence among various stakeholders (Beer & Nohria, 2000). Kotter (1995) establishes an eight-step process to facilitate change in the organization. The steps are as follows:

1. Establishing a sense of urgency
    - An organization should research market and competitive matters.
    - It is vital to consider and communicate the need for change, e.g. a crisis or potential opportunities.
2. Forming a powerful guiding coalition
    - It is important to appoint a leading improvement group with enough power to secure the change effort.
    - Teamwork in the improvement group is critical.
3. Creating a vision
    - Creation of a vision for change will aid the transformation process.
    - Also, it is important to develop methods and tools for achieving the vision.
4. Communication a vision
    - The organization should use all possible resources to communicate the vision and strategies to reach their goal.
    - The improvement team should be a living example of the vision.
5. Empowering others to act on the vision
    - It is important to eliminate obstacles to change.
    - Facilitate change by altering systems and structures so they support the new vision.
    - Encouragement of alternative ideas and actions is important.
6. Planning for and creating short-term wins
    - The organization should plan for visible performance improvements.
    - The organization should then create these improvements
    - Afterwards, the organizations should recognize and rewarding employees that are involved in improvements
7. Consolidating improvements and producing still more changes
    - The process is continuous; further momentum by utilizing past wins to continue improvements, even those that don’t fit into the vision.

    - It is essential to develop, promote and hire employees to implement vision.
    - The project efforts should be re-energized with new projects, themes, and change agents.
8. Institutionalizing new approaches
    - It is fundamental to visualize the connections between the new behaviors and corporate success.
    - The organization needs to further develop positive leadership and succession.

2.4.2 Implementation of Lean Practices

There are various tools and techniques to implement lean principles to an industry (Vinodh et al., 2013). Lean Enterprise Method, LEM, visualizes the architecture in lean operation and works as aid in directing organizations in lean efforts (Seitz, 2003). LEM is a guide of how the concepts of lean apply to organizations and their practices (Seitz, 2003). Table 2.4 illustrates the overarching principles of LEM with regards to human-oriented process practices and system-oriented process practices. Eder and Liebhart (1996) describe human-oriented process as the work-flow supported mainly by humans thus the process must support the coordination and collaboration of the operators to secure consistent results. System-oriented processes are characterized by their high automation and limited human support required (Eder & Liebhart, 1996).

Table 2.4: Lean principles conceptualized and applied on processes (inspired by Seitz, 2003).

Human-oriented processes	**System-oriented processes**
Promote lean leadership at all levels	Assure seamless information flow
Relationships based on mutual trust and commitment	Implement integrated product and process development
Make decisions at the lowest appropriate level	Ensure process capability and maturation
Optimize capability and utilization of people	Maintain challenges to existing processes
Continuous focus on the customers	Identify and optimize enterprise flow
Nurture a learning environment	Maintain stability in changing environment

As commented many company attempts to implement lean manufacturing fail (Losonci, Demeter, & Jenei, 2011; Scherrer-Rathje, Boyle, & Deflorin, 2009). The process to achieving lean manufacturing is a long and practically constant process during which the participants are required to continuously manage and experience changes (Losonci et al., 2011). The implementation of lean requires more than the utilization of tools and methods: the integration of the sociotechnical system philosophy is also fundamental (Losonci et al., 2011). Scherrer-Rathje et al. (2009) consider a success when the organization excels in the both major strategic and operational components of lean. Strategic components include management commitment, employee autonomy, information transparency, and cultural fit (Scherrer-Rathje et al., 2009) Operational components include implementation of a number of practices to support the operational level of lean including tools and methods (Scherrer-Rathje et al., 2009). Many of the successful cases have focused on the soft issues with overlap of Kotter's (1995) transformation theory.

In order to be successful in creating a new system, e.g. lean manufacturing and sociotechnical system, there must be a willingness to change (Kotter, 1995). A key component is leadership in the organization (Kotter, 1995; Liker & Meier, 2006). Leaders for lean support operations and promote the system by allocating both time and resources to communicate knowledge and fix deviations (Liker & Meier, 2006). Lack of senior management commitment is an underlying source of project failure (Scherrer-Rathje et al., 2009; Kotter, 1995). Lack of commitment from management may lead to impeded access to resources, lengthy decision-making processes and limited communication (Scherrer-Rathje et al., 2009). Management commitment should be both active and visible (Scherrer-Rathje et al., 2009).

The success of lean manufacturing, from a shop floor perspective, is largely defined by the operators' own experience (Losonci et al., 2011). In general, operators are concerned with their own work tasks and environment that centers around their work (Losonci et al., 2011). Common arguments against lean manufacturing include reduction of work autonomy through standardization by creating rigid work routines (Biazzo & Panizzolo, 2000; Losonci et al., 2011). However, Losonci et al. (2011) argue that lean manufacturing frees operators to divide work within their group and holds them responsible for the level of quality they provide. Biazzo and Panizzolo (2000) comment that the flexibility of work tasks and employee development can be increased by lowering the decision-making level, managing the process instead of the function, increasing the integration of work task, accentuating the critical importance of teamwork and trust, and developing flatness in the ways of communication. Scherrer-Rathje et al. (2009) state that the facilitating of team autonomy by developing formal mechanism that enhance this nature is key for lean. Thus, leading to quick decisions and undertaking business process changes via employee autonomy (Scherrer-Rathje et al., 2009). No participation and no communication prompt the highest barriers to change (Levasseur, 2001).

Communication of information related to changes in the organization, e.g. policies and procedures, to employees is positively related to an employee's commitment, on both an organization and individual level (Losonci et al., 2011). Mid- and long-term goals should be communicated to the entire organization (Scherrer-Rathje et al., 2009). The fail to disclosing tactical and strategical goals leads to frustration and confusion for those involved (Scherrer-Rathje et al., 2009). Furthermore, as exemplified by Scherrer-Rathje et al. (2009), company-wide communication can ease tension, answer questions, and minimize rumors.

Lean wins should also be communicated (Scherrer-Rathje et al., 2009). Achieving and visualizing early lean successes serves as important teaching tool for employees and benchmark for the organization (Scherrer-Rathje et al., 2009). Success lies in leaders using the credibility gained by short-term wins to tackle even larger issues (Kotter, 1995). Kotter (1995) comments that a successful transformation includes leaders actively looking for opportunities to achieve clear performance improvements and encourage employee involvement through recognition (Kotter, 1995). Leaders play a key role in communicating early success through the organization (Scherrer-Rathje et al., 2009). Losonci et al. (2011) state that good communication leads to greater employee commitment. Especially the shop floor perspective can be largely shaped by communication (Losonci et al., 2011).

In addition, it is important to develop and utilize mechanisms to ensure that lean changes are sustained (Scherrer-Rathje et al., 2009). The sustainability of change involves altering the structure of the business practice (Kotter, 1995; Scherrer-Rathje et al., 2009). Mechanisms include implementation self-auditing teams, tactfully assigning certain work tasks to employees that promote the lean culture, and supporting employee empowerment by recognizing new ideas without punishing failure (Scherrer-Rathje et al., 2009). Scherrer-Rathje et al. (2009) also press the importance of continuous evaluation and measurement during the lean transformation process. Thus, bringing mistakes to the surface so they can be addressed promptly and their impact can be minimized (Scherrer-Rathje et al., 2009). The purpose is to establish a learning organization via continuous reflection and improvement (Liker & Meier, 2006).

3
Method

This chapter examines the method and tools used in this research study. Furthermore, the research quality aspects and ethical considerations are addressed in this chapter.

3.1 Research Procedure

Research can be conducted in a variety of ways. Since the purpose of this research project is to gain insight on how mass customization impacts the production system, flow efficiency was a key concept and lead time was a key measurement. As described in Liker and Meier (2006) there are several options on how to proceed with improving the flow efficiency. Vinodh et al. (2013) constructed a similar experiment within development of a value stream map, VSM, for achieving leanness in a production system. Freivalds and Niebel (2009) production methods engineering encompasses a structured approach to develop work stations and improve work environment through increasing e.g. productivity and quality. The research from Freivalds and Niebel (2009) focuses on the human factors which is important to the sociotechnical system. Therefore, the methodology in this research project is an adaption from the value stream model approach by Vinodh et al. (2013) and the process of Methods Engineering of Freivalds and Niebel (2009), resulting in the research procedure shown below:

1. Design of Study
    - Define case study
    - Literature review
    - Define method
2. Data Collection
    - Selection of VSM that characterizes the research topic
    - Studying of the processes defined in the scope of the VSM
    - Collection of data and constructing current state VSM
    - Studying and collecting data concerning the case's sociotechnical system
    - Continuous dialog with company
3. Analysis of Data
    - Answering research questions
    - Development of future state map for VSM and improved state for the sociotechnical system
4. Develop Recommendations
    - Development of road map with practical improvement suggestions

3.2 Design of Study

The research approach should be derived from the research question (Borrego, Douglas, & Amelink, 2009). This research focuses on how mass customization impacts the production system which encompass a review of the material and information flow as well as the sociotechnical system. Bryman and Bell (2003) discuss how a qualitative strategy is suitable for research focusing on understanding the social world through examination of its participants. Thus, a qualitative strategy was applicable to fulfill the purpose and answer the research questions. The research strategy takes into consideration the case study and theoretical framework. A case study provided deeper insight of a specific situation. A literature review provided theoretical framework by describing current knowledge and offering perspective for conducting future research (Cronin, Ryan, & Coughlan, 2008).

3.2.1 Case Study

A case study is characterized by the high detail analyzes of a single case (Bryman & Bell, 2003). This allows the researcher to examine the subtleties and intricacies of complex social situations (Denscombe, 2014). A holistic perspective is utilized in the analysis. Furthermore, a case study approach advocates the use of multiple sources of data and thus facilitating triangulation to validate data (Denscombe, 2014).

Denscombe (2014) emphasizes the importance of clarifying case boundaries. This initial site for fieldwork is determined by the expectation to provide relevant information on the situation of interest (Denscombe, 2014). The thesis was designed around the company, Cogra Pro AB, which is a small sized enterprise within the PCB industry. Their products are produced in small batches and are highly customized.

3.2.2 Literature Review

A literature study expands the range of the research depth and is used to validate and analyze results from the qualitative and quantitative study as well as identify gaps in literature. Literature review includes gathering and analyzing previous research and theories (Denscombe, 2014). Denscombe (2014) explains how studying previous research can allow relevant problems, issues, and ideas to surface and facilitate prioritization of those various aspects of the situation to be observed.

As data is gathered from multiple sources including Chalmers University of Technology Library, Google Scholar and Scopus, Cronin et al. (2008) promote a systematic procedure for reviewing literature. The literature review procedure is adapted from Cronin et al. (2008) and can be viewed below in Table 3.1

This research project's theoretical framework encompasses a literature review. The intention is to review of the material that already exists on the topic. Ridley (2012) highlights the significance of exploring previous research and theories related to the specified research topic. The gain in awareness and understanding facilitates

Table 3.1: Procedure for literature review (modified from Cronin, Ryan, and Coughlan, 2008).

Procedure	Application
Define knowledge areas	Literature pertaining to the research question and keywords are deemed appropriate for consideration.
Search for literature in electronic database	A range of databases, including Chalmers University of Technology Library, Google Scholar and Scopus, are utilized to collect literature. Comprehensiveness and relevance of literature are taken into consideration.
Read, analyze, and synthesize literature	The collected literature is previewed, questioned, read, and summarized for each of the themes.
Document and create a literature review	The selected theory was summarized and documented, resulting in a literature review. The aspiration is to present knowledge in a clear and consistent way in order to support the research question.

positioning the specified research question and findings on the academic map of knowledge creation.

In the beginning of the project, the literature review provided the authors with an initial understanding of the research topic including lean concepts, work with SMEs, and the complications of mass customization. As the study progressed, the authors utilized the literature review to gain further understanding on how best to collect and analyze data. The theoretical framework greatly aided the analysis since it provided comparison for the case study. It constructed validity by providing alternative sources of evidence. Lastly, the theoretical framework helped the authors construct recommendations for improving the flow and provided ideas on how to present recommendations for developing a sociotechnical system.

3.2.3 Forming the Method

The research tools utilized in this research are VSM, company surveys, interviews, and observations. VSM is an established method for streamlining the process and promoting the elimination of waste (Vinodh et al., 2013). The collection of data through company surveys, observations, and interviews aid in the forming of a holistic perspective of the organization, in particular the production system. In addition, feedback from the company through continuous dialog and benchmarking were woven into this research.

The research project started with the defining of the case study. Then the authors conducted a literature review on e.g. production systems, lean production, production flow, and sociotechnical systems. VSM and various tools were then selected for identifying and solving issues found in the case organization. Later, the material and information flows were defined from the VSM studied. In addition, the authors collected data concerning the sociotechnical system, constructing the current state map visualized waste in the production system. Interviews were employed to gain a deeper perspective of the dynamics within the working environment. Qualitative methods were utilized to identify improvement areas concerning the sociotechnical system. Development of a future production system is based on the future state

VSM and the desires for the sociotechnical system. Suggestions and their sequence to reach this desired state were developed. The appropriateness and practicality of these suggestions were discussed continuously with the organization. The suggestions were further developed to facilitate practical application and adaptability of this study in industrial scenario.

A single case study is an intended part of this research project's qualitative research process. Qualitative research is characterized by the collection and analysis of such textual data research with emphasis on the context within which the study occurs (Borrego et al., 2009). Qualitative research places large emphasis on the following (Borrego et al., 2009):

- Credibility: project establishes that the results are credible
- Transferability: result are applicable to other settings, this is facilitated by a thorough description
- Dependability: the research accounts for the constant modification of the context within which the study occurs
- Reflexivity: the researcher is self-conscious of and discusses their own bias

This research project also utilizes quantitative data. For example, survey results aid in quantitizing qualitative behaviors into quantitative data for statistical analysis. Quantitative methods enable a more objective approach in answering the research question (Borrego et al., 2009). The data collected permits the research to generalize and results become applicable in other settings. Quantitative research criteria includes (Borrego et al., 2009):

- Validity: project's instruments measure the intended parameters
- Generalizability: results are applicable to other settings, this is facilitated by a thorough description
- Reliability: replicable and repeatable results
- Objectivity: researcher limits their influence on the participants and the findings

3.3 Data Collection

This project utilized several different methods to collect data. For the information and material flow, VSM was mainly utilized. Interviews, and observations were also utilized to analyze the material and information flow. Moreover, surveys, interviews, and observations were collected to examine the sociotechnical system. Although majority of data was collected by the authors, this report also contains secondary data. Secondary data is data that the researchers themselves have not collected (Bryman & Bell, 2003). Example of such is data imported from the company's internal database and Enterprise Resource Planning (ERP) system.

3.3.1 Value Stream Mapping

VSM, is used as the data collection and analysis method in this thesis. King and King (2015) state that the VSM should be the first technical activity in any lean transformation. The purpose is to gain an understanding and visualize the organization by studying the design of operations and communication.

Baudin (2002) lists four limitations to the VSM for discussing the method:

1. It is complex. Graphic vocabulary has a large quantity of icons used, including certain rules corresponding. It is a language to be learned to generate and read the maps (Baudin, 2002).
2. It is intended for end-to-end mapping from the raw material supplier to end customer, including supermarkets and operator location. For displaying processes more complex than viewed in "*Learning to See*" (Rother & Shook, 2003), VSMs often cover up entire walls.
3. As Rother and Shook (2003) recommend paper and pen, icons and shapes become time-consuming to draw and times cannot be computed in spread sheets or similar without retyping.
4. Level of detail is high enough to address production control issues but lacking detail for design of assembly stations. Baudin (2002) states that VSM analyzes time *between* operations in contrast to *at* operations. To achieve flow by conveyance, Baudin describes two levels of detail required:
   (a) First, aim at analyzing what happens *within* the station to better describe the flow of products and amount of work required. For instance, Baudin (2002) gives an example of a 46 second process may involve 16 seconds of assembly and 30 seconds of picking.
   (b) Secondly, find the imbalances between different stations. Baudin (2002) also adds that balancing tools were later complemented by Rother in *"Creating Continuous Flow"* (Rother & Harris, 2001), addressing the issue.

To validate the VSM method, adaptation between using VSM and further shop floor participation, was utilized to understand what happens inside the process (Baudin, 2002). In addition to the VSM, flow map and workshops are used to make sure that appropriate level of detail is caught for analysis considering mass customization, material and information flow and sociotechnical status. The focus will be on the analysis from a production flow perspective, initially by a VSM approach and then identifying areas of improvement and possible lean methods to support them. Mapping current state by identifying product families, customers and their needs, activities in the process, buffers, information and material flow and the time line.

The authors put a large weight on this tool. The research is limited to following the shop floor flow of the three main product families: single, double and multi-layer PCBs, in the format of production panels. The value stream map will be adapted to fit the three families. This scope was found to be appropriate as the families circulate similar routes and give a better understanding of the actual current state of the shop floor due to shared resources between the three families. Analyzing the families individually would bring additional limits and constraints to resources, complicating the process of developing and analyzing possible improvements of the future state.

3.3.2 Surveys

A survey approach is a research strategy that provides a breadth of study while stemming from empirical data (Denscombe, 2014). Surveys are strategic since they are cable of transforming empirical data through a structured and purposeful path (Denscombe, 2014). This research project utilized postal questionnaires. Denscombe (2014) explains postal questionaries as sending self-completion questionnaires through the post thus convenient for both researcher and respondent. During this study, questionnaires were both sent through email and delivered manually, however completion of the surveys was not overseen. The surveys were distributed by employees at the company and the authors.

The surveys utilized in this study were created by Swerea IVF, a research institution. The survey form and questions are directed towards SMEs attempting to incorporate lean manufacturing. For this research project, the survey results analyzed customer feedback and the working environment at the company.

3.3.3 Interviews

Bryman and Bell (2003) comments on how interviews are an attractive data collection strategy for qualitative research. The implication of a set of understandings and assumptions concerning the situation are elaborated in interviews that are not normally associated with a casual conversation (Denscombe, 2014). In general, interviews aid the researcher in attaining information which provides more of an in-depth insight into the subject, drawing on information provided by fewer informants (Denscombe, 2014). This study used both semi-structured and unstructured interviews. Semi-structured interviews describe the context to which the interviewer has a series of questions prepared but allows the sequence of the questions to vary and follow a more natural form of dialog (Denscombe, 2014). Additional questions can be asked to expound upon significant replies (Bryman & Bell, 2003). Unstructured interviews are useful since they place emphasis on the interviewee's thoughts (Denscombe, 2014). The major distinction between semi-structure and unstructured interviews is the degree of control exercised by the researcher over the nature and length of the responses permitted (Denscombe, 2014).

Although no formal interviews were conducted during this research project, there were meetings with prepared questions that resembled semi-structured interviews. This type of semi-structured interviews was conducted with both management and production staff at the company. This study also incorporated unstructured interviews. Unstructured interviews allow the interviewees to use their own words and develop their own thoughts which allows for discovering things about complex issues (Denscombe, 2014). The authors utilized unstructured interviews to conduct in-depth investigation, gathering personal accounts of experiences and feelings concerning the production system and working environment. Unstructured interviews were conducted with both white- and blue-collar workers. All interviews were conducted on a face-to-face basis. Majority of the interviews were conducted in the first few months of the project since the authors worked daily at the company during that time period. Notes were transcribed but no audio-recordings were made.

3.3.4 Observations

Observation offers the researcher a distinct way of collecting data (Denscombe, 2014). In addition to listening to accounts of activities, data by observation can be utilize to gather the direct evidence of witnessing what actually happens (Denscombe, 2014). The data recovered by observation has been found by participation as the observer where the researcher's identity is openly recognized. This is further stressed as Denscombe (2014) addresses that a researcher should be as long as possible on site with the aim to learn about the process, not to be considered a hit-and-run research method. To fulfill this, the authors worked on site the first few months and then maintained contact with management as well as visiting several times during the time they worked from the university. The authors conducted two forms of observations, timestamping and participant observation sessions.

Baudin (2002) states manually timestamping machining operations is a commonly used method to find the means to calculate assembly. This material can preferably be kept up to date by the operators themselves and used by managers to calculate the time needed for an operation(Baudin, 2002). The quality however, is improved by stamping times on a digital ledger (Baudin, 2002). Stopwatch studies can be conducted but requires briefing beforehand with information of the purpose of the study and how the data will be used (Baudin, 2002). Rother and Harris (2001) summarize some guidelines when conducting these types of sessions including:

- Present yourself and explain the purpose and method of your work
- Allow the operator to see your notes recorded during the interview
- Show gratitude

Stopwatch studies were used to collect data for the VSM process. The guidelines derived from Rother and Harris (2001) were followed in order to build trust and work ethically. For example, when timing operations and work tasks, the authors always clarified their intention, showed respect for the operators when collecting information, and thanked them after for their time and input.

To gain insight regarding daily activities and work tasks managed by operators, participant observation sessions were executed. Participant observations were frequent during the first half of the research study and aided in understanding the current state of the production system. Denscombe (2014) lists advantages and disadvantages for this form of "shadowing" a group or person, witnessing the events of interest. These advantages and disadvantages are highlighted in Table 3.1 and were taken into consideration during the study.

Participant observation			
Advantages		Disadvantages	
Basic equipment	The researcher himself is the main instrument, requires little technical support	**Access**	Limited options to what settings to participate in
Non-interfering	Better chance of retaining naturalness of setting	**Commitment**	Can be very demanding in terms of personal commitment and resources
Insights	Rich insight of process with complex reality	**Danger**	Potentially hazardous
Holistic	Observations incorporate relations between various factors	**Reliability & Repeatability**	Open to doubt as researcher notes lack verifiable data
Subjects' point of view	Includes the actor's meanings as they see them	**Representative-ness of data**	Difficult to generalize from the findings
Ecological validity	The data has potential to be context sensitive and ecologically valid	**Deception**	If researcher identity and target is kept from target, ethical problems arise if consent is absent

Figure 3.1: Advantages and disadvantages of participant observation (inspired by Denscombe, 2014).

Bryman and Bell (2003) explain the purpose of participant observation sessions as a a way to observe the culture, norms, and patterns of work task behavior. Often during these sessions operators commented and explained the activities providing additional insight in the working environment. These sessions were documented during or after where the authors compared understanding and summarized notes.

3.3.5 Feedback from Company

Dialog with the company and benchmarking were part of this study. The primary reason the authors positioned themselves on site was to gain a holistic and realistic depiction of the current state production system and open dialog with the company's employees. Communication was facilitated through both informal and formal meetings. Moreover, the authors took care to discuss issues with various employees working at different hierarchical levels. The main topics discussed were production planning, material and information flow, product design, and working environment.

In the first weeks, the authors presented the research case to the entire company. Two more formal presentations followed to present the case's progress and were always followed by thorough discussions. The authors also held workshops, with 3 employees at a time, after constructing the current state map. The aim of the workshops was to ask for responses to error-proof the map, receive feedback, and ask for improvement suggestions based on weaknesses found in the current state. VSM is considered a valuable tool since it visualizes and promotes discussion for streamlining the process (Rother & Shook, 2003; Liker, 2004).

Talluri (2000) deems benchmarking a critical step for organizations performing continuous process improvement and business re-engineering efforts. The benchmarking method comprises of juxtaposing and integrating multiple key performance indicators in order identify the best business practices and improve productivity (Talluri, 2000). From an academic perspective, subsequent sites for fieldwork are selected by researchers due to their relevance to emerging categories and concepts (Denscombe, 2014). They allow for comparison and contrast and increases flexibility of research by shedding light upon investigation areas that had not been foreseen (Denscombe, 2014).

This study utilizes industry benchmarking; industry benchmarking is characterized of identifying the best practices of other firms within the same industry and utilizing them to guide the organizations improvement practices (Talluri, 2000). Benchmarking was conducted by visiting two firms, Brogren Industries AB and Scania CV AB.

A benchmarking visit to Brogren Industries AB with several of the employees from Cogra was conducted. Brogren Industries AB started their lean journey four years ago. In recent years, the firm has grown from 25 employees to circa 100; machining complex geometries like turbines for e.g. the aerospace industry. The size, recent development, and geographical proximity (e.g. shared community) quantified them as a case for benchmarking.

In addition, an inspirational visit to Scania in Södertälje was conducted. Scania is viewed as one of Sweden's leading lean practitioners (Vene, 2012). This visit exemplified lean theory in the practical application for continuous improvement and the lean management process. Moreover, the visit served as inspiration in creating long-term visionary goals since Scania demonstrates the success of lean in production practices. Scania's products are also mass customized and their ambition to shorten lead times is similar to Cogra's.

3.4 Analysis of Data

After the data is collected, it is analyzed to answer the research questions. Moreover, in this project, improvement areas and solutions were also retained from the analysis.

Qualitative research is characterized by the concern with meanings and the way people perceive surrounding elements and a concern with patterns of behavior (Denscombe, 2014). Denscombe (2014) explains how qualitative data is the product of a process of interpretation, e.g. words or images. Therefore, a researcher's personal experiences play a role in qualitative research (Denscombe, 2014). A key part of qualitative research is reflecting over and attempting to identify pattern and processes, commonalities, and differences (Denscombe, 2014). For example, in the case study, the participant observation sessions aided in the categorization of the eight wastes and their frequency.

Although this research is primarily focused on qualitative research, some quantitative research is also incorporated. Quantitative research carries a certain scientific respectability due to its ability to convey a sense of objective research through forms of graphs and tables (Denscombe, 2014). The transformation of data to information can be made difficult to that the researcher must often compromise between the amount of information that can be conveyed and the visual impact of the information (Denscombe, 2014). This research project analyses quantitative data when analyzing e.g. WIP and customer demand.

3.4.1 Answering the Research Questions

For the analysis, qualitative data derived from interviews and participant observation and quantitative data from surveys are juxtaposed with the theoretical framework to answer the research questions.

One of the fundamental difficulties with qualitative research is that it quickly generates a large, cumbersome database (Bryman & Bell, 2003). To make the data set manageable the empirical data was first grouped according to subject matter as seen in Chapter 4. This entails that some subsections contain data from different sources. For example, the sociotechnical environment data contains survey, participant observation, and interview results. The empirical data was then compared to the theoretical framework to answer research questions, as seen in Chapter 5. The analysis considered how the flow efficiency was affected in the current state of the production system. The research analyzed how well products and information flowed through the system along with considering the sociotechnical environment. Several improvement opportunities for facilitating the flow were identified.

3.4.2 Design of Future State

Based on Rother and Shook (2003), the eight future state questions, in combination with found improvement areas, guided the creation of the future state map. Improvements required to achieve greater flow efficiency were connected to either material, information or people to show goals in relation to the sociotechnical system.

- What is the real customer demand? What is the takt time?
- Will the organization produce for direct delivery or to finished goods stock?
- Where can the organization produce in continuous flow? Where can the organization reduce waste?
- Where are the supermarket pull systems (buffers) placed to regulate flow?
- Where in the flow does the pacemaker plan production?
- In which batch size should we produce?
- How is production mix leveled?
- Which process improvements are needed?

3.5 Further Development of Research

After analyzing the current state that studies three product families in the in-house production flow, recommendations were generated. As stated in the previous section, the focus was on developing the production system. Through participation in company strategy workshops, interviewing and observing production identified areas connected to key company principals forming future state recommendations. The focus was on improving the efficiency of the production flow, specifically involving value-adding time and kaizen.

Due to the qualitative nature of the results, the improvement suggestions, can be vast and overwhelming. Once recommendations were identified, they were mapped onto a sequential framework. Denscombe (2014) suggests structuring qualitative findings so that they address and highlight key issues, are clearly comprehensible to the reader and are is logically ordered. The suggestions were mapped out using category placement and their dependency upon each other. Furthermore, the sequential diagram with recommendations provides a visual guideline and discussion forum for lean implementation in an industrial scenario.

3.6 Research Quality Considerations

Bryman and Bell (2003) emphasize the need to address and reflect over the trustworthiness when assessing the quality of research. Methods to establish trustworthiness of research is addressed differently by different authors. Various aspects of the research should be considered when designing an experiment. In particular, this research examines the case study's validity as well as examining research criteria for quantitative and qualitative data.

3.6.1 Case Study Validity

The conducted research of a single case study draws certain limits to what conclusions that can be found. The case study examined was found appropriate to facilitate examination of the research questions from a sociotechnical perspective utilizing a qualitative method research approach. This research was primarily validated by constructing validity. Yin (2013) describes constructing validity as the act of identifying correct operational measures for concepts studied. Yin (2013) also comments on how constructing validity can be attained by using multiple sources of evidences, establishing a chain of evidence, and having key informants review draft case study report. The case study used multiple sources of evidence, e.g. the material flow was documented through semi-structure interviews, unstructured interviews, and participant observation results. The chain of evidence was fairly weak in this case due to the lack of formal interview transcripts makes it difficult to trace a notion through the study. The project's results were accredited by a variety of sources including management and operators from the company. The research findings are presented and discussed as part of the continuous dialog with the company. Sometimes the research findings were discussed in more formal setting, e.g. workshops and meetings, and occasionally in less formal settings, e.g. unstructured interviews and participant observation sessions. Furthermore, the authors utilized peer debriefing e.g. after participant observation sessions. The quality of the research was also audited by asking other researchers not directly incorporated in the research to review the findings through peer review.

Interviews were an important part of the study and consequently have a large influence over validity. Bryman and Bell (2003) comment on how qualitative interviews gather information about the interviewee's point of view. This should be taken into consideration when discussing the internal validity of the case study since casual relationships were established, whereby certain conditions are believed to lead to other conditions. Yin (2013) notes that internal validity can be strengthened by performing pattern matching, explanation building, addressing rival explanations, use logic models. To increase internal validity of the case study, the authors utilized pattern matching and explanation building. The authors compared notes from various sources in the data analysis to find patterns. Moreover, the authors practiced explanation also utilized both qualitative and quantitative data when analyzing the working environment.

Due to the nature of the study and the prolonged immersion of the participant observation sessions, there exists a risk that the researchers have "gone native". Going native is a quandary where the research becomes so wrapped up in the perspective of the participants that they lose their orientation as a researcher Bryman and Bell, 2003. This causes problems since it can be difficult to develop a business angle on the collection and analysis of the data gathered Bryman and Bell, 2003. The accuracy and validity of the data gathered through participant observations can therefore be subjected to questions concerning accuracy and validity of the current state analysis. However, the authors believe that the participant observation has played a key role in developing sustainable improvement suggestions since commitment to an improved working environment was expressed during these sessions and participants became more or less active members of the transformation.

3.6.2 Other Research Aspects

As described in Section 3.2, this research project utilized both qualitative and quantitative data. The qualitative research's criteria comprises of credibility, transferability, dependability and reflectively (Borrego et al., 2009). These aspects were all taken into consideration when designing the study.

Since the research project also contained quantitative data, it is important to assess the validity, generalizability, reliability, and objectivity of the research. Tools and methods were developed to ensure the measurement of the correct variables. The evolving and customized nature of the production system made reliability difficult. Despite this, detailed descriptions on how the measurements were recorded contributed to the reliability of the research as it is possible to reconstruct the same result again if measured with similar conditions. The discussion's aim is to broaden the applicability of the research findings to other settings. However, due to the nature of the single case study, the generlizability has been limited. The authors have attempted to retain a sense of objectivity by utilizing quantitative data secondary data in addition to the data they collected themselves.

Since the authors were neither a part of the formation and distribution of the surveys, the validity of this tool may be deemed questionable. The survey was formed by Swerea, a research company with high credibility. Additionally, due to distribution process of the various surveys, only a portion of the entire population was collected. The evident consequence of this is that the survey's result reflects only the result of approximately two thirds of the company. Thus, it cannot be assumed that the results are representative of the whole. However, (Denscombe, 2014) adds that a case study can be a valuable compliment to a survey approach in order to weigh the results of the survey, which has been used to confirm the results and add credibility.

This research is case specific and therefore special attention should be paid when examining transferability and generalizability aspects. Research findings are based off the combination of theory and case study and therefore are influenced by but not limited to the case. This is based the real-life case study where aspects change as time goes on thus making it difficult to produce entirely replicable and repeatable results. This is especially noticeable in the VSM method due to that it is characterized as a snap shot at the specific time of data collection. On the other hand, traces of these results have proven to be prevalent at the company several months after the VSM was conducted. The authors attempted to hold a degree of objectivity by encompassing several different types of empirical results including quantitative data. Nonetheless, there has been a continuous discussion between the company's employees and the authors.

This research project has struggled to find a balance between practicality and ownership of improvement suggestions provided in the case. On one hand, the stakeholders desired fully explained and exemplified improvement suggestions. However, an important aspect of change management is the incorporation of the various stakeholders in the formation of improvement suggestions and thus the suggestions should be customized throughout the process. The authors' participation was in the early phases of the transformation process so were not present during the implementation phase. The company's ability to go on after the research project is finish is therefore directly connected to the balance of the improvement suggestions. In addition to the continuous dialog with the company, the authors utilized benchmarking to identify appropriate business practices at relevant stages. For example, benchmarking assisted the forming of operative and strategic suggestions in the sequential improvement diagram.

3.7 Ethical Considerations

It is critical to be aware of the ethical aspects when conducting research (Bryman & Bell, 2003). One of the principles that Bryman and Bell (2003) address is harm to participants; harm can be described in multiple ways including physically inflicted along with damaging a research participant's self-esteem and/or future career (Bryman & Bell, 2003). The authors attempted to foresee circumstances where the participant could possibly be put in harm's way and thereafter implement precautions. To ensure the participant's well-being, the authors have been careful to not distract the participant's during their work, e.g. operating machinery, and have not disclosed their identity in the report without consent. Submitted information to authors, dissipation to stakeholder, and usage in report was approved and censored if necessary and/or requested.

This also touches upon another principle listed, lack of informed consent (Bryman & Bell, 2003). Informed consent concerns providing the potential research participants with information so that they can make an informed decision regarding whether or not they want to participate in the study. For this research, the authors attempted to always clarify their intent and procedure to the participant involved. Furthermore, questions that the employees had were answered immediately and thoroughly by the authors to safeguard a high level of transparency with the research project.
It is also crucial to be careful in the research method to avoid deception; Bryman and Bell (2003) preach that deception should be mitigated when possible. This principle, deception, is closely related to the previous one, informed consent. This is counteracted by the authors being straight with the purpose of the project prior to performing research activities. The collection and handling of information has had clear intentions and performed in a way that promotes transparency and visibility of the intention. In addition, the authors tried to minimize the power of inequalities between them and the research participants by ensuring that the research has benefits for all. The various stakeholders' desires have been considered and a consensus has been reached involving how the benefits found through the thesis to build a foundation for continuous improvement, rather than slimming production for short term gains by mean lean implementation (Anderson-Connolly, Grunberg, Greenberg, & Moore, 2002).

4

Empirical Data

This chapter regards the current state of the production used in the case study. A thorough description of the production flow and daily routines are presented.

Cogra is an SME in the outskirts of Gothenburg with 18 employees, specialized in the production of PCBs. They are one of three businesses still producing in Sweden. Large parts of the Swedish manufacturing of PCBs has been sold or moved overseas, as competition from emerging market are efficient on low-cost production and trading. Most of their products are made do order, focusing on short lead times and quality. A standard order PCB typically ships five days from point of customer order placement. During which, all internal process are included; production planning, production, and shipment.

As all products are unique PCBs make to order in small quantities, decoupling points usually in form of supermarkets (as viewed in Rother and Harris, 2001) are difficult to adapt without increasing the unique product's lead time. As a result, handling with fluctuation issues due to variants and varying customer demand are factors increasing the need of high responsiveness of the production system. With approximately 700 unique customers during 2016, effectiveness in production planning and forwarding the products the shop floor, as well as short production lead time are of importance to their strategy. At the point of order placement, Cogra receives order data from customers either through their web-application or by e-mail. The data includes the engineered PCB and desired specifications. An example PCB build can be seen in Figure 4.1. The layers of copper indicate if the product is a single, double or multi-layer PCB. A single layer has one copper surface with processed conductive tracks according to the specification, double layer indicates two layers, and multi-layer indicates inner layers and outer layers of copper pressed together with a non-conductive. As viewed in Figure 4.1, specifications all components include thickness and type of conductor and non-conductive material used in a specific build. Cogra accepts orders with up to three inner layers of copper.

Cogra has largely been stabilized by its vast number and wide spread of customers, reputation for quality and being able to produce in house. Large customer value is provided in Cogra's flexibility and ability to create small series with a broad span of attributes (color, size, shape, ect.) within days of order placement. In addition, the location of the company adds security in delivery speed and customer relations as a majority of customers are located in Sweden and Norway.

A constant struggle is planning as all products are made to order fluctuations in

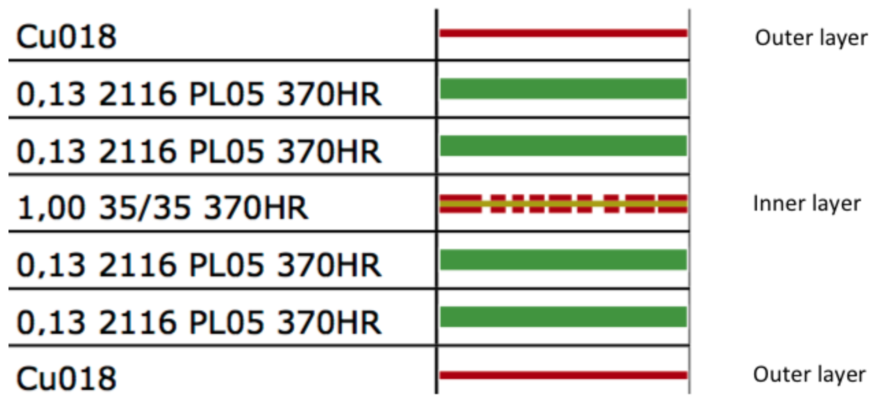

Figure 4.1: Example of the build of a multi-layer PCB.

customer demand cause uneven load for production planning and production. Another weakness is the complexity of the process as orders are highly customized, processes are put under various levels of stress. Cogra experience staffing and competence issues, where they need to adapt to absenteeism as best possible. As such, their delivery dependability has been a concern due staff retirement and increasing customer demands. A frequently occurring problem is that production cannot keep schedule. Orders are re-prioritized and marketing is forced to address the issue of explaining and excusing late deliveries, offering post order confirmation discounts to keep customers satisfied. Cogra's management is eager to find new solutions and improve their production methodology to meet customers are demands.

4.1 Production System

Production is grouped in a functional layout (Bellgran & Säfsten, 2010), which can be seen in Appendix A. Machining equipment however, is built for large batch production of PCBs. Handling time is increased since Cogra handles small batches with high variety. Additionally, certain processes mismatch the equipment. This leads to that the operator must stay and observe the process, e.g. when dealing with too thin of panels for the original equipment.

Reactive maintenance is the strategy to maintain equipment functionality. Insufficient stability in processes lead to overproduction. Due to the uncertainty of producing acceptable quality, production planners inflate the production order increasing actual number of PCBs in the order. For instance, a customer may order only five PCBs, while production schedules the eight PCBs to make sure that the order can be sent on time. The issues is repeated due to inability to follow-up on inconsistencies. As a result, several quality control steps are added, as seen for instance when multi-layer panels are inspected in Automated Optical Inspection, AOI, and tested for conductivity twice. The PCBs that are overproduced cannot be sold and are thus scrapped.

4.1.1 Mass Customization of Orders

Cogra has three main product families including single layer, double layer, and multi-layer. In general, all three types of product families follow the same manufacturing processes with smaller deviations, the conductive circuits makes the products in every order unique and is seldom reordered by customers.

Customers can order standard PCBs as well as development PCBs. The latter is for customers that wish to test the functionality of their design, not requiring routine quality checks etc. The development PCB demands higher speed of delivery as customers wish to test the product for instance when prototyping. Customers require two-day delivery on this type of order, but ask to receive them as promptly as possible. As production follows the same steps for all type of PCBs daily re-arranging of production order has been Cogra's procedure to maintain customer satisfaction, e.g. desired lead times. This type of order is identified as rush orders.

Although rush orders play a vital role in the company's business model, they lack standards and limits for handling rush orders. Practically, rush orders are dealt with by negotiating with the customer and reprioritizing orders already in production, which affects delivery precision. Additionally, as Cogra is unable to produce within the customer's requests and deliveries are missed.

4.1.2 Customer Demands

The customer demand can be observed in Figure 4.2. The customer demand is represented as number of panels order per month. The measured timeline spans January 2015 to January 2017. The total, including single, double, and multi-layer, line is light gray. The dark line represents the mean value, 979 per month. Consulting the CEO, he explains the fluctuations are dependent on holiday seasons for the months with low production. July includes the period of industry vacation in Sweden, while December operating weeks are cut due to Christmas holidays. Peak demand is viewed during spring is explained by the Chinese new year. As Asian factories close down for the holiday, Cogra receives large orders from customers that otherwise purchase from China. The CEO pointed out that the last days of the month are periods often under high pressure as well. Moreover, this is explained as a result of companies purchasing, evening excess in monthly budgets.

Promised delivery times vary between 2 days and 3 months (most orders are sent within a week) depending on volume, complexity, and status i.e. rush order. Promised delivery times are agreed upon between sales and the customer. Delivery precision, shipping the finished product within the expected time frame, oscillates especially when during the customer demand peaks.

Last-minute deliveries are frequently occurring. A large effort is put in place to reduce delivery tardiness. Re-prioritization on the production floor is frequently occurring. Final stock is minimized as finished products are shipped the same day

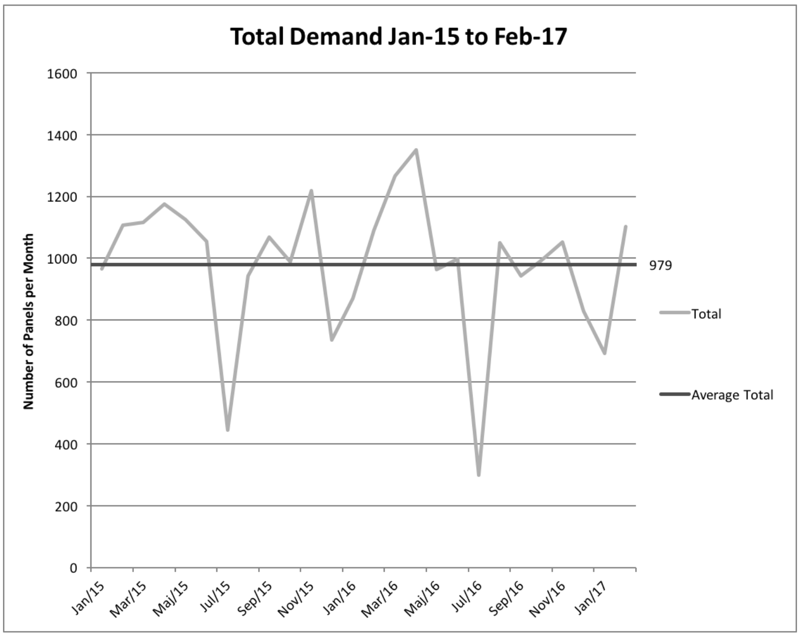

Figure 4.2: Display of customer demand of panels including single, double and multi-layer products.

as they are completed. The packaging department is well aware of when the postal truck is expected to arrive. Oftentimes, employees are required to drop off finished products at the postal office since the postal office closes later in the evening.

Delivery precision is only one of the characteristics that customers perceive. To gather the customer's opinion of the current situation, Cogra administrated a survey to eight customers. Sales contacted three top customers asking for feedback. The writers visited an electronics conference with the purpose of meeting customers. The authors gathered five survey results.

Customers were asked to rank Cogra's perceived performance on a scale 1-10, where 10 was high and 1 was low. Questions centered on how well Cogra was able to meet the customers' needs including quality and service. The average scores can be displayed in Table 4.1. The categories that received the lowest score from the customers were delivery precision and quality.

Table 4.1: Customer feedback survey with scale (1-10).

As the customer, how do you perceive.....	**Average**
Cogra, overall, as a supplier?	7.63
Cogra's products and services?	7.50
Cogra's quality?	6.75
Cogra's delivery precision?	6.38
Cogra's expected delivery times?	8.13
Cogra's prices in relation to the product?	7.75
Cogra's service towards you?	7.88
Cogra's ability to solve problems and all around improvement work?	7.33

Scale	1	2	3	4	5	6	7	8	9	10
	Extremely poor (drastic & immediate improvements needed)	Very poor	Poor		OK		Good		Very good	Excellent (no improvements needed)

4.1.3 Sociotechnical Environment

The company structure is flat, with 18 employees, two employees are in sales, three in production planning, two in management and administrative, tasks, one in maintenance, and ten in production. Of the seven in the office, three have board positions. Two of the operators are available only part-time. Although, it can be considered that there is only one shift, start and end times for various employees differ. In addition, it is common, especially at the end of the month, that work weeks exceed 40 hours since tasks are performed outside of daily routines. For instance, CEO, sales and administrative positions work additional hours when needed to cover-up for production.

Majority of the employees have been there more than five years, however in the last year three new operators have been hired. Majority of the operators are seasoned in their routines and are more or less stationary in their work tasks. There is a centralized technological competence. During the first two months of the thesis, on average the attendance at Cogra was approximately 87% (including long-term sick leave).

At the start of the project, Cogra administered a company-wide survey in order to assess employees' opinion of the current situation. The results are summarized in the plots below. Thirteen out of 18 employees answered the survey. Employee answers were divided into production and management. Viewed in Appendix C are additional areas, complementing Figure 4.3.

Figure 4.3 juxtaposes different perceptions concerning the current working environment. The survey researched how employees perceived their individual incentive, challenges, and influence. The scale measures the magnitude the participants felt that the organization incorporated the characteristics in their work. For example, a positive score is representative of how well a characteristic is achieved in the current situation and a negative sores represents how much the employee felt that their work was missing this characteristic. The largest range in answers addresses how well the employees felt that their work provided individual incentive. There is also a wide range in the answers how well work tasks incorporated stimulating challenges for different types of employees. Answers involving autonomy or work influence are also contrasting.

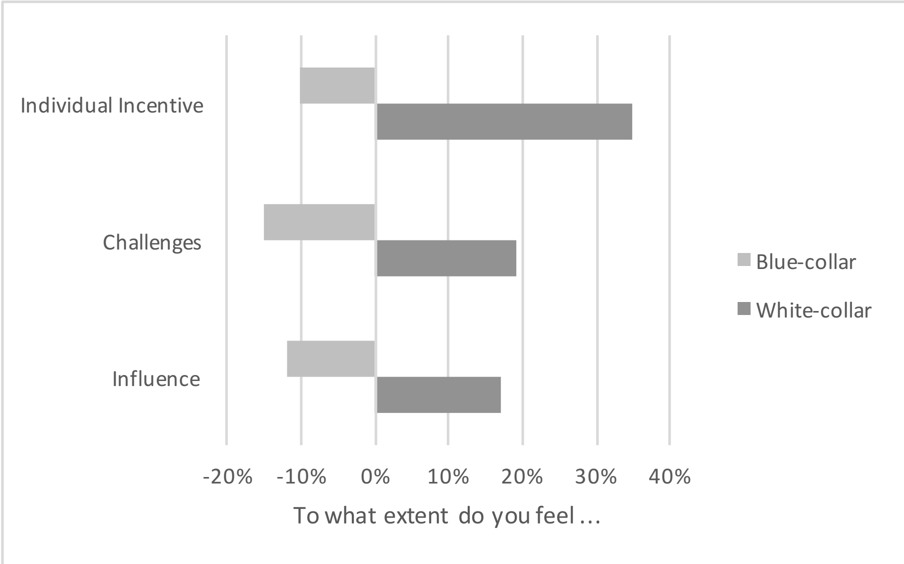

Figure 4.3: Employee Commitment Survey.

4.2 Production Flow Efficiency

Production flow refers to the movement of material through the organization, e.g. information and material. The analyzed production flow follows the product from when the order is received by production and stretches to packing the product for shipment. The material flow specifically follows the product across the shop floor, from gathering the raw material to when the products are split to individual PCBs for packaging. In addition to material flow, the information flow is defined similarly, starting with the production receiving the order and ending with the handling of the order shipment.

4.2.1 Production Planning and Control

After initial sales, an order is placed in the planning queue for pre-processing of customer schematics. The production planners check customer material through various computer aided manufacturing, CAM, systems before orders are placed in production queue sorted by delivery date and product family. At this stage, Cogra combines different customer orders of similar structures into one PCB forwarded into production, called the production panel. In Figure 4.4 an example of a production panel is shown with three different customer PCBs in one production panel. As seen in the figure, material utilization is high. Higher utilization impacts total number of total panels required to fill a customer's order. As an example, the customer ordering the smallest PCB in the figure requests 500 PCBs. Their order is split to fill several production panels and combined with other orders. Thus, downstream processes receive less unique production panels with high utilization, filling several customer orders.

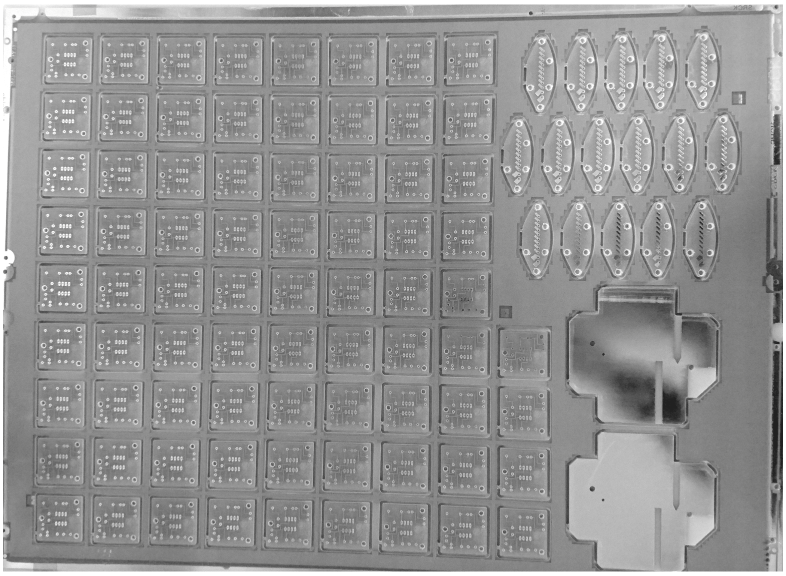

Figure 4.4: Physical production panel with multiple customer orders.

Production panels placed in production are assigned with name, work task description, and expected delivery. An order form with the information is compiled for the production panel and manually handed to the first operator. See Appendix B for production order example. Their working procedure utilizes more material compared to the option of producing every order as one production panel. Incoming orders are varying in size, quantity and complexity. Process planning gives a competitive edge for supplying smaller customers with fast delivery at an acceptable cost. The production planners compose an order form with a maximum of 12 products to facilitate production by starting a moderately sized batch. However, once in production the operators split the order into manageable quantities for their respective processes.

The paper production order accompanies the production panel as it moves through the series of production steps. Urgency is masked in color coding white-green-red on the date. In the example shown in appendix, green is used. Some of the operators sign-off on the production order form but not all. Due to the limitation in information passed on through the production order, there is a high reliance on tacit knowledge. This is further impacted by the lack of standardized production steps; hence each operator creates their own way of working. When a product order is unclear, operators consult the production planners. Since orders are complex and highly customized, this is a frequent phenome. The only information passed on from production planning and control is the production order, no other scheduling is used.

To control the information flow, Cogra has developed their own customized ERP. The ERP is intended for the production planners for queuing and sorting orders, operators to report status of products and by management to see status of the company. However, few employees utilize the centralized production planning and control system in the current state. WIP is unregulated leading to difficulty in locating orders once they have entered the shop floor and contributed to an unawareness of how many products are in the system. Furthermore, there are several processes that have varying and unknown cycle times when starting the machine, e.g. drilling. Due to the limitations in WIP control and unclear picture of cycle times in several of the processes, it is difficult to predict lead and cycle times in the current state.

4.2.2 Flow Map

Cogra's production is composed of four departments, mechanical, chemical, photo, and packaging. The workstations for the various departments are spread across the production floor. Production panels can circulate multiple times through various departments depending upon the customer's desired characteristics for the panel. Such is the case for multi-layer panels, where inner and outer layers are processed. Raw stock, tools, and WIP are scattered throughout the shop floor. Due to there is no reserved areas for products and various items, they are relocated with respect to space available and the individual employee's opinion.

Figure 4.5 below depicts the flow of a typical product, a multi-layer PCB. The line connects all the processes sequentially from the starting point, cutting and punching the base plate, to the end, packaging. The different blocks represent various larger items in production. dark blocks represent machines. Gray with black border depicts working areas, i.e. workbenches, and gray with white border shows larger stock areas.

Figure 4.5: Material flow on the production floor.

4.2.3 Value Stream Map

The current state VSM shows single, double, and multi-layer panels' journey through production, as seen in Figure 4.6. A larger scale version can be found in Appendix D. Striped push arrows visualize the push movement through the main flow. For double and multi-layer panels, the flow deviates from the main flow at several points creating alternative flows. Due to the high customization of Cogra's products, not all products follow the same path, the VSM follows instead a typical product path. As stated previously, the path visualized and analyses stretches from the gathering the raw material to when the production panel is split into individual PCBs to be packaged. The VSM also records the utilized information flow, via electronic exchange, and visualizes by arrows formed as lightning bolts. The raw material supplier delivers upon demand, roughly every other week, and the production orders are submitted to production as soon as the production planners have composed them. For the VSM, the end customer is the process of separating the panels into cards for shipment.

Takt time for the production is determined to be six minutes per panel. Takt time multiplied by the specified volume of products represents the time measurement in the VSM. The timeline is located under the inventory triangles and process boxes. The timeline compiles lead time by visualizing both the time a product is involved in the manufacturing processes, value adding time, and waiting in inventory.
Eight, full-time, operators support the four production departments. Two operators work in mechanical, two operators in chemical, three in photo, and one in packaging. Despite working one shift, operators start and end various times between six am to seven pm to fit their process.

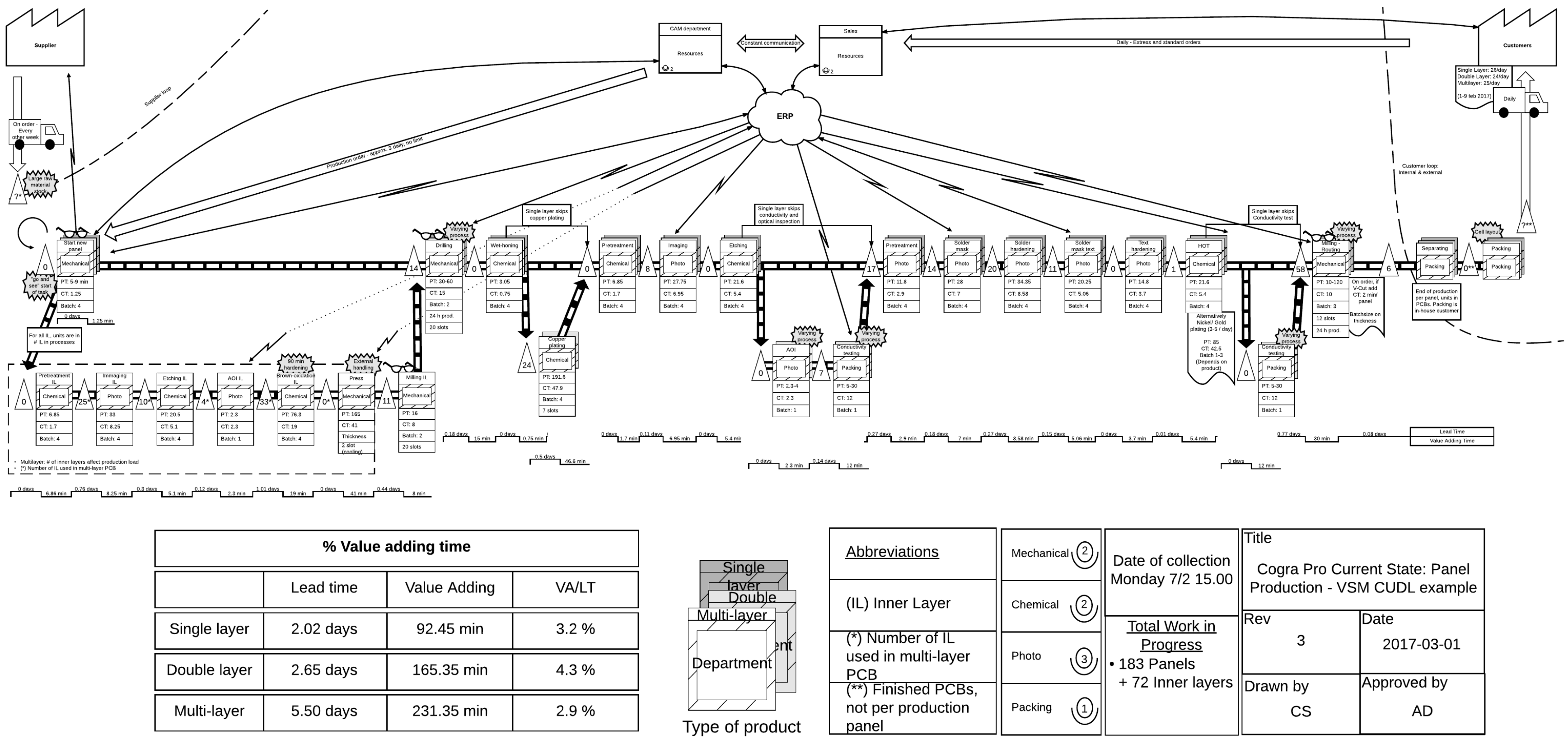

Figure 4.6: Current state VSM displaying the three product families, data used and resources available. See Appendix D for larger scale.

Single layer PCBs are among the simplest products manufactured at Cogra Pro and make up a small percentage of the total production of capacity. Single layer panels are processed along the main production flow. The initial step is similar to the other products however due to their simplicity several of the production steps including quality control can be skipped. All three departments handle single layer products, however they have a fairly similar path through production. The work tasks were grouped in activities and for single layer cards include:

1. Start a new panel
2. Drilling
3. Wet-honing
4. Pretreatment
5. Imaging
6. Etching
7. Pretreatment
8. Solder mask
9. Solder hardening
10. Text hardening
11. HAL (Hot Air Leveling)
12. Milling-routing
13. Separating
14. Packaging

In the current state, lead time for single layer panel is slightly more than two days. The value-adding time is slightly more than 90 minutes. The takt time is based on a 10 day period when the demand was extraordinarily high. As seen in Figure 4.6, the current customer demand is 75 panels per day.

Double layers are slightly more complex than single layers hence a longer lead time. The additional complexity leads to more quality control activities in comparison to single layer panels. In general, double layer panels make up roughly 50% of the production capacity. However during the time of data collection the VSM double layer cards made up 33% of the production capacity. A double layer passes through 18 work activities and has a lead time of 2.65 days. The total value adding time is a little less than three hours. Double layer panels are handled by all three departments and their respective work activities include:

1. Start a new panel
2. Drilling
3. Wet-honing
4. Copper plating
5. Pretreatment
6. Imaging
7. Etching
8. AOI
9. Conductivity testing
10. Pretreatment
11. Solder mask
12. Solder hardening
13. Text hardening
14. HAL
15. Conductivity testing
16. Milling-routing
17. Separating
18. Packaging

Multi-layer panel processing is similar to double layer's with the addition of the production of inner layers. Multi-layer panel production have a longer process since the inner layers are imaged and pressed before conjoining the main flow of products. These types of panels have at least 25 work activities. Note, that as number of inner layers increases the number of production activities and process times increase, this loop's unit is set as number of inner layers. The work activities include but are not limited to:

1. Start a new panel
2. Pretreatment IL
3. Imaging IL
4. Etching IL
5. AOI IL
6. Brown-oxidation IL
7. Press
8. Milling IL
9. Drilling
10. Wet-honing
11. Copper plating
12. Pretreatment
13. Imaging
14. Etching
15. AOI
16. Conductivity testing
17. Pretreatment
18. Solder mask
19. Solder hardening
20. Text hardening
21. HAL
22. Conductivity testing
23. Milling-routing
24. Separating
25. Packaging

Multi-layer panel represent 33% of the production capacity at the VSM's point of time and 26% of the production capacity in general. The lead time is 5.49 days and the total value adding time for production is roughly five hours for a four-layer multi-layer panel.

The VSM shows that the total amount of work in the system at the point of time is 183 panels in addition to 72 inner layers. The mechanical department has 83 panels; photo has 29 inner layers plus 70 panels; chemical has 43 inner layers plus 25; packaging has 13. The multi-layer panel deviates the most, out of the three product families, from the main flow. However, as can be visualized in the VSM, the majority of production activities are shared. Viewing WIP location in the VSM, one can observe that many of the stations are empty while others have large numbers of WIP waiting for processing. Emptying whole areas and forwarding products in bulk is hereby called the surge effect. The eight operators support all three product families, servicing both the main and alternative flows. The product is transferred between numerous work activities and departments.

4.3 Feedback from the Company

In order to assure that the research would be applicable to the single case study, the authors positioned themselves at the company for the first third of the project. The purpose was to have a continuous dialog with the company. Moreover, the authors had three larger presentations and one workshop. The aim was to attain to secure validity in information, transparency of the project, and involve the employees at an early stage. During the workshops the employees analyzed the current state and suggested various improvement areas. During the final presentation, the authors received the following feedback regarding the purposed improvement suggestions from the company:

- The production layout needed to take into consideration further constraints.
- The company wished to postpone the suggestions regarding the material flow to a later time due to a desire to focus on information flow and development of people.

- Additional clarification was required concerning several of the content of the improvement suggestions.

The feedback aided the authors in further development of the improvement suggestions. In addition, the authors took lessons learned from the benchmarking visits at Scania and Brogren Industries AB. The primary lesson was that lean production is achieved by small and continuous improvements with a long-term orientation. The secondary lesson was that the transformation is a group effort even though the executive board plays a key role in enabling the process.

5
Analysis

The empirical data from the current state is analyzed and the results of the analysis are presented in this chapter. The research questions are answered concerning how mass customization, material and information, and sociotechnical systems impact on flow efficiency in the current state. Various improvement opportunities are identified.

5.1 Impact of Mass Customization

As most of Cogra's products are highly customized, production is complex. The number of possible variants of panels is immense which has caused issues with production planning. Mass customization can be divided into four categories (Stump & Badurdeen, 2009). In this case, customer involvement is early in the process without modularizing products. Customers are involved at the point of design and differentiation of modularity is at fabrication, classifying Cogra as a Fabricator. Fabricators require the highest degree of mass customization, characterized by the low levels of standardization, which leads to low stability (Stump & Badurdeen, 2009). Further, applicability of lean manufacturing processes is directly related to the degree of mass customization (Stump & Badurdeen, 2009). This is because control of variants quickly increases.

Flow efficiency is characterized by the act of maximizing a product's value adding time (Modig & Åhlström, 2012). This is challenging considering the circumstances and the difficulty of production planning. Production complexity is increased as it is difficult to forecast demand and plan work content (Stump & Badurdeen, 2009). Small businesses have an especially tough time planning and controlling the variations in production as they tend to have limited control over their supply chains (Rymaszewska, 2014). Seitz (2003) adds that this is due to limited formal infrastructure.

5.1.1 Volume Flexibility

The oscillating nature of the customer demand makes leveling strenuous. As viewed in Figure 4.2 there are several peaks and valleys in customer demand ranging from approximately 400 to 1300 panels monthly. Complexity of mass-customization is increased by the difficultly to forecast magnitude and variety of customer demand (Blecker & Friedrich, 2006; Stump & Badurdeen, 2009). On average, the demand is roughly 50 panels per day, but during certain time periods demand soars to 75 panels per day. During one particular week, the amount of production panels put into the system per day was found to vary between 26-63. A varying input of products in the system with such a range stresses the system and indicates unstructured handling of material flow. As viewed in the current state VSM, Figure 4.6, several operations are starved, showing that handling of volume flexibility due to variation in demand can be improved at Cogra. Customer orders appear to be inconsistent and unpredictable. Promised lead times are the sum of production planning, production, and distribution times. Flow efficiency at Cogra is directly related to the nature of orders received, the decision-making processes and the production system. The distribution is outsourced and considered stable, and is therefore not taken into account in this analysis. Large fluctuations in demand place stress on production planning and production lead times at Cogra. from a system perspective with sequential processes, lead time will increase with an increase of WIP (Modig & Åhlström, 2012). During peaks in customer demands, lead times for production planning and production become longer thus obstructing Cogra's ability to deliver as promised.

As Holweg and Pil (2001) describe, volume flexibility indicates how well an organization responds to changes in demand and shifts in production volume. On one hand SMEs have an easier time adapting to variations in customer demand. This is due to their reduced complexity of interactions which attends to streamlining communication, consequently accelerating decision-making (Seitz, 2003). However, as observed in this single case study, large fluctuations lead to the overburdening of resources.

Developing a systematic approach to deal with the fluctuation in demand will prove beneficial as there are clear cycles reappearing yearly. Development of processes, tests of new machinery and overtime are examples of activities that can be scheduled in advance so that customer demand and kaizen activities do not interfere with daily work. Utilization for smoothing effects for handling variety of customer demand is exemplified by adapting hybrid make to order strategies (Holweg & Pil, 2001).

5.1.2 Product Flexibility

The make to order strategy implies a closer customer relation as the company deals with customers first hand. Better customer relations create the opportunity to get constant feedback on what future developments are sought and what issues are raised with current products and quality. Engaging the customer early in the value chain results in imposing multiple pull signals on the upstream design and fabrication processes (Stump & Badurdeen, 2009). Lead times for a single product are increased due to the downstream nature of the customer decoupling point (Bellgran & Säfsten, 2010). Stump and Badurdeen (2009) comment that modularity in products can enable higher efficiency as it creates a commonality between products. At Cogra, differentiation of products occurs at an early stage of the value chain. The first processing step makes the product unique and cannot be postponed to later steps in manufacturing. By customizing early in the process, the company becomes slower to respond to orders which makes stabilizing production schedules challenging (Holweg & Pil, 2001).

Product flexibility is described as how well the organization adapts a product to the customer's specification and their ability to delay or reduce the degree of tailoring (Holweg & Pil, 2001). Liker and Meier (2006) comment that a production system's aim should be to deliver the required variety and meet the customer's needs. As seen in the customer feedback survey, Figure 4.1, Cogra has struggled with quality and delivery precision. To successfully tend to the voice of the customer, attention should be redirected to nurture the relation which is part of the make to order strategy.

The magnitude of product variety, derived from customization, can make it difficult to identify and address quality issues as the concept of good quality becomes obscure and challenges quality control on the shop floor (Stump & Badurdeen, 2009). Differentiating product families from one another instead of viewing similarities has caused issues with tracking quality. Locating quality issues derived from planning and production respectively becomes increasingly difficult as the number of incoming orders rises. It is the nature of mass customization with unique products to have an increased number of steps where human errors might occur. For instance, at Cogra due to short lead times products cannot be tested for machinability, reliance is placed on the expertise of production planners to make panels that are produced correctly. As all products are produced for the first time and shipped to customers, errors are transferred from planning stages through production, and are first found in quality tests. Planning errors need to be considered when tracing faulty quality, making root cause analysis increasingly difficult if not isolated.

Dealing with the increasing demands of tighter tolerances without improving process stability has lead to the scenario displayed in Figure 5.1. Displayed is the possible result of instability where Cogra struggle to find room for continuous improvements, process knowledge and increased workload, and ultimately fail to improve quality.
Customers are closely linked with the customization of their products, which indicates high product flexibility (Holweg & Pil, 2001). Order data received by production planners is normally received at the point of order confirmation, containing the unique build of the PCB. After production initiation however, customers' ability to alter the order is low, as first processing steps make the product unique by separating variants from another (by drilling or etching). Mistakes in handling the order or failure to meet quality requires recreating the product at the beginning of the process chain, exposing weaknesses.

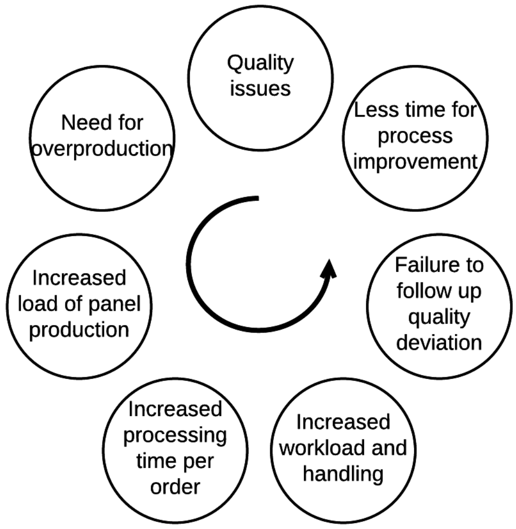

Figure 5.1: Results of instability of processes in the case. Faulty quality leads to increased workload and less time for process improvement.

5.1.3 Process flexibility

Process flexibility is described as the speed at which a company can alter processes to meet customer needs (Holweg & Pil, 2001). From a manufacturing standpoint, Cogra can fairly easily adapt the manufacturing process to fit the product requirements. The equipment is flexible with regards to changeover and setup times. Most machinery required for the process has the same setup with smaller adjustments (approx. 30 s) or none at all. The flexibility of the production equipment makes it viable for the mass customization strategy.

Variation in design of panels can cause varying cycle times for various production processes. Varying process times means that one part does not have the same run time as the next inside a process. For example, product designs with long milling routes create long process times for the machine. As a process can in worst case vary from 10-120 minutes, an order of eight products with processing times above 100 minutes hinders output of products completely during a shift. Varying processing times in certain machinery introduces difficulties in building standardization of work sequences. Having the means of knowing actual process times by simulating machining should be investigated aiming to create stability supporting customization.

To reduce instability and variance in lead times and flow efficiency one needs to identify the root cause of the fluctuation and attend to the issue. If all components are varying, the task of finding the cause may seem impossible. Liker and Meier (2006) state that one should reduce variability by isolating it, which has been difficult in the case of Cogra. For unstable processes the problem may shift from one process to another and the issue could be overlooked. With the aim to reach shop floor stability, it is necessary to gain initial stability as stated by Liker and Meier (2006). Get initial flow, avoid standstills and target unbalances in the system (Rother & Harris, 2001).

Uncertainty of how to handle process breakdowns or other issues observed, has proven difficult for Cogra to meet customer requirements of short lead times, settling for not actually giving the customer as fast deliveries as they require. From the customer's standpoint, delivery precision and speed are the most important issues, as seen in Figure 4.1. Customers have other purchasing options that have greater cost competitiveness as well as quality when order lead times exceed a week. To stay competitive, maintaining high deliverability and short lead times is of essence due to increasing global competition (Bellgran & Säfsten, 2010).

As previously stated, lacking maintenance protocol listing activities and frequency has brought uncertainty to processes. For personnel trouble shooting becomes difficult as there is no structured service routines to follow in case of disturbances to the process. Departments become harder to learn and supporting activities are easily forgotten. Close to full time there is a contracted mechanic who attends service tasks at Cogra. Older machinery requires increased maintenance, which currently could be evaluated further if standards meet the needs. Lacking systematic maintenance schedules performed by the companies' own operators increases the need of external functions when they break down. External service and repairs do not build competences of the in-house processes and further fuels the need for external aid.

5.2 Impact of Material and Information Flow

Stability in processes is a prerequisite to achieving continuous flow (Liker & Meier, 2006). Instability is the result of variations in processes (Liker & Meier, 2006). Modig and Åhlström (2012) argue the more variations that exist in the process, the longer the lead time. Variations in the material and information flow can be disruptive to flow efficiency. In Table 5.1, indicators of instability, observed in the cased study were recorded.

5.2.1 Layout

Bellgran and Säfsten (2010) state three categories of influencing factors on the production system which all form the current state: influence of external factors, strategy and fundamental attitudes, the actual options. The current layout at Cogra is a result of investing in equipment and placing it where there has been space for the past twenty years. The functional layout as described in Bellgran and Säfsten (2010) book, is the grouping of processes by function, which is appropriate when the production variance is high and the products are made by batch. A drawback of the layout is increased transportation between functional areas when processing smaller batches. Another issue with batch production is that it focuses on resource efficiency. Resource efficiency is the opposite of flow efficiency (Modig & Åhlström, 2012). This contradicts Cogra's strategy of responsiveness to customers with shorter

Table 5.1: Liker and Meier (2006) display eight indicators of instability, of which seven has been observed at Cogra.

Observed	**Liker & Meier's 8 Indicators of Instability**
X	A high degree of variation in performance measures.
X	Changing the "plan" often when a problem occurs. Relocating labor or leaving a position vacant when an absence occurs and stopping work in the middle of an order to change to another order
X	It is not possible to observe a consistent pattern or method to the work
X	Batches or piles of work in process (WIP) that are random sometimes more, sometimes less.
X	Sequential operations that operate independently (island processes)
	Inconsistent or nonexistent flow, indicated by random WIP
X	Frequent use of the words usually, basically, normally, typically, generally, most of the time, when describing the operation, followed by except when, as in: "Normally we do this... except when... happens, then we do this...."
X	Statements such as, "We trust the operators to make decisions about how the work is done" (misguided employee empowerment)

lead times. Clear directives from management strategy and production philosophy can be developed to spread clarity of what is expected and prioritized, aiming for strengthening the system. Affected by the functional layout, processes are not designed for loading and unloading at the same place. This leads to difficultly with imitating recognition of product status and increasing the space required for workstations.

The current state has no limits on buffers, nor dedicated locations for products being transitioned in trolleys per batch on the shop floor. Visually drawing material flow and dedicating zones for product delivery aids in pointing out products' status for processes, simplifying areas where multiple product flows are transitioned. As viewed in previous flow maps of the product families in Chapter 4, products re-circulate through several production steps. Re-circulation adds to the conception of chaotic flow and difficulty understanding both product status and production load. The customization of products entails both variations in process times and alternations in process sequences. The mapped production process displays a lengthy route of the multi-layer production. However, the figure does not divulge the preparation steps connected to the processes. Operators make additional movement beyond the material flow, supporting the flow of the product within workstations. Moreover, walls and various objects, e.g. machines, workbenches, and stock areas, hinder visualization of product flow and status. This adds complexity in evaluation of status for intermittently connected stations.

5.2.2 Product Circulation

(Stump & Badurdeen, 2009) state defining new systems, learning from successful flexible production systems combining push and pull strategies. This aids in regulating and reducing dependency of priorities. As current approaches and reprioritizations contradict leveled flow throughout the system, it creates space between products starving downstream processes. This ultimately hinders flow efficiency and increases total lead time of all orders but the one prioritized, as well as decreasing utility of machinery and resources. Products in the system are dependent on the operator to move them and start the next process. A process where operators load, observe, unload and move the product while running multiple machines has made flow efficiency difficult to procure. Evaluation of pull-effects and interdepartmental connections would increase flow efficiency of the system.

The takt time was set to 75 panels per day as viewed in Chapter 4 in order to handle even the highest peaks in customer demand. As seen in the Appendix D VSM, products between operations are pushed downstream. Contradictory to pull systems, pushed product flow hinders flow efficiency (Liker & Meier, 2006). Prior to the study, the company had not been using customer demand and takt time analysis. This concept is new, and as a result, processes have not been evaluated on a system perspective with this terminology. All resources are shared with all processes within a department. Meaning the operators manage several machines simultaneously and by experience make informal schedules depending on the current load and type of products, forwarding as many products as possible from their department.

As viewed in the solder mask process in the photo department, there are five sequential processes in this department as seen in Figure 5.2. The imbalance of the sequential processes creates waiting upstream, as seen in solder hardening processes in the VSM, with increasing buffer sizes within the department. This is the surge effect that the company experience when a large group of batches are forwarded in unison.

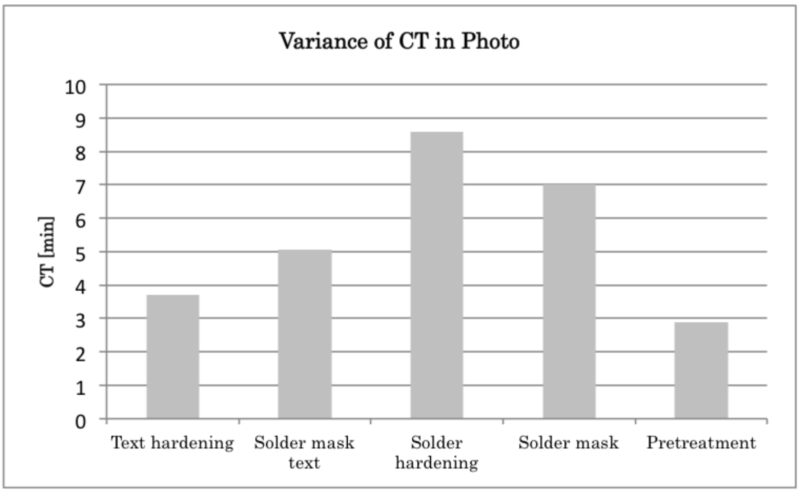

Figure 5.2: Shows cycle-times for the last five processes of the VSM in the Photo department.

Sequential processes with unbalanced cycle time fuels the surge effect. Operators manage work in their department to fit their area of responsibility, maximizing output in a subsystem releasing products in bulk to downstream processes. Thus, a silo perspective arise when departments do not see the effect of forwarding a smaller batch or all batches together. Counting the number of departmental changes in the VSM, there are 16 changes with risk leaving parts in buffers, waiting for a process, operator breaks etc. As the product is passed through different departments where vision is obstructed, products can be overlooked in buffer zones when they arrive in irregular patterns.

5.2.3 Production Planning and Control

Since production planning and sales is separated from production, the production flow is lagging due to an inconsistent stream of orders received. As an effect of informal forwarding orders to production (go-and-see start of tasks viewed in the VSM), the task of leveling is shared between the production planners and mechanical department. The result is that consensus of what hinders flow of products is not reached. Not knowing actual capacity of the system makes planning troublesome. Continuous flow and standardized releasing times of orders would increase repeatability and raise actual issues hindering flow efficiency. Current releasing of orders to shop floor is handled from experience, where previous lead time of similar orders is approximated to be valid for the next order as well. Lacking communication, order start can be delayed as the mechanical department stress levels rise, possibly starving downstream processes. On a daily basis, operators receive surges of products arriving to their department and the task is to send them forward in bulk. To address the issue and reduce stress of operators and machinery, a maximum batch size of 12 panels has been set, as a trial, to increase flow efficiency. Through not following up the results, the effects of batch size limits remains unknown. Maximum batch size is in practice worked around as stations wait for additional products to start operations.

While procuring order data, production planners need to consider the trade-off: high material utilization versus time in production planning queues. The higher utilization of material can potentially reduce the number of production panels, as orders are combined to fit the panel. Another issue not touched upon, is that the processing times of the varying processes seen in the VSM is indirectly affected by utilization. For instance, processing time of the final milling operation, routing the PCB, increases with the total perimeter of all PCBs on the production panel. The longer the distance, the longer time the milling operation requires. Currently unknown processing times, production planners and operators in the mechanical department merely roughly estimate processing times with their knowledge of the process. Simple simulations could possibly ease production planning's task, giving rough forecasts of when and what product is required to be milled in order to be delivered.

Sorting orders together by type raises utilization of material in the production queue but adds complexity of keeping track of possible differing delivery dates in packaging.

It also increases the time an order spends in the queue with sales and production planning before reaching the shop floor. On the other hand, order complexity can lead to re-arrangement of orders when the orders are not leveled against one another. Planners and sales do not have limits to how many products they can put into the production system, which fuels the surge effect.

Slomp et al. (2009) state leveling, pull mechanism and takt time control as techniques to eradicate sources of variability. Varying customer demand leads to variance in WIP. From a system perspective with sequential processes, lead time will increase with an increase of WIP (Modig & Åhlström, 2012). Production planners and sales do not follow indicators of saturation of normal production load or capacity planning. This is often an issue of mass customization strategies that needs to be addressed (Stevenson et al., 2005). The lack of transparency of order acceptance and capacity utilization hinders teamwork and causes mistrust. As the shop floor does not receive any formal scheduling, additional information is recorded on individual production orders (seen in Appendix B). On the front page of an order a desired production date is stated. When at risk of missing a delivery the operators in some cases turn the paper, viewing when the order is due for shipping then expediting the product through the flow. In addition, the production orders are color-coded with respect to urgency (white, green and red). However, this system is insufficient due to the colors not being updated as time goes on. Thus, an order that was not urgent to begin with, can be delayed by a longer period of time and also risk being late.

Production Measurements

The organization does not use indicators connected to daily workload. Cogra has the possibility view the number of orders and panels for production queued in the ERP. This view is meant for sales and production planners to get a brief view of current production load. Seen as a rough estimate, the report is seldom used which indicates that orders are accepted without knowledge of the actual production load. When work characteristics can be described as temporary, fragmented or short-term, this has a negative impact on the effectiveness of a project team (Chan & Chan, 2004). Lacking indicators of status in the production system, production planners may without their knowledge add additional tasks to the already stressed system. Lacking predetermined guidelines and limits of production capacity, the quantity is steered by the capabilities and opinions of sales and production planners.

Another issue is that communication between production, planning and sales is lagging and uneven in quality. Constant and lively communication between groups can aid in evaluation and support operations (Bellgran & Säfsten, 2010). Due to the secular work, operators have difficulties acquiring a general indication of the overall company performance. Uneven flow of information from production in addition to varying lead times from initiation to finished product, forces sales to seek out products asking for their status and delivery. In some cases, sales merely ask for the status of the product. Although, this can be misinterpreted as the product being late and pushed forward. Other times, sales rearrange production orders causing additional stress.

Achievement of success can be facilitated by defining success with correct measures to achieve the goal (Chan & Chan, 2004). Without a proper agreement on how to measure success, management will allocate resources based on their own perception and intuition (Chan & Chan, 2004). At Cogra, with no measurements they have no recurring discussion of successful or unsuccessful events. The communication of success is limited and staggering in showing hard facts to present, when there are no figures to display. Production measurements are topics that can be part of quarterly reports, creating aspects of progression and aiding in building team spirit.

Modig and Åhlström (2012) comment on how re-prioritization both causes and is the result of long, undesired lead times. In this case study, frequent re-prioritization makes the production status insufficient, and sales rather seeks out the product in the value chain for inquiries of delivery. This behavior fuels the feeling that manual reporting of completed process steps serves little purpose in today's production. Hence, production orders tend to be left blank after completed operation, and the ERP production status of orders is not used. Delivery precision is of interest but the numbers are not trusted due to various observed practices including altering the delivery date on the physical production order but neglecting to update the database. The intention is to assist operators in decision-making of prioritizing deliveries, e.g. when to expedite an order and when to put products on hold. Physically altering the delivery date and not the ERP, registers the order as a late delivery when shipped after the original date. When doing so the delivery precision becomes unreliable and is experienced as disconnected from production. The general mindset is that production has little effect on delivery precision as it becomes more dependent on sales and production planning.

Production planners use overproduction as a smoothing tool against instability of the process. To meet customer demands when producing uneven quality, overproducing enables quality and delivery on time. As quality is an important selling attribute, mistrust in the process inclines adding an additional number of products to orders to be able to secure the correct quality and quantity upon delivery. Planners consider the complexity of product and customer importance when deciding on the number of additional PCBs to add to the order. At the end of the process remaining PCBs not shipped to the customer, are scrapped.

Varying Process Times

Varying processes hinder continuous flow. To work around the issue, "go-and-see" start of process is used to re-prioritize orders and if possible load the machine with the specific panel to be processed during the night. As seen in Table 5.1, seven out of eight indicators of instability have been found at Cogra. Instability needs to be considered when regarding flow efficiency as it breeds varying processing times (Liker & Meier, 2006). The effect will starve and block downstream processes respectively, which has been viewed during observation sessions. As no formal planning considers variation, the normal processing time for orders is longer than necessary, including delays.

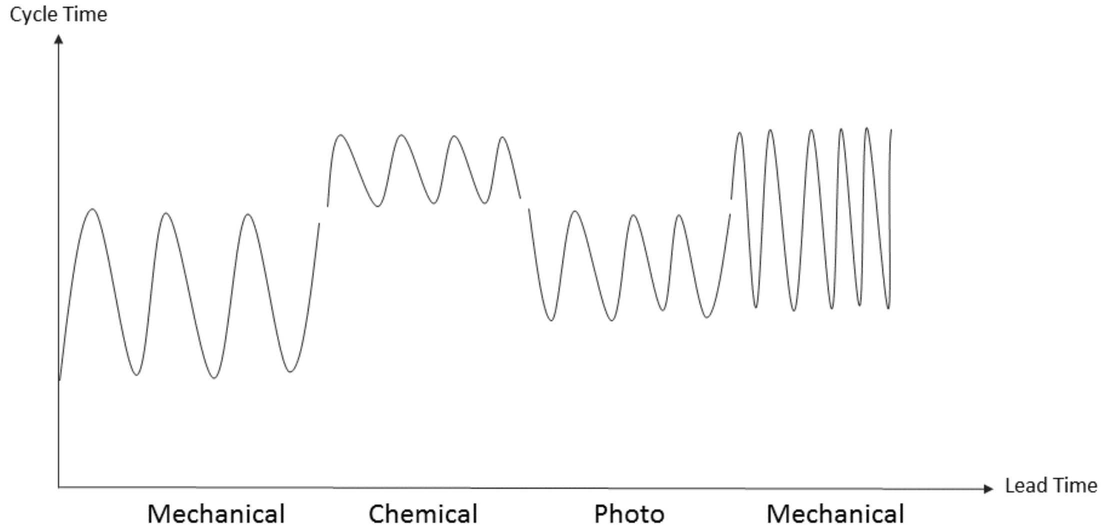

Figure 5.3: Simplified example of how varying cycle times of departments can vary for a single layer PCB.

As exemplified in Figure 5.3, if several lead times are varying inside the system calculating total lead time is narrowed down to educated estimates. A strategy is to compensate for the effects of the variability, mitigating the impact (Liker & Meier, 2006). If unable to control the variability, the next best option is to isolate it (Liker & Meier, 2006). Shifting focus from material utilization to standardized time of the process, fitting machining with sequential processes would be such an effort. Current operations and unawareness of processing time leads to the operators and the product waiting. Furthermore, shared resources used within departments and machining complicates the issue. As there is no scheduling of the machine, operators make decisions of which run order best fits the mix of products in current go-and-see examples. A lack of standardized machining time can create local and temporary bottlenecks hindering the flow of the entire system. Similar issues arise in the photo department, as the multi-layer production with multiple inner layers acquires long processing times and a lot of handling due to the batch size.

5.3 Impact of the Sociotechnical System

The results of a sociotechnical production system are directly related to human activity (Geels, 2004). Hence, flow efficiency is also impacted. Flow efficiency is hindered when operators are unable or unwilling to service the system. As Losonci et al. (2011) emphasize, the integration of the sociotechnical perspective is fundamental.

As the employee survey in Section 4.1.3, Figure 4.3, highlights there is a difference in perception between white- and blue-collar workers regarding the current sociotechnical working environment. There is room for improvement with concern to individual incentives, challenges, and influence. These workplace characteristics reflect several of the key intrinsic requirements highlighted by Trist et al. (1978)

including: variety and challenges, autonomy, recognition and support in work tasks. In Figures 5.4 through 5.6, the survey questions related to experienced challenges, influence, individual incentives are depicted.

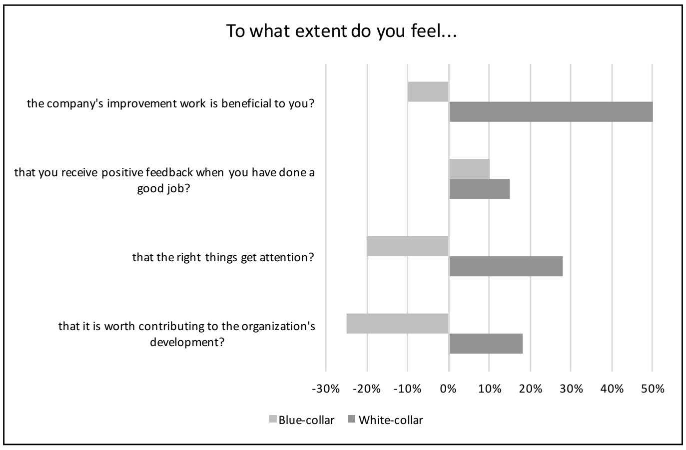

Figure 5.4: Perceived employee individual incentives

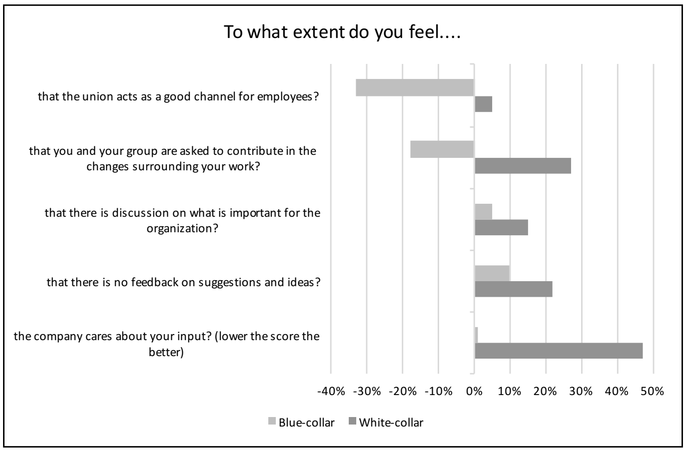

Figure 5.5: Perceived employee influence

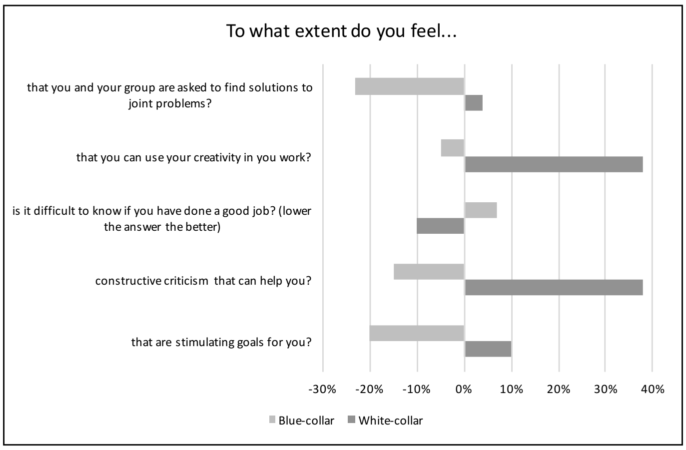

Figure 5.6: Challenges in employees' perceived work tasks

In general, for the case study, white- and blue-collar workers perceive the work situation differently. Figure 5.4 highlights the contention in identifying improvement areas and what is value adding work. In the current state, there are very few meetings, outside of the quarterly reports, where the entire staff is gathered. The limited communication channels aggravate the gap as can be viewed in Figure 5.4. Lack of communication of values, ideals, and company direction counteract the holistic view of the entire system, thus placing focus on the single job and not the function of the entire system. As can be illustrated in Figure 5.4, there is a lack of collective views of the work organization. The silo mentality is an effect of the inability and disability to share information and resources inside the organization thus creating a dearth of teamwork.

Figure 5.4 also highlights the difficulty of knowing when a job is done well for blue-collar workers. Trist et al. (1978) remark on how intrinsic work motivation requirements include the capability to influence decisions directly effecting working environment. Trist et al. (1978) also note that recognition and support in work tasks is important for intrinsic motivation. It is important to consider the operator's needs when developing the system, as they will be interacting with the technology (Bellgran & Säfsten, 2010). The low levels displayed in the figures leads to the conclusion that intrinsic motivation can be improved by increasing the weight placed when considering input from production and facilitating communication between white-collar and blue-collar workers.

In Figure 5.5, the survey questions related to influence are depicted. The range in answers is especially wide concerning how the organization handles employee feedback and the employee's degree of decision-making regarding their specific organizational tasks. In the current state, there is a large amount of stress embedded in the system. Certain processes require less handling as the number of products increases. As products catch up to one another in production due to fluctuation and waiting, the surge phenomenon reappears handling larger batches than intended. Large grouped processes, e.g. photo department, are especially sensitive to this phenomenon due to its sequential processes and one-piece machinery. Operators know in advance during which hours of the day they will have high stress levels as this is the way it has been for some time. It has gone to such a length that they know how much they can produce and in some cases, neglect incoming orders with unrealistic due dates and continue that task the next day.

Due to the lack of production measurements and rearrangement of orders stress is caused in production. As there is no boundary object to use as a base for decisions, a gap in perceived production load gives a feeling that there are insufficient resources for development aside from daily tasks, concentrating on last minute arrangements to meet individual orders. Re-prioritization causes the feeling that one is never complete with tasks, and the cycle starts over the next day. Lacking levels of autonomy, influence of the process and ownership reduces motivation (Trist et al., 1978). Motivation can to some extent be connected to the absenteeism experienced at Cogra. Production's general outspoken feelings and lack of motivation was further confirmed by the high absenteeism. There is a general feeling in production that the workload is infinitely increasing and management do not take human capacity into account. Capacity limits are based on the machines, not on the humans performing the work. Missing the forum for continuous improvement and raising daily issues, inclusion of the operator's observations and opinions are missed. This can be connected to the Toyota Principle viewed in Figure 2.4 - Scaling of the Toyota Way, considering respect for people. The ability to challenge and develop the people in the system becomes a way of showing them and their work respect.

The company's informal leadership and communication channels lead to delays in problems being raised. The ¨squeaky wheel gets the grease¨ concept is applicable to production where certain issues are raised as they are more visible. Other activities could be more urgent but the resources are allocated to the station that makes the most noise for its cause. Cogra lacks visibility of what improvement projects are currently ongoing which creates uncertainty of who is doing what. Improvements and success is not shared through official channels meaning operators need to seek out the information themselves. This influences autonomy of improvements and involvement of work. Several operators commented on feeling that they had little influence and that their improvement suggestions proceed unheard. There was deep frustration concerning the lack of communication channels and everyday stress levels.

In Figure 5.6, the survey questions related to challenges are illustrated. These survey answers also displayed contrasting opinions on utilizing employees' creativity to solve problems and reach goals. Blue-collar workers reported a low level of variety and challenges especially relating to work task goals and challenges as expressed when asked about involvement in solutions and whether they were inspired by organizational goals. Trist et al. (1978) comment on how work tasks should challenge and develop employees through complexity and variety. With respect to how the employees perceive their current working environment there is room for employee empowerment by providing challenges and variety in work tasks.

Although Stump and Badurdeen (2009) describe mass customization as challenging, employees in production experience that they have few stimulating challenges and goals. This phenomenon likely stems from the low level of experienced support available and a lack of understanding of how the employee's contribution fits into the whole production scheme. In this case study, centralized competence deters employee motivation. As Shin et al. (2001) explain management and communication of knowledge is a critical factor for competitive success. Development of knowledge especially explicit plays a central role in knowledge management (Shin et al., 2001).

The lack of routines surrounding supportive work tasks has increased reactive maintenance over the last few years; for instance, as operators retire without being able to successfully transfer knowledge of the process to new personnel. A large proportion of the daily routine is used for production; there is little room for process improvement and learning the process. Technical competences of the processes are centered around operators who have been working at specific departments for a long time. Lacking successful information dissipation, the strive for continuous improvement becomes difficult without proper documentation and routines of how to lift knowledge of the process and product. Operators limit the boundary of tasks to one department, which hinders a holistic view of production and further fuels the silo mentality.

New operators at the company may shed light on longtime camouflaged problems and thus be able to lift them. For example, new operators may have new opinions of how to accomplish work and are not stuck in old routines. However, knowledge management at the company can make it difficult to introduce new employees into the production system. First, the lack of formal information for new operators made understanding the production system difficult. There is limited information for daily operations for machines and there are no checklists for the station's supportive activities. Most information is tacit regarding operating machines as well as procedures. Several observations of missed routines have led to production disturbances causing standstills and missed deliveries. Furthermore, observations of occasions where operators were not able to properly complete production tasks due to insufficient process knowledge was noted. This interrupted production until further help could be retained. Cogra normally addresses the physical issues and there is no routine on how to pass the lesson learned on to the operator to avoid future disturbance. They lack a structure of who is responsible for certain work tasks, main and supportive. Effectively, tasks that are not directly connected to processes are pushed to prioritize handling rush orders or similar. Dealing with issues last minute, or not at all, increases the risk of possible breakdowns and disturbances to flow efficiency.

This results in operators letting go of products as soon as they pass their station. At several stations the aim is to clear their station at the end of the day producing as much as possible. Observations of experiments with production processes and equipment are conducted during the day which interrupts normal production has been noted. There is a lack of communication of the purpose and timing of these experiments, and implementation of changes without consensus between white-collar and blue-collar workers. Unstructured changes of the process involving few agents' increases the risk of damaging equipment and increased number of attempts needed for success.

5.4 Additional Improvement Opportunities

Elimination of waste leads to better flow efficiency (Hines et al., 2004). Based on the observations from the current state's flow efficiency, the authors have categorized the forms of waste found in the production system, as seen in Table 5.2 with the eight types of waste identified by Liker (2004). Large importance has been place on "seeing" or observing in person.

As viewed in Figure 4.5 and Figure 5.2, flow of products and transportation are a result of the layout and cause large proportions of waste. Currently, operators keep simultaneous operations running from a distance, adding complexity and cognitive workload. Layout and workplace design should fit to serve the flow of products while preserving ergonomic soundness. Reorganization of the shop flor and development of workplace design has the potential to reduce handling and aid visual management.

Table 5.2: Observed waste.

Type of Waste	Description	Frequency
Overproduction	- More products produced than customer ordered	Daily
Waiting	- Reprioritization - Faulty machinery causes long waiting times - Unbalanced processes - Operators supervising process - Lagging communication between production, planning, and sales	Hourly
Transportation	- Movement of carts between departments	Hourly
Overprocessing	- Additional quality checks - Difficulty producing desired order	Hourly
Inventory	- High raw stock within production - PCBs produced on separate panels must wait in each other	Weekly
Movement	- Search for "lost" products - Reprioritization	Daily
Defects	- No follow-up on quality problems - Reliance on tacit knowledge	Daily
Creativity	- Lack of teamwork - Development of work tasks	n/a

In addition to categorizing the typical wastes that deter the flow efficiency, the frequency of which the waste occurs is also described. The wastes that are described as occurring hourly are the types of waste that are most noticeable and important to address due to their constant nature. For example, prioritization of orders caused both products and operators to wait-in items; this occurred multiple times daily. The wastes ranked daily, occurred less frequently but were still noticeable. For example, searching for products resulted in excess movement thus slowing the flow at least once per day. Wastes such as underutilized employee creativity are difficult to identify an applicable frequency since on one hand it is prevalent perpetually and on the other it is only noticeable sometimes. In conclusion, all seven plus one wastes are represented in this case study.

Many of the methods the company utilizes today to meet promised delivery times cover-up for the causes of lateness instead of resolving them, contradictory to lean productions goals of becoming a learning organization solving problems (Liker & Meier, 2006). In particular, re-prioritization aggravates the issue since prioritizing one item automatically postpones another item. The ranges in grades given in the customer survey are thought to be the result of handling rush and regular orders. Rush items are prioritized and expedited through the system thus wait-listing and minimizing attention paid to regular orders. Following are a few examples of how smoothing activities hide problems without dealing with the root cause. CEO, sales and administrative positions work an additional fifteen hours per week after production hours to avoid late deliveries. The additional hours effectively hide problems in the system. As this happens weekly, operators no longer react to products left in queues as the problem is handled after hours. The additional work undermines the limited batch-size system as it forwards big batches of units from one department.

6

Design of a Future Production System

The recommendations for a future production system are presented and described in the following chapter. This chapter also presents steps to reach the future production system for the case study.

6.1 Design of the Sociotechnical System

Mass customization and flexible manufacturing are areas receiving more focus in design of new production systems for increasing customer value (Stump & Badurdeen, 2009). In fast moving markets, make to order strategy decreases the risk of product devaluation and ability to sell finished stock (Hart, 1996; Holweg & Pil, 2001). Thus, reducing products in the system by lean strategy and methods, combined with make to order increases flow efficiency and aids stabilizing the system. Despite that SMEs are lagging in successful lean adaptions, their company structure allows them to be more responsive to change than larger companies (Rymaszewska, 2014).

The ambition of the development of the sociotechnical system is to create an environment where employees can perform to the best of their ability by considering the holistic perspective (Bellgran & Säfsten, 2010). A change towards a more sociotechnical system allows commitment to grow and minimizes alienation (Trist et al., 1978). A sociotechnical base integrates education and innovation carried out by industry (Bellgran & Säfsten, 2010). Skills and competence of employees form the production system's boundaries for the production system's ability to optimize daily production and participate in the organization's continuous improvement of processes required for global competitiveness (Teknikforetagen, 2013).

Due to the nature of the market that Cogra is involved in, the development of a sociotechnical system will aid in the betterment of the flow efficiency. The development of the future state model serves as an aid for the SME studied to adapt lean manufacturing. Since this is the company's primary attempt at adapting lean practice with respect to the sociotechnical system, there has been a large emphasis on working with the big picture and practical applicability in the value chain. The analysis has focused on the production system's flow efficiency and hence the future state and recommended measures address the holistic picture. Emphasis is placed on enabling flow efficiency and adapting a sociotechnical perspective which in turn stabilize the system, reducing variability in lead times and improve the working environment.

With the current state model as basis and improvement areas analyzed in the previous chapter, eight future states questions based on Rother and Shook (2003) are answered in order to build the new system.

1. *What is the real customer demand? What is the takt time?*
   The average customer demand was identified at 50 production panels a day. Due to the oscillating nature of the customer demand and by request of the company, the aim is to design a production system that is able to handle even the highest peaks. This is equivalent to a takt time supporting mixed variances of 75 panels per day. Calculations for takt time based on customer demand and hours production is operational:

	7.5 h availability	12 h availability
50 products	9 min	14.4 min
75 products	6 min	9.6 min

   The future production system will be operational 12 hours daily. Tasks should be within 9.6 min CT to meet the takt time.
2. *Will the organization produce for direct delivery or to finished goods stock?*
   As part of the make to order strategy all products will be made for direct delivery. In the value stream, mechanical department use supermarkets for regulating the flow, constantly having 15 batches in the production system (see Figure 6.1).
3. *Where can the organization produce in continuous flow? Where can the organization reduce waste? What activities can be eliminated, combined or simplified?*
   Due to the multiple processing units and low cycle times of individual machines, production will be in batches in POLCA/ CONWIP systems (Stevenson et al., 2005). The primary choice is CONWIP, however POLCA is employed when the takt is mismatched between departments. For example, the mechanical department utilizes a POLCA structure to feed imaging with an appropriate number of leveled batches. As imaging processes do not vary, standards are to be developed so that imaging is saturated with constant WIP of six batches at all times. As the mechanical department controls first and last process, they are responsible for control of the CONWIP sustaining 15 batches in the system.

   Waste is identified at multiple points in the process as viewed in Table 5.2. Below several practical examples are given for waste removal condensed for the report.

   - **Defects** are brought to light to gain lessons learned from defects after individual processes. After identifying defects in quality, flexible personnel is to analyze the root cause with the aim to continuously improve the process.

- **Overproduction** should be minimized by excess PCBs due to process instability. Problems should be lifted not hidden. By finding and eliminating instability of processes, overproduction of products exceeding actual customer orders can be reduced.
- **Transportation** of products in the current state is a result of the functional layout. Excessive manual transport is required to move products from one function to another, which should be minimized to reduce non-value adding time. Additionally, walls obscure vision of products which should be removed for subsequent processes. A brief list of process transitions with transport improvements are listed below:

Table 6.1: Observed transportation obstructions

Upstream Process	***Downstream Process***	***Transportation Obstruction***
Start of panel	Pretreatment	Distance
Pretreatment	Imaging	Distance & wall
AOI	Brown-oxidation	Distance & wall
Drilling	Wethoning	Distance
AOI	Conductivity testing	Distance & wall
Conductivity testing	Pretreatment	Distance & wall
Soldering	HAL	Distance & wall
Conductivity testing	Milling	Wall

- **Waiting** occurs with the imbalance of processes linked in the value stream. This is noticeable within the photo department, as viewed in the CT analysis in Figure 5.2. Waiting for machinery is reduced when operators can perform more activities simultaneously grouping imaging, AOI and conductivity testing.
- **Inventory** is hidden as there are no dedicated inventory locations. Implementing limits to inventory by control of buffers, First In First Out (FIFO) lanes and WIP will clarify status of products and help raise issues of process instability.
- **Motion** is observed with large proportions on non-value adding time within workstations. Reaching for equipment, unloading machines etc. workplace design is to be reevaluated.
- **Overprocessing** is observed in activities not adding customer value, lingering as precautionary measures due unstable processes. Excess quality checks as dual runs should be evaluated for removal (see eliminated activities).

Activities should not be removed during initial implementation actions but evaluated by process owners to make sure that new procedure does not affect quality of the end product. That said, introduction of kaizen activities to eliminate wasteful overprocessing and extra work should be performed at every chance by a cross-functional team and take the opportunity for dissipating knowledge of the process.

- **Eliminated** processes include one wet-honing operation, reduced hardening times and multiple tests such as conductivity.
- **Combined** activities for reducing handling time when possible so that one loading operation allows two or more processing steps. For example, combining wet honing with chemical line and pretreatment, solder mask and solder hardening. Also, re-evaluating responsibilities of who starts processes so products are started promptly will reduce complexity and handling greatly.
- **Simplified** operations are in three areas. First, there is workstation analysis and standardization of tasks. Secondly, improvement of handling of varying process times can be simplified. Rough simulations for processes to calculate process times will enable the mechanical department to keep an even flow of products. Thirdly, simplification of communication can be employed. It can be done by standardizing how and when to report into the ERP system, rework the production order to clarify tasks and scheduling, and communicate what results re-prioritization has on the system with routines when and where re-prioritization is allowed.

4. *Where is supermarket pull systems (buffers) placed to regulate flow?*
   Buffers are placed before milling, conductivity test and drilling. The rest of the operations are constrained by FIFO lanes. The broadening of an employee's current tasks includes start of downstream processes reduced handling as well as the number of product locations on the shop floor. The CONWIP system will regulate the number of products in circulation, reducing risk of a surge effect as well as keeping the total lead time of products in main flow stable.
5. *Where in the flow does the pacemaker plan production?*
   The mechanical department will have the role as pacemaker. The pacemaker process introduces products into the system of the right mix and at the right time. The mechanical department initiates production, and the rest of the system is to follow. To handle varying times of processes and mix of products, the heijunka boxes for milling and drilling machines can be implemented. The heijunka box can enable decisions and serves as the pacemaker station (Rother & Harris, 2001). The pacemaker reorganizes the production schedule with regards to the varying process times. This is facilitated by pulse meetings; the team leader coordinates the priorities and issues raised regarding the production system and communicates them to the pacemaker and production planners. It is suitable as the mechanical department handles some of the varying processes and located close to production planners.
6. *How is production mix leveled?*
   In product planning, sales and planners require higher level of awareness of the production limitations. Planning is constrained by CONWIP and orders are sorted into two separate queues, mixing weekly and daily deliveries. The result is a hybrid make to order strategy which enables leveled scheduling by mixing product variants and due dates (Holweg & Pil, 2001). This requires simulations of process and product mix viability. To enable mix of products, scheduling can be altered upon until the first processing point (i.e. reception of express orders), where the schedule becomes fixed and should not be changed

inside the system without team leader approval.

7. *In which batch size should we produce?*
   Batch size has been set to level the handling times which is dependent on the cycle times. The batch size is set to eight layers (i.e. eight inner layers or eight panels). By setting the batch size of layers the same as panels, handling inner layers of panels will not stop the main flow of products through the photo department.
8. *Which process improvements are needed?*
   The final question discusses changes required in existing processes in order to reach the future state. This is discussed in the following section to coordinate the transition from current to future state.

As viewed in Figure 6.1, the resulting future state VSM achieved by the analysis of the current state and the eight future state questions is presented. The future state map illustrates the vision the authors have composed for Cogra; the authors believe that the the future state is possible for Cogra to reach within the next couple of years. To enable the future state improvements for gaining flow efficiency with regard to material, information and the sociotechnical system is required.

Answering the future state questions result in the construction of the future state map, viewed in Figure 6.1. The aim is to level input and output of the system around actual customer demand. Following is a list of nine highlighted areas of the future state map including kaizen bursts and the items that impact flow efficiency in respect to the material and information flow.

1. Planned capacity utilization
2. Fixed batch size of 8 layers
3. Reduced to 30 min drying
4. Leveled drilling by heijunka box
5. Handle imaging as bottleneck
6. Leveled milling by supermarket
7. Two flexible workers
8. CONWIP, 15 batches in the system
9. Simulation of CT scheduling for varying processes

The flow Map, Figure 6.2, was designed to facilitate the future state map layout changes, improving transportation and remove barriers where possible. Three pieces of machinery are invested in this figure. The first is a new oven for text hardening paired with the existing solder mask spray, and two smaller wet honing machines prior to chemical line and pretreatment machinery. Certain constraints for the layout include not being able to move the press, electrical line, and chemical line. In addition, all imaging equipment needs to be kept in the enclosed photo department.

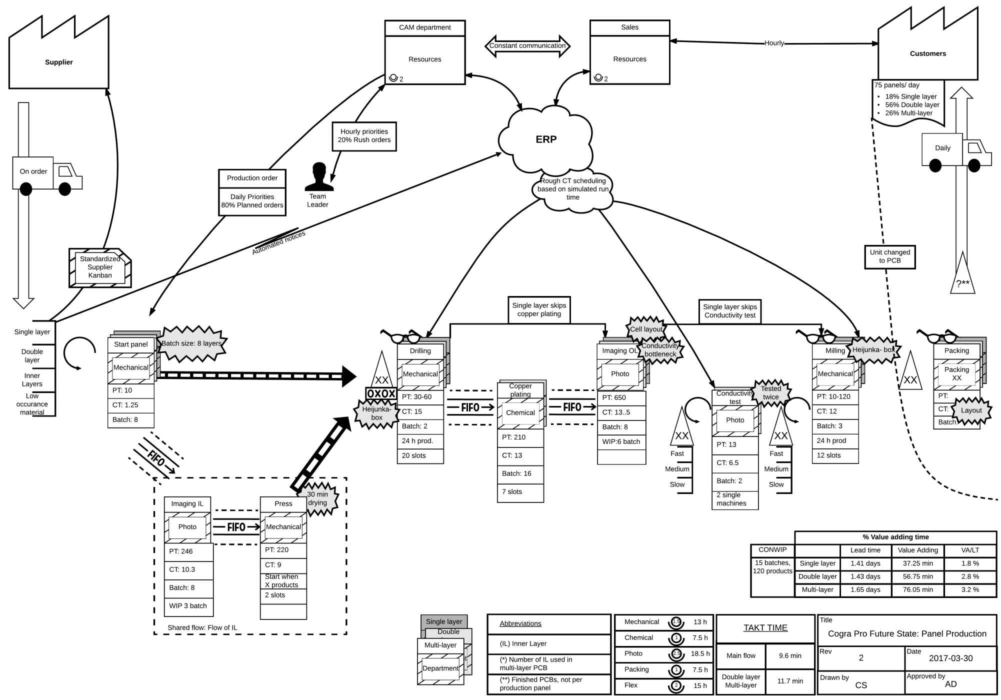

Figure 6.1: Value stream map of the future state. See Appendix E for larger scale.

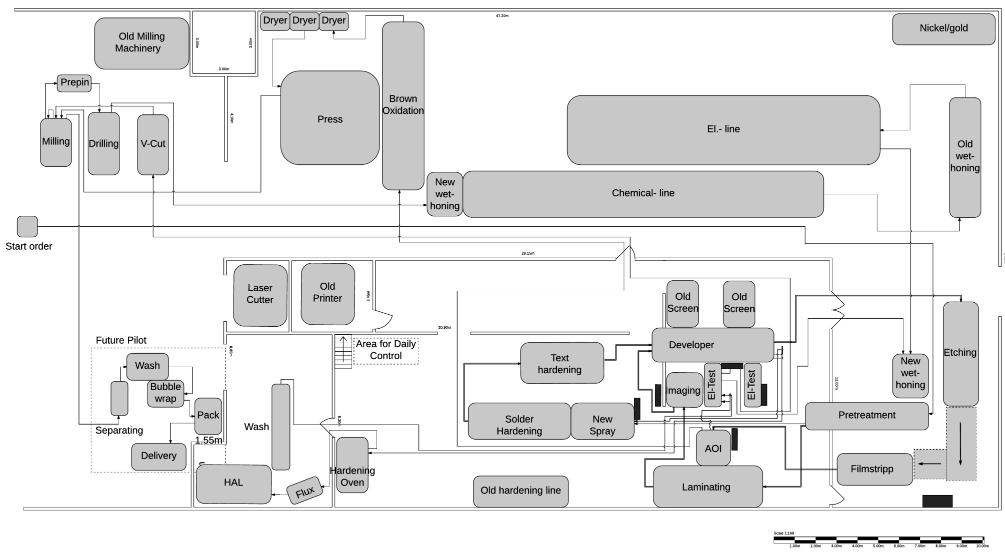

Figure 6.2: Flow Map - Facility layout including flow with regard to the future state; shows the flow of a multi-layer panel. The thick lines indicates the product's path as it recirculates twice along a specific route (filmstrip - AOI). See Appendix F for larger scale.

6.2 Implementation of Lean Practices

According to Liker and Meier (2006) there exists multiple ways to achieving flow; enhancement of flow efficiency stems from the tailoring of lean practice towards the situation. From a production standpoint, lean manufacturing success is characterized by the operator's own experience (Losonci et al., 2011). In Cogra's case, this involves decreasing stress and boosting motivation. From a executive standpoint, corporate success is measured in increased shareholder value (Beer & Nohria, 2000). For the case study, the executive board desired to decrease lead time and improve delivery precision. From a theoretical perspective, Scherrer-Rathje et al. (2009) argues that true lean victory is when the organization successfully incorporates the strategic and operational parts. This case study has examined both the hard and soft sides of the organization in order create the proper sociotechnical environment, simultaneously enhancing shareholder value.

As the employees are both the drivers and benefactors of the change, great effort has been placed to involve them as early and as much as possible in the transformation process. The fact that Cogra has less than 20 employees and a relatively flat structure can facilitate these improvements. There exist a clear source of power in small businesses (Seitz, 2003); if the executive management clarifies the direction and willingness to adapt a more sociotechnical perspective, then the actual implementation will prove easier in comparison to the larger company according to literature. Also, an SME has the ability to consider every opinion (Seitz, 2003).

The improvement suggestions presented in this report are based on Cogra's current state and therefore are not directly applicable to other organizations, types of products, or other circumstances. Furthermore, due to the fact that the case study was conducted January to March 2017, these suggestions are based off the data collected and analyzed during this period. The improvement suggestions were formed to have a general nature. Due to the general nature of the suggestions, more detailed investigations and implementation plans are required. Many researchers accentuate the importance of involving employees in the transformation process (Kotter, 1995; Liker & Meier, 2006). The intention is to inspire Cogra with the ideas that they could form to their own. A full list of improvement suggestions was given to the company.

According to Liker and Meier (2006), lean is composed of incremental and continuous improvements; large periodical improvements can destabilize the whole improvement process (Liker & Meier, 2006). Thus, the improvement suggestions are broken down into several key suggestions. Achanga et al. (2006) advises proper planning of lean initiative prior to implementation and comments on the importance of including supporting factors, e.g. provision of resource availability and readiness to acquire and develop suggestions. In order to make the suggestions more realistic to implement, they are presented in a suggested sequential order. The sequential order takes resource utilization, time, and relativity of the suggestions into consideration. Kotter (1995) accentuates that a successful transformation process takes time and that skipping steps often lead to traps. However, Liker and Meier (2006) note that the time frame for creating a connected value stream can be accelerated by working in multiple process areas simultaneously. Figure 6.3 takes this into consideration, proposing several tasks at once but still allowing the transformation process a considerable length of time.

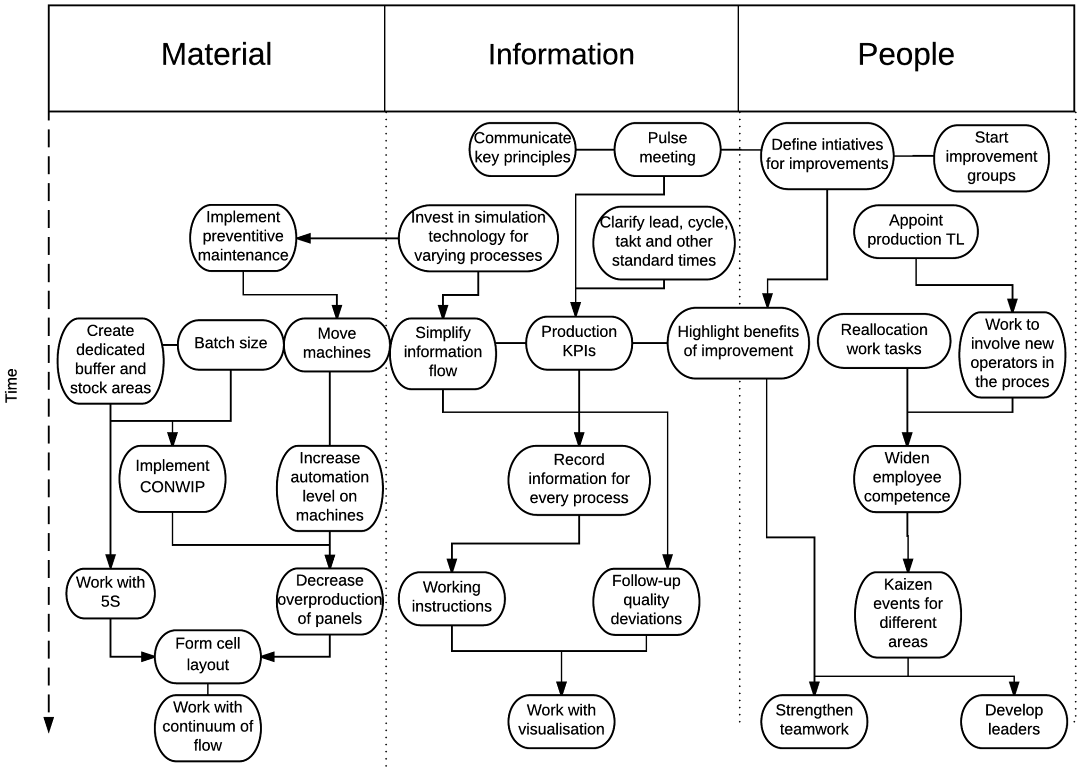

Figure 6.3: The Sequential Diagram shows recommended implementation waystages.

Zhou (2016) highlights the limitations that SMEs can experience when incorporating lean principles and impacts. The limiting aspects include financial capital, management concept and philosophy, knowledge and human resources, and accessibility to lean methods and tools. Zhou (2016) The suggestions are developed to incorporate a comprehensive and holistic approach while attempting to be not overburdening. Rymaszewska (2014) accentuates that the success and sustainability of lean improvements is primarily dependent on the long-term orientation and ability to sacrifice short-term benefits (Rymaszewska, 2014). This can be extra difficult for SMEs due to the lack of a standardized mechanism for analysis and measurement of value-adding capabilities within organizations (Achanga et al., 2006). The suggestions stem from four long-term goals for Cogra. The long-term goals include continue to work with continuum of flow, improved visualization, strengthen teamwork, and develop leaders. The size of the suggestions are designed after the case study at Cogra in order to be accomplishable and thereby a benchmark along their lean journey.

As viewed in Figure 6.3, implementations are divided into different levels. There are five operational levels which lead to the sixth level with visionary objectives. The sequential diagram is composed of various levels and illustrates the relationships between the improvement suggestions, shedding light upon prerequisites and aim of the improvement suggestions. Several components are included in the future state map, which cannot be implemented over night but should be seen as part of the continuous improvement steps for successful implementation. Transforming the system from push enabled processes to sequential pull requires development of people supporting the process. A vital part of the sociotechnical system is managing strategic goals of lean production application and translating goals to means for employee development.

Furthermore, the suggestions are placed into at least one of three categories, material flow, information flow, and people. Material flow encompasses the physical processing and transportation of material in production. Information flow encompasses the communication channels and knowledge attainment related to production. The people category stems from the conviction that the people should be developed in harmony with the system (Bellgran & Säfsten, 2010). People refer to the development of the Cogra's personnel as drivers of change and continuous improvement. All three categories are essential to the improvement of flow efficiency in production.

6.2.1 Material Flow

Material flow is the movement of products throughout the process, from raw material to finished goods, (King & King, 2015) and is the most commonly referred to flow when discussing the production system. Flow efficiency is increased by eradicating non-value adding activities from the value stream (Rother & Harris, 2001). Stable processes are a prerequisite to achieve flow efficiency (Liker & Meier, 2006). Process instability is inherited to old machinery and reactive maintenance at Cogra. Adding weekly and monthly preventative maintenance will increase equipment predictability (Tsang, 2002).

Currently, Cogra's material flow through the functional layout results in excess material transport. Liker and Meier (2006) recommends designing the work processes to achieve "flow" as it typically results in products being completed in a fraction of the time that was previously required. The reorganizing of the machines could greatly reduce handling times and enable better means to form efficient workstations thus facilitating the future state. As displayed in Figure 6.2, machines are grouped differently with input-output relations of material for downstream processes. Therewith, excess movement, transportation, and waiting time will be minimized.

The utilization of a pull mechanism will help prevent time being spent on overproduction (Liker & Meier, 2006). Limiting the number of products in circulation enabled by CONWIP will decrease lead time of production as well as require flow efficiency of the system. Thus, the pull mechanism aids in identifying obstructions of flow and creating a basis for continuous improvements. Since the CONWIP system requires a functioning release mechanism (Slomp et al., 2009), the implementation

CONWIP is delayed until after the information flow and people has been further developed.

A longer term goal is to reach cell layouts able to handle variance in volume flexibility by flow efficiency. Cells able to operate 1-3 operators is very effective in handling variance experienced would be beneficial. The authors however perceive that forming cells from the current state requires certain prerequisite steps as viewed in the sequential relation of improvements Figure 6.3 e.g. the standardizing of the material flow. Liker and Meier (2006) encourage viewing the material flow on a continuum. With regards to the current state, a sequence pull and cell formation are applicable for implementation. However, as the system develops it is possible to proceed towards an ideal state of lean thus the long term goal for the material flow is to work with the continuum of flow.

6.2.2 Information Flow

Rother and Shook (2003) comments that the information flow should be treated with as much importance as the material flow. Information is data communicated and knowledge is authenticated information (Shin et al., 2001). Shin et al. (2001) highlights the importance of identification and transfer of knowledge within organizations. From an entrepreneurial perspective, knowledge management should focus on the sharing of explicit knowledge thus sharing information for rapidly growing performance associated with a broad knowledge source (Shin et al., 2001). The coordination of resources and customer orders has room for improvement in the case study. With regards to the current state, the planning and control could help improve the system by facilitating communication through short and daily meetings. Furthermore, the organization needs to come to a consensus around how to define and handle lead times, cycle times, and shipment dates.

The inadequacy of communication is one of the highest barriers for change (Levasseur, 2001). Scherrer-Rathje et al. (2009) emphasize the importance of communicating long and short-term goals to the entire organization as well as lean wins. Due to project success can be defined differently for different people, the aim of KPIs is to facilitate measurement of project and organizational performance (Chan & Chan, 2004). A prerequisite is that the KPIs are accepted, understood, and owned across the organization (Chan & Chan, 2004). Although KPIs need to be evolved as time proceed (Chan & Chan, 2004), the authors suggest implementing a form of measurement in the earlier stages of the transformation in order to enable measuring of improvement activities and thus benchmarking and aiding the communication of short-term wins.

Standardization of information and documented way of working is an essential phase of lean processes (Liker & Meier, 2006). However standardization is a large and labor-intensive process. Due to the fact that Cogra has neither work task documentation nor stable processes, standardization of work tasks has been broken down into a number of smaller sized suggestions. Stability and standardization include repeatable works tasks, reliable resources and equipment, and a minimization of quality issues need to be attained before standardization of work can be attained (Liker & Meier, 2006). In addition, proper work documentation is a prerequisite for establishing standardized procedures (Liker & Meier, 2006).

The long-term goal for the information flow is to work with visualization, with the purpose of facilitating communication. In order to work with visualization, the processes must be standardized. Due to the large scale of this task, the authors broke the standardization of information into several steps and constructed visualization as a long-term goal. Continuous improvement of the information flow is inspired by Liker and Meier (2006) continuous improvement spiral: stabilize, create flow, standardize, and then level incrementally.

6.2.3 Development of People

Continuous participant involvement is essential to implementation of lean manufacturing (Losonci et al., 2011). Managers and operators alike should be involved in the lean transformation (Liker & Meier, 2006). Since this is the company's primary attempt at adopting lean production practices, there is great potential for educating and involving employees. In the beginning of the transformation, the authors suggest starting improvement groups and motivating work force by defining the incentives to change. As Kotter (1995) counsels, it is essential to define the need for change and to make it relatable on all levels.

The development of people suggestions are formed with respect to the sociotechnical system by fading out the division of labor and enhancing employee empowerment. Bellgran and Säfsten (2010) promoted the utilization of work rotation, work enlargement, and work enrichment. As the majority of employees have been there for more than five years, such activities can invigorate knowledge management and empower employees. Suggestions, include starting improvement groups, involving more operators, and broadening employee competence, as means to expand an operator's scope of work and lower the decision-making level in the organization.

Although the intention is to disperse power to the lowest level possible, the presence of leadership in lean transformation is essential (Liker & Meier, 2006). Beer and Nohria (2000) recommend setting the direction from the top and engaging people from the bottom. Thus incorporating the whole system. In TPS, a leader's three main responsibilities is to support operations, promote the system, and lead change (Liker & Meier, 2006). In the current state, there is no existing production leader. The purpose of a leader in production at Cogra is to give unity to the system by coordinating the various departments in real-time. Moreover, the production leader would work to bring process instability issues to the surface in order to treat.

The aim is to develop corporate culture and employee capability. The long-term goal for the development of employees involves improving teamwork and developing leaders. Due to the complexity of products, a cross-functional team is needed. Trust in the system and in one another is not won overnight thus the long-term orientation. Since leaders have a high degree of responsibility, the selection and development takes time.

7 Discussion

In the following chapter, discussion concerning the findings of the master's thesis is presented. Moreover, the chapter also reflects over the method and quality of the research attained.

7.1 Mass Customization

Sustaining a competitive edge through offering customers the ability to tailor purchased products has gained more attention in industry. In certain industry sectors, customers require customization and view the ability to get the variant, color, or type as defining criteria when purchasing. Ability to meet these demands by understanding and creating what the customer desires reduces the risk of having build to stock. The ability to produce what the customer desires relies on process flexibility, product flexibility and volume flexibility while maintaining cost efficient production (Holweg & Pil, 2001).

The mass customization strategy becomes even more desirable in fast moving markets, such as the electrics industry. Product depreciation in electronics makes the industry well suited for make to order strategies. Achieving competitive factors as reviewed by Bellgran and Säfsten (2010), flow efficiency acts upon making an organization more sustainable in today's globalized market and responsive towards the end customer. Flow efficiency aids the organization in making customization feasible by manufacturing what the customer desires, when they require it, while avoiding product depreciation.

Prerequisites for flexible manufacturing include stable quality, deliverability and cost (Bellgran & Säfsten, 2010). As found in the case, experiencing unstable processes and deliverability is related to mass customization, and improvement is required to meet customer demands. Mass customization enables greater customer focus, attempting to meet the actual demand by allowing the customer to tailor their product. Although, as customer interaction increases the ability to know the customer, it has been found to impact flow efficiency by the increasing the number of variables in the system. In this specific case, high variation in volume, requested by customers, stresses the production system, especially in regards to resource management. Inability to control demand in combination with resource utilization will dramatically increase lead time (Modig & Åhlström, 2012). Stump and Badurdeen (2009) reviewed the four types of mass customization where costumer perceived lead times are increased as modularity is moved upstream in the value chain. As activities cannot be postponed, Fabricators experience increased difficulty to maintain short lead times and high flow efficiency.

Securing quality becomes increasingly difficult in mass customization environments. Production is made less stable and more difficult to standardize due to the desire to deliver highly customized products to individual consumers. Production processes are fairly adaptable to highly-customized products in this case study. However, process variations make it challenging to detect problems. Lead times become difficult to determine with variations in the system. The variations force planners and operators to roughly estimate the needs, based on unreliable terms containing additional time buffers to compensate for the variations. Further adding varying cycle times of customized products in processes, (which are non-predictable) elongates the lead time even more. When a system is suffering variance and long lead times, placing even more products in the system than normal to improve output, further curtails throughput.

As observed in the case study, mass customization when not handled properly results in low flow efficiency. It is especially difficult for Fabricators to achieve a balance in flexibility and lead times. Flexibility as a competitive factor becomes, in comparison to other factors, more difficult to achieve, as flexibility is displayed at the top of the Sand-cone model as viewed in Bellgran and Säfsten (2010). There are certain prerequisites and needs identified in the case that have not received appropriate attention for effectively executing a mass customization strategy. The stability of processes has been found to be insufficient. Out of Liker and Meier's (2006) eight indicators evaluated, seven were found during the case study which confirms instability of the process. Adding the complexity of products, to an already unstable production system results in large deviations and uncertainty in predicting lead times.

The formation and repeatability of a standard working procedure may give the means to identify and eliminate the instability and support the mass customization environment. It was found that production planning has large impacts on the total lead times in mass customization systems. In addition to the actual production planning lead time, planning affects how well the production loop can perform. Constraints lingering from production planning remain throughout production impede the ability to give customers the right product at the right time. Scheduling and planning have the ability to isolate variances in the system and create internal demand. Internal pull systems exemplify how to internally stabilize the system and reduce complexity of information flow, exemplified by the heijunka-supermarket system.

Secondly, information quality plays an essential role in highlighting the customers wishes and limiting waste. Hart (1996) explains how customer value is the difference between perceived benefits and customer sacrifice. At Cogra, the customer focus by identifying what customers truly want plays an important role in retaining the customer. Informal communication as seen in the case can lead to poor communication of important customer details, e.g. promised delivery date. Moreover, knowledge concerning the customer demands can reduce the number of variables in the system thus limiting the product range. If the product range is limited, then the authors speculate that it is possible to increase quality of products produced since information routes can become more standardized.

Thirdly, deliverability in the mass customization strategy is difficult to attain, as the product type and circumstances concerning planning and production may change for the individual products or orders concerning the products. A key component is to find the means to track deliverability deviations. For the case, it has been found that failure in deliverability is tied to production of different product families in the system. Close customer contact enabled by mass customization can play an important role to direct focus towards hindrances of flow. By further learning the customer demands, one can potentially limit the product range to yield a system with fewer variables and possibly gain deliverability. As viewed in the value stream map of the current state, lead times vary greatly from single to multi-layer PCBs which has complicated deliverability of the different products as they are processed in the same machinery.

The authors concur with Stump and Badurdeen (2009), each company engaged in mass customization will need to tailor their application of lean in order to fit their specific circumstances. SMEs are especially challenged by the customization of products due to their resource constraints. The solutions and their interdependence for improving the information flow, material flow and workforce improvement is complex and highly customized. Flow efficiency improvements may be quicker to implement within an SME. However the limited resources require careful selection of which development projects to pursue. External support is beneficial to an SME when working with flow efficiency improvements. It is possible that an outsider, with allocated time, has an easier time gaining the holistic perspective needed to benefit flow efficiency. For example, there is an issue with "gone native" when a researcher becomes too acquainted with the material and thus becomes blind to the business angle on the collection and analysis of the data gathered. This is why a fresh perspective through external support is so beneficial. External support can aid in the selection and development of improvement opportunities. During benchmarking visits at Brogren Industries AB, it was found that they have dedicated a new position for monitoring and developing improvement areas. This example can be seen as how new ideas and views can be used to identify and drive practical implementations adapted to individual SMEs. It is also important to consider the relationships between the different recommendations in order to not thwart organizational growth.

7.2 Material and Information Flow

Lean production tools enable creating systems which have products pulled through the value stream. Continuous flow without product decoupling points in the form of modules, increases the need for production planning and control. Lean capabilities and tools are highly applicable to production systems with low-levels of mass customization, as seen in Assemblers and Modularizers (Stump & Badurdeen, 2009).

Cogra's practice needs to be adapted to fit Fabricator- level mass customization as every order is unique. Flow efficiency is negatively impacted when product variance in not under control, creating both unstable deliveries and idleness. Both scenarios should be addressed to either drive improvement projects or raise the question of what causes the disturbances.

Flow efficient processes require repeatability and predictability gained by pull- systems (Liker & Meier, 2006). Functional layout hinders flow due to excess of transportation between functional areas as well as construction of efficient workstations or cells for regulating flow of material. Material being pushed between processes, as viewed in the case study, does not aid in either resource effectiveness nor shorten lead times. Stump and Badurdeen (2009) exemplified similar issues in their case study, when WIP is uncontrolled there are problems with visibility and it amounts to a significant cost. Redirecting focus towards flow efficiency by limiting the WIP in the system (or subsystem) aids visualizing flow of products. Viewing individual departments or machines as islands disconnected from the system's bottleneck will effectively raise the number of products in the system. A varying number of products in the system hides issues for processes and leads to increased lead time of production when processes are flooded. A varying number of products in the system also creates unstable production lead times.

In the continuum of flow, the aim is to reach continuous single piece flow. One piece flow is not applicable for all situations and material systems. CONWIP and POLCA, in combination with FIFO lanes of batches have been identified as suitable for this case. This solution is motivated as lead times of processes are short and varying, where the batch has been found as a tool to smooth out cycle times of individual products, while increasing processing time per batch. Holistically viewing the effect of batch size for several processes has been found to give the effects of lower value-adding time per product, reduced handling and waiting, as processing times become more leveled.

Mass customization's impact requires process planning and control to support the multiple product families sharing the same resources. Due to case study's size, product re-circulation of processes in varied levels of completion raises the need for tracking the current status of the product within the system. Without proper production and control measures, keeping track of products results in more waste in the form of product inquiries and hides delivery precision problems. Slomp et al. (2009) exemplify similar issues within their case study, inefficiencies and poor control over the production system lead to long and unpredictable flow times. SMEs are at especially high risk for implementing improper, hence not effective, production planning and control systems (Stevenson et al., 2005). Communication has been made difficult due to a lack of references and structures when downstream processes do not respond when products are delayed. Further, the lack of production measures destabilizes the process since it is unclear which actual maximum capacity and utilization are in play. A wide range of customers and multiple points of customer contact create additional complexity of handling inputs to the system when short lead times are required. Standardization of information handling aids in finding similarities between the product and process variants thus locating possible improvements.

In the SME studied, flow efficiency and predictability need to be sought in order to reach a steady state of production. The prevalence of fire fighting draws attention away from the root cause and is resource inefficient. The range of lean tools is extensive and therefore it is unclear which tools are best applicable for the case's enhancement of flow efficiency. Constructing a future state in the case was not intended to be the ideal state of handling the value stream. The authors settled for developing an improved state to breed future learning within the new system. However, with better handling of daily tasks, room for improvement projects and the possibility to broaden employee competence will appear and allow further improvements. For successful implementation, tools need to be both identified and practical application needs to be learned to understand how methods are applied to the means in order to reach final goals. If not learned and reflected at the organization itself, true understanding of the methods risks being lost when not adapted to the individual company, due to complexity and individuality of the situation.

It has been found, that flow efficiency improvements by lean production methodology will smooth out irregularities and create a more balanced pace of product deliverability. Focusing on flow efficiency, by leveling the pace of stations exceeding the customer demand, or takt time, aids in focusing the direction of system improvements. Re-prioritization, due to inability to keep balanced pace of different orders, impacts operators stress levels. If stations are balanced and producing in sync with takt time, products will not accumulate in the production system's value stream. As observed in the case study, unbalanced processes as well as mixed products in the system, due to mass customization, result in products accumulating and a surge effect is created as described. Unbalanced processes lead to the waiting time for both WIP and operators. With regards to efforts on production planning and control, balancing the operations by standardization with respect to variants would be beneficial.

7.3 Sociotechnical System

Constructing sustainable production systems requires consideration of the technical requirements, as well as the human interference with the means to enhance the sociotechnical interaction. Trist et al. (1978) argue that conversion to such a system leads to better cooperation, heightened commitment, lower absenteeism and increased productivity. Addressing the needs of people in the system undergoing change processes is a way of involving and gaining support of the changes. Additionally, the viewing of humans as the main part of the production system becomes increasingly important as they are perceived as the drivers of change. Without support of system changes and enhancements of the humans in the system, there will be no lasting change. Finding the motivation is key for such endeavors and should be focused on during transition periods to facilitate change. Kotter (1995) encourages employee involvement early in the process. Additionally, lifting the actual issues of the people involved brings valuable insight which is otherwise at risk of being overlooked.

Teamwork and leadership is vital for the sociotechnical system. If silo mentality arises, where employees do not have appropriate levels of decision-making power and feel influence and incentive over work, focus drifts from the original purpose. The ability to make decisions on the lowest level possible requires a highly knowledgeable work-force. Development of knowledge strengthens the production system through employee empowerment and teamwork, which in turn creates a basis for continuous improvements and flow efficiency improvements. Mass customization systems put greater stress on teamwork, which requires effective means of communication and responsiveness of the system to handle the variation of products. A highly skilled and cross-functional workforce facilitates flexibility in the mass customization production system. For SMEs, it is possible to better hear the voice of employees due to the size of the company and see the individuals' contribution.

7.4 Sustainability of Research and Future Research Recommendations

The authors conducted this research with the intention of contributing to sustainability. In addition, the authors identified several aspects that were outside the scope of this study, this research can be further developed and improved.

7.4.1 Sustainability Aspects

This research contributes to sustainable development on several levels. The suggestion of developing a sociotechnical system addresses the improvement of working environments. The conversion to a sociotechnical system leads to higher motivation, lowered absenteeism, and decreased accidents among employees. In addition, the authors have been especially conscious of handling the ethical aspects of the research. In particular, respect for the individual and parties involved has been protected by careful reflection over the usage of material in this thesis.

Furthermore, this research contributes to the economic sustainability of SMEs and thereby aids in providing local employment opportunities and financial security for the community. Waste within a production system regarding low utilization and scrap of defective products affect environmental sustainability. Examining the waste that stems from overproduction and unstable processes, e.g. poor quality, can be improved for higher yield, reducing the environmental impact of production. In the case study, reduction of the number of panels produced decreases load on machinery and people, which improves the sociotechnical environment by reducing stress, increasing sustainability by reduced material and resources needed to run the machinery. Mass customization further reduces items made to stock, which if not purchased become depreciated and scrapped, which damages sustainability aspects.

7.4.2 Further Research Recommendations

The case study was found to be appropriate for answering the questions during the time the research was published. The problems identified and the solutions for improving the flow efficiency were deemed applicable for the case, as it was conducted from January to March 2017. The applicability in the future is questionable and therefore the authors recommend iterations of the study in order to maintain relevancy of suggestions for the company. In addition it should be noted that SMEs could vary much in appearance and the type of products they produce. Therefore, the authors conclude that the results are case specific and a new study is required to take into consideration the qualities of other SMEs.

Possible future research areas include studies concerning the various types of mass customization. Further research of how Fabricators within mass customization could implement efficient cell formations would be of interest. Moreover, considering how SMEs can strengthen employee empowerment by developing leaders and reinforcing teamwork would also be constructive. Due to the company in the case being classified as a Fabricator, it can be of interest to investigate how Involvers, Modulizers, and Assemblers influence flow efficiency and how various lean tools can be applicable.

Suggestions for the company could be improved with further research. Further analysis and simulations of the material flow, considering batch size and layout, would enhance the design of the material flow suggestions. The quantity and nature of the production system's constraints made it difficult to analyze and therefore a simulation would be beneficial. The authors feel that the company would benefit from researching cellular manufacturing and design of workstations combining one-piece machinery and line-machines.

8

Conclusion

This chapter highlights what was investigated and discovered. Moreover, the research project's contributions are summarized.

SMEs are challenged by today's global market to produce complex goods and services. Mass customization strives to provide customized products in a cost efficient manner. This is made challenging due to the vast number of unknown variables customized products introduce to the production system. High variation in demand places stress on the production system's performance. The higher upstream customization occurs, the more difficult it is to standardize routes in production and secure desired lead times. Small, individualized batches create strenuous workloads for production planning and production. High customization of products results in longer lead times and causes instability in processes. It is difficult to achieve a balance between deliverability and flexibility, especially for Fabricators. Improvement of the information and material flow and development of people all contribute to betterment of an organization's flow efficiency. These conclusions, from the empirical and theoretical findings describe how the production flow is impacted, thereby answering the first research question: *How does mass customization impact the production flow efficiency of an SME?*

High customization of products results in complex information and material flow. Production planning and control plays a large role as it both proceeds and is present during production. Due to lack of communication and planning, large amounts of waste depreciate shareholder value and contribute to an unsupported working environment. Product circulation contributes to flow efficiency in SMEs, whereby re-circulation in functional layouts hinders flow of material. For example production layouts such as functional layout hinder the flow of material. Traditional batch and queue, i.e. push, produces excess WIP and camouflages problems. Introducing a pull sequence will aid in reducing lead times. Moreover, establishment of batch size should take into account the production system's constraints and be considered from a holistic perspective. All in all, these findings answer the second research question: *How do the material and information flows impact on production flow efficiency?*

Employees play a central role in the production system thus influencing flow efficiency. A system should be designed to support operations by considering the employee's needs in the sociotechnical system. Mass customization demands a highly skilled and cross-functional workforce. Lowering the decision-making level, boosting influence over work, and developing knowledge among employees can benefit employee performance, which in turn results in enhancement of flow efficiency. Employee participation, is essential for the success of a sociotechnical system. Especially during transformation processes, employees should be emboldened to be involved in developing and weaving in new ideas, perspectives, and approaches. In conclusion, these findings answer the third research question: *How does the sociotechnical system impact production flow efficiency?*

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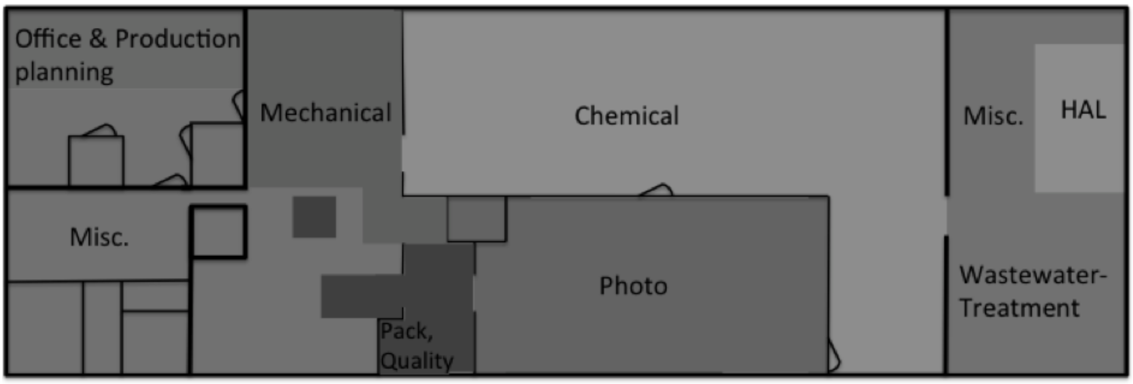
A

Current State Functional Layout

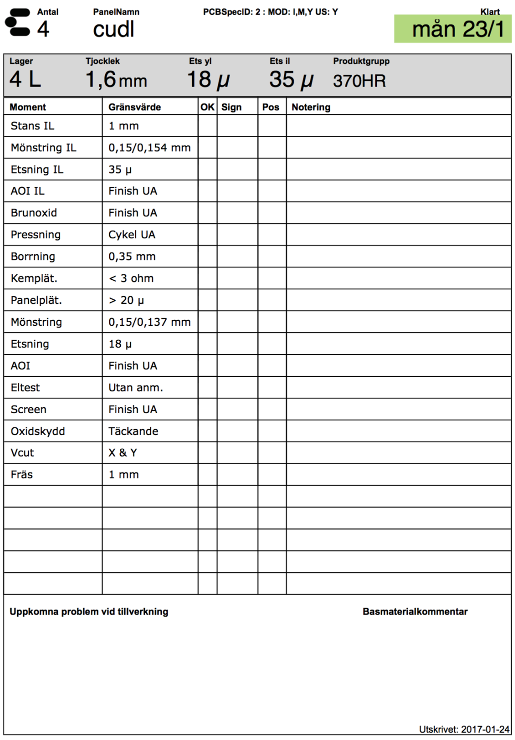
As identified the production system utilize functional layout (Bellgran & Säfsten, 2010). Departments are displayed with their localization in the factory.



B

Production order of typical Multi-Layer Panel

Viewed is a typical production order of a multi-layer build for production panels. Regards all information forwarded from production planning to shop floor. The top right corner states desired date of production completion, color coded with white-green-red status for urgency.



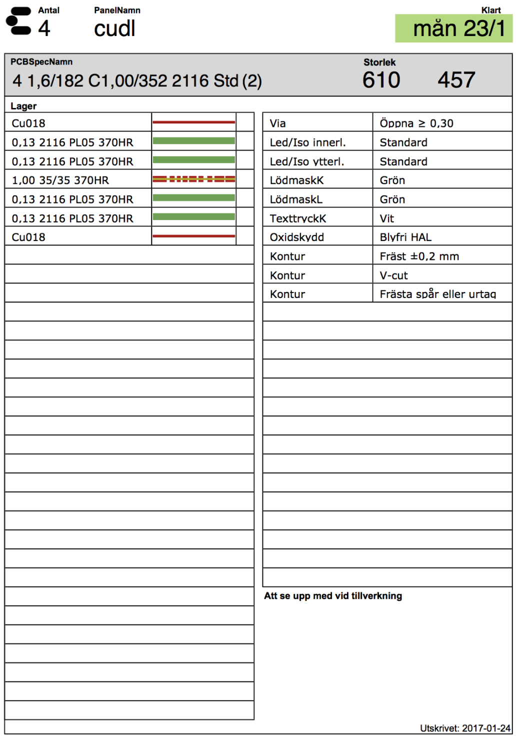
Antal 4 | PanelNamn cudl | PCBSpecID: 2 : MOD: I,M,Y US: Y | Klart mån 23/1

Lager	Tjocklek	Ets yl	Ets il	Produktgrupp
4 L	1,6 mm	18 μ	35 μ	370HR

Moment	Gränsvärde	OK	Sign	Pos	Notering
Stans IL	1 mm				
Mönstring IL	0,15/0,154 mm				
Etsning IL	35 μ				
AOI IL	Finish UA				
Brunoxid	Finish UA				
Pressning	Cykel UA				
Borrning	0,35 mm				
Kempläts.	< 3 ohm				
Panelplät.	> 20 μ				
Mönstring	0,15/0,137 mm				
Etsning	18 μ				
AOI	Finish UA				
Eltest	Utan anm.				
Screen	Finish UA				
Oxidskydd	Täckande				
Vcut	X & Y				
Fräs	1 mm				

Uppkomna problem vid tillverkning | Basmaterialkommentar

Utskrivet: 2017-01-24



Antal 4 | PanelNamn cudl | Klart mån 23/1

PCBSpecNamn	Storlek	
4 1,6/182 C1,00/352 2116 Std (2)	610	457

Lager

Cu018	
0,13 2116 PL05 370HR	
0,13 2116 PL05 370HR	
1,00 35/35 370HR	
0,13 2116 PL05 370HR	
0,13 2116 PL05 370HR	
Cu018	

Via	Öppna ≥ 0,30
Led/Iso innerl.	Standard
Led/Iso ytterl.	Standard
LödmaskK	Grön
LödmaskL	Grön
TexttryckK	Vit
Oxidskydd	Blyfri HAL
Kontur	Fräst ±0,2 mm
Kontur	V-cut
Kontur	Frästa spår eller urtag

Att se upp med vid tillverkning

Utskrivet: 2017-01-24

(a) Front of production order **(b)** Back of production order

Figure B.1: Example of production order form for Production Panel CUDL. Displays all information used in production as well as expected date of completion. The date can be highlighted in green or red, showing urgency of order and priority

C
Workplace Environment Survey Results

Following surveys are the result of the online forms sent out to employees. The survey was conducted during first phases of the thesis to gain understanding of the current state perceived areas;

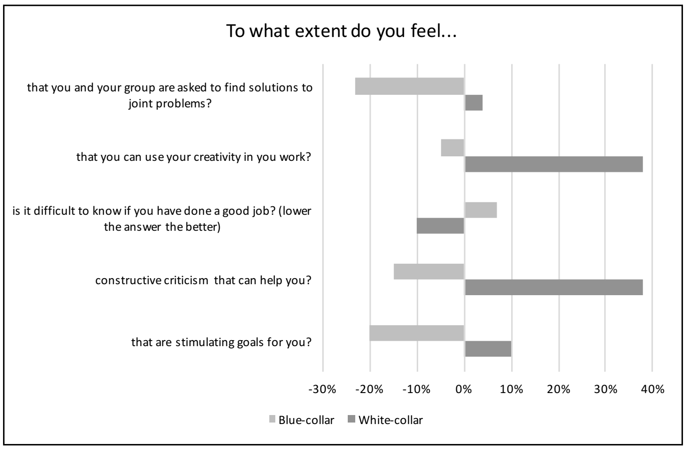


Figure C.1: Challenges in employees' perceived work tasks.

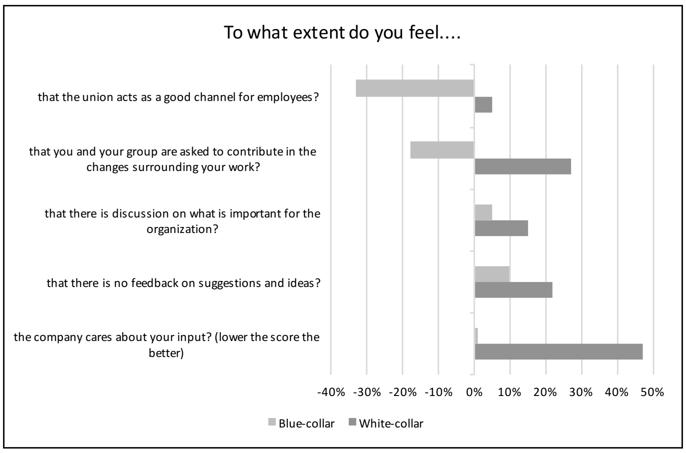


Figure C.2: Perceived employee influence.

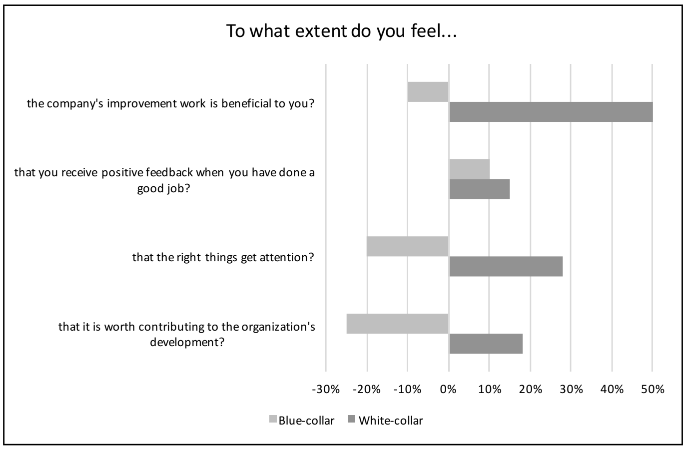
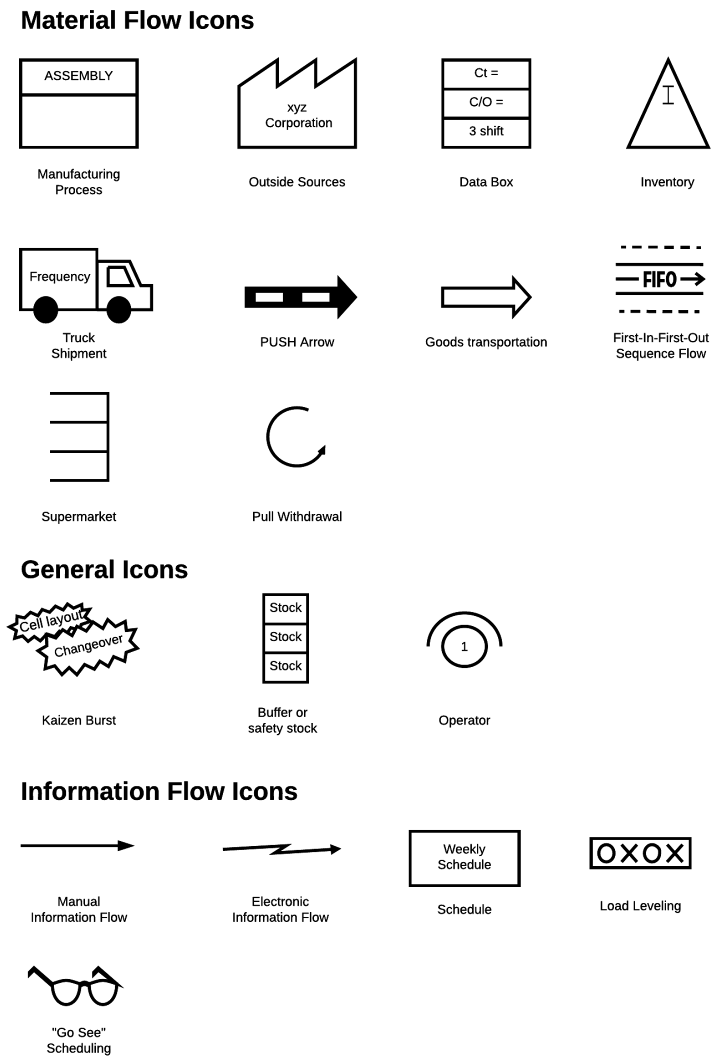


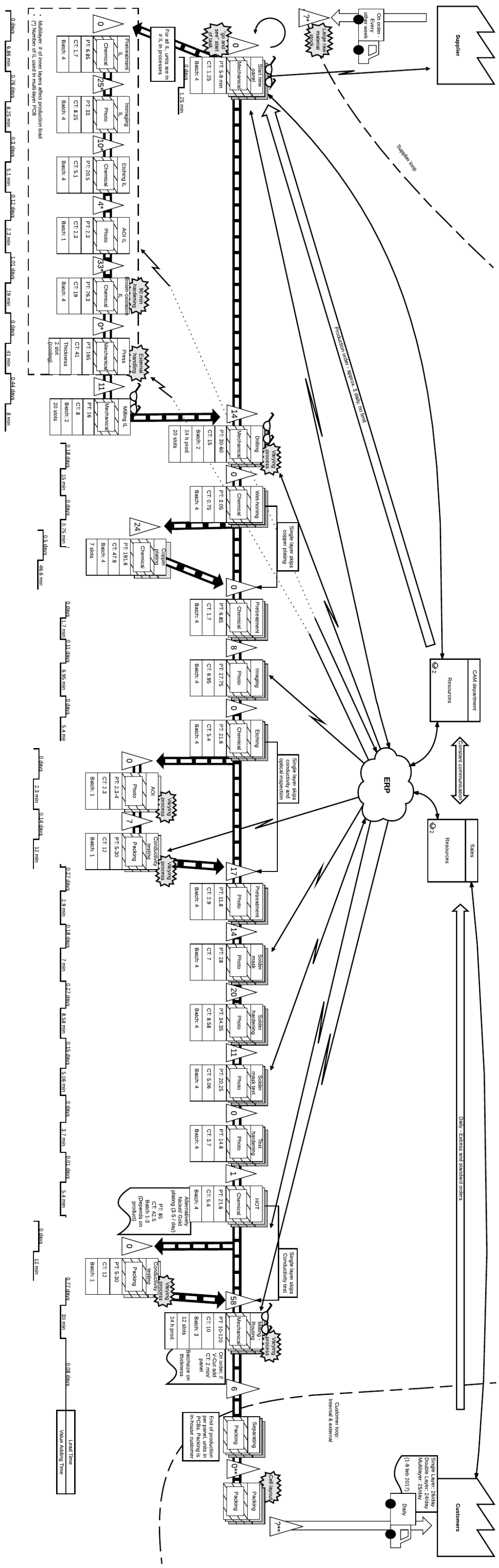
Figure C.3: Perceived employee individual incentive.

D

Current State Value Stream Map

Viewed below is the figures and icons used in value stream maps in this master thesis. Icons are used as seen in Rother and Shook (2003), Bellgran and Säfsten (2010), with minor adaptations. Additionally the current state map as viewed in Chapter 4.2.3, displayed then split into three enlarged pieces.





% Value adding time			
	Lead time	Value Adding	VA/LT
Single layer	2.02 days	92.45 min	3.2 %
Double layer	2.65 days	165.35 min	4.3 %
Multi-layer	5.50 days	231.35 min	2.9 %

Type of product: Single layer, Double layer, Multi-layer, Department

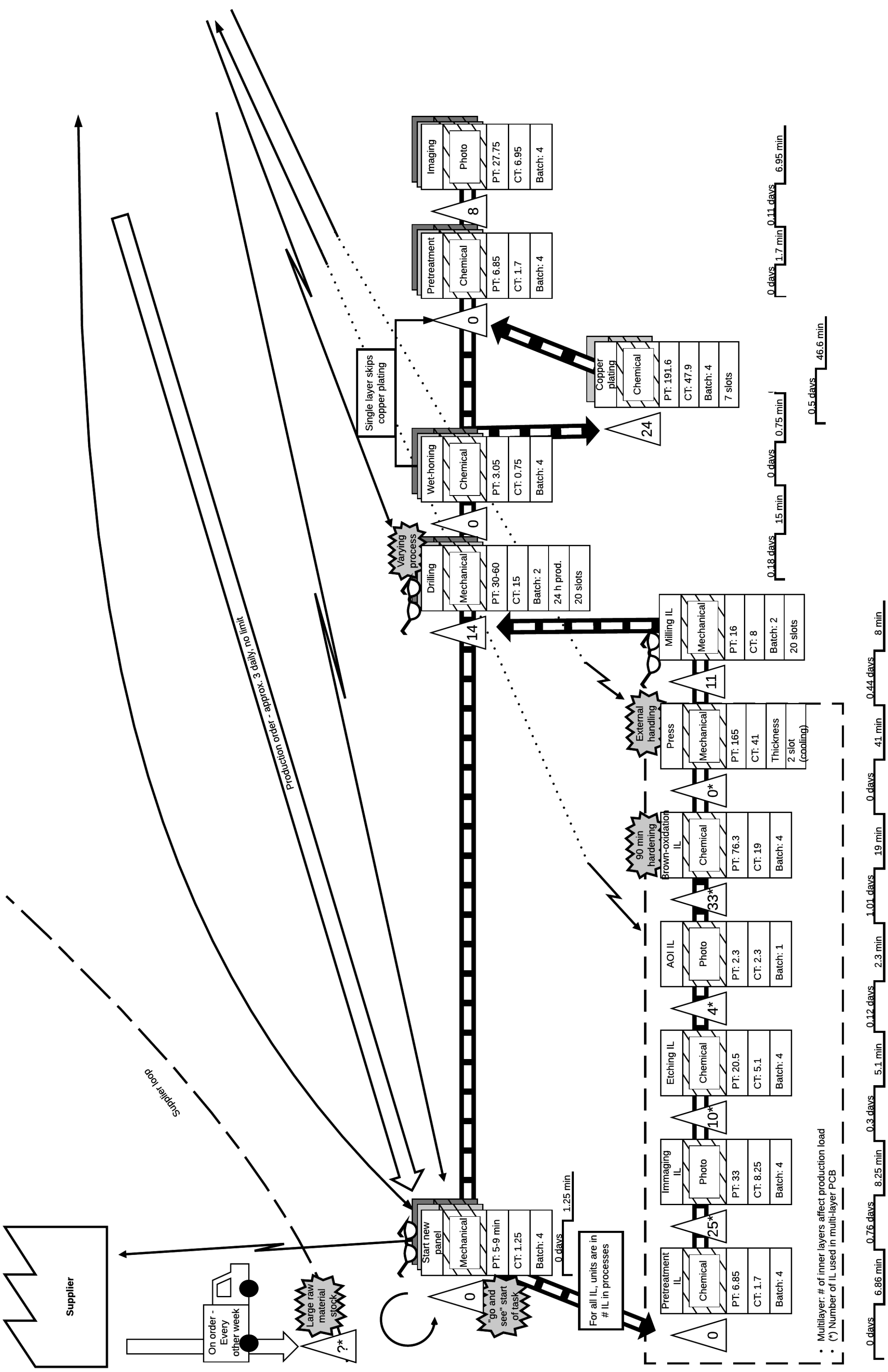
Abbreviations
(IL) Inner Layer
(*) Number of IL used in multi-layer PCB
(**) Finished PCBs, not per production panel

Mechanical	2
Chemical	2
Photo	3
Packing	1

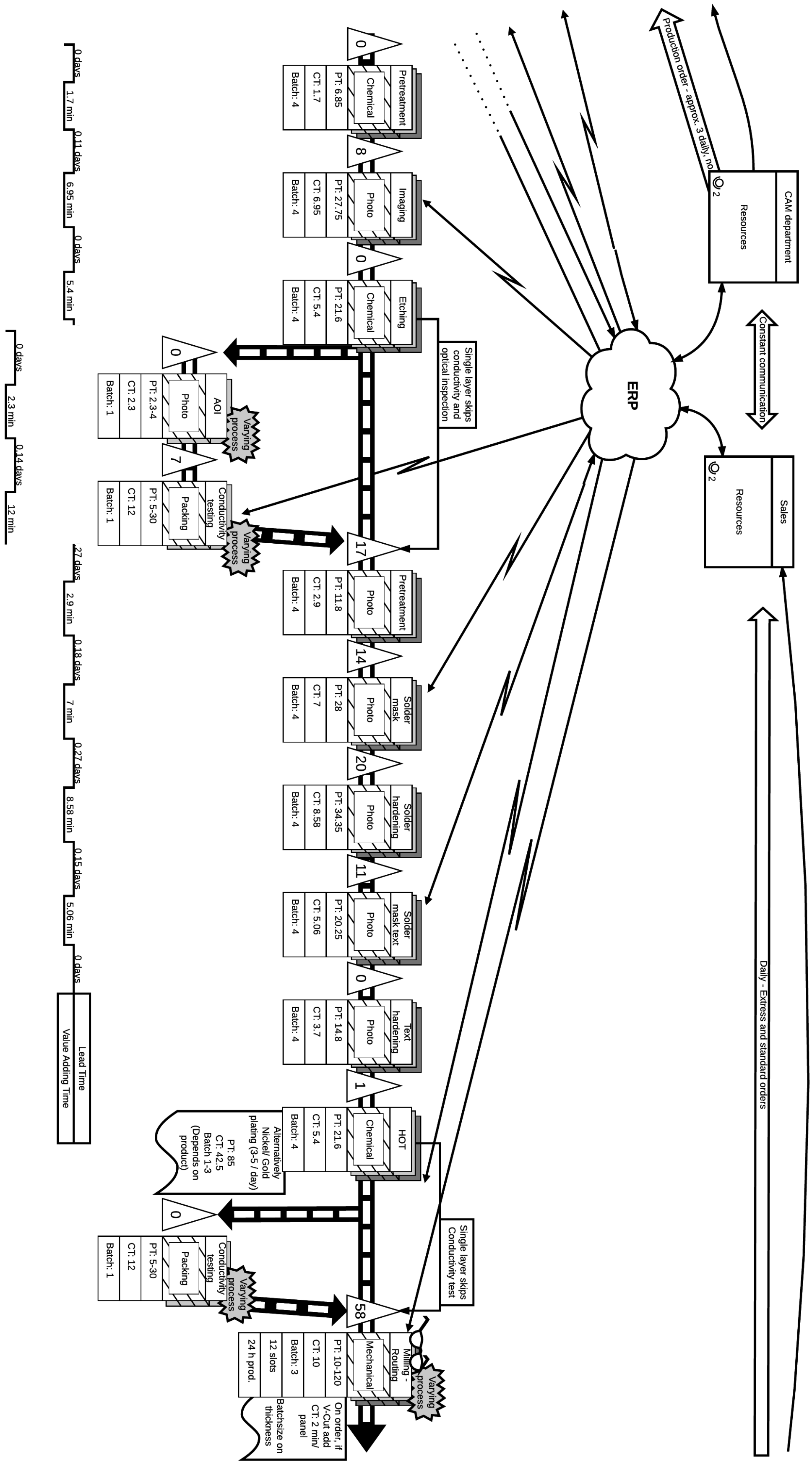
Date of collection Monday 7/2 15.00

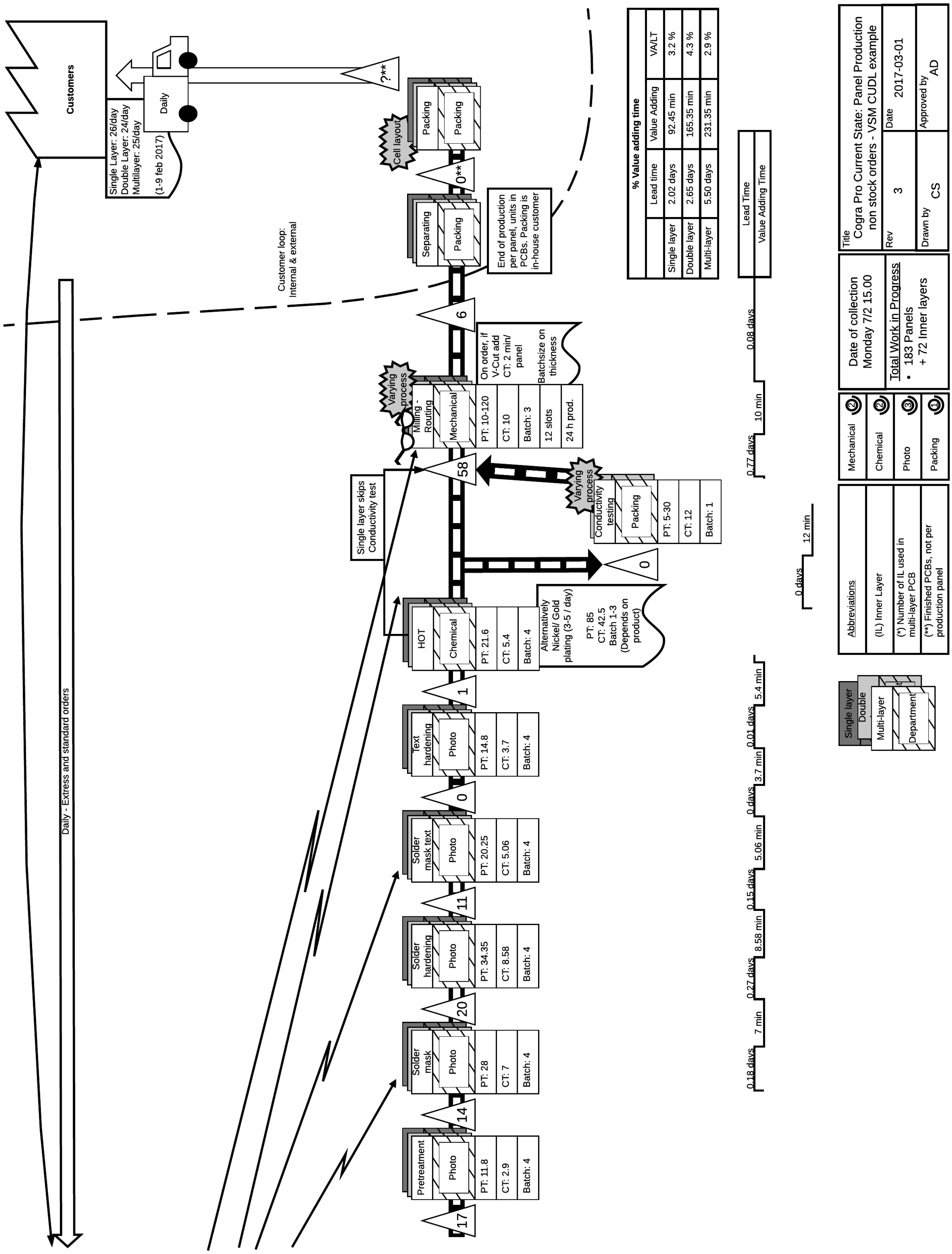
Total Work in Progress
- 183 Panels + 72 Inner layers

Title	
Cogra Pro Current State: Panel Production - VSM CUDL example	
Rev: 3	Date: 2017-03-01
Drawn by: CS	Approved by: AD



Supplier
On order - Every other week
Large raw material stock
?*
Supplier loop
Production order - approx. 3 daily, no limit
Start new panel
Mechanical
PT: 5-9 min
CT: 1.25
Batch: 4
"go and see" start of task
For all IL, units are in # IL in processes
Drilling
Mechanical
PT: 30-60
CT: 15
Batch: 2
24 h prod.
20 slots
Varying process
Wet-honing
Chemical
PT: 3.05
CT: 0.75
Batch: 4
Single layer skips copper plating
Copper plating
Chemical
PT: 191.6
CT: 47.9
Batch: 4
7 slots
Pretreatment
Chemical
PT: 6.85
CT: 1.7
Batch: 4
Imaging
Photo
PT: 27.75
CT: 6.95
Batch: 4
Pretreatment IL
Chemical
PT: 6.85
CT: 1.7
Batch: 4
Immaging IL
Photo
PT: 33
CT: 8.25
Batch: 4
Etching IL
Chemical
PT: 20.5
CT: 5.1
Batch: 4
AOI IL
Photo
PT: 2.3
CT: 2.3
Batch: 1
Brown-oxidation IL
Chemical
PT: 76.3
CT: 19
Batch: 4
90 min hardening
Press
Mechanical
PT: 165
CT: 41
Thickness
2 slot (cooling)
External handling
Milling IL
Mechanical
PT: 16
CT: 8
Batch: 2
20 slots
0
14
0
24
0
8
0
25*
10*
4*
33*
0*
11
0 days
1.25 min
0.18 days
15 min
0 days
0.75 min
0.5 days
46.6 min
0 days
1.7 min
0.11 days
6.95 min
0 days
6.86 min
0.76 days
8.25 min
0.3 days
5.1 min
0.12 days
2.3 min
1.01 days
19 min
0 days
41 min
0.44 days
8 min
· Multilayer: # of inner layers affect production load
(*) Number of IL used in multi-layer PCB


CAM department
Resources
Production order - approx. 3 daily, no
Constant communication
ERP
Sales
Resources
Daily - Express and standard orders
Pretreatment
Chemical
PT: 6.85
CT: 1.7
Batch: 4
Imaging
Photo
PT: 27.75
CT: 6.95
Batch: 4
Etching
Chemical
PT: 21.6
CT: 5.4
Batch: 4
Single layer skips conductivity and optical inspection
AOI
Photo
PT: 2.3-4
CT: 2.3
Batch: 1
Varying process
Conductivity testing
Packing
PT: 5-30
CT: 12
Batch: 1
Pretreatment
Photo
PT: 11.8
CT: 2.9
Batch: 4
Solder mask
Photo
PT: 28
CT: 7
Batch: 4
Solder hardening
Photo
PT: 34.35
CT: 8.58
Batch: 4
Solder mask text
Photo
PT: 20.25
CT: 5.06
Batch: 4
Text hardening
Photo
PT: 14.8
CT: 3.7
Batch: 4
HOT
Chemical
PT: 21.6
CT: 5.4
Batch: 4
Alternatively Nickel/ Gold plating (3-5 / day)
PT: 85
CT: 42.5
Batch 1-3
(Depends on product)
Single layer skips Conductivity test
Milling - Routing
Mechanical
PT: 10-120
CT: 10
Batch: 3
12 slots
24 h prod.
On order, if V-Cut add CT: 2 min/ panel
Batchsize on thickness
0
8
0
0
7
17
14
20
11
0
1
0
58
0 days
1.7 min
0.11 days
6.95 min
0 days
5.4 min
0 days
2.3 min
0.14 days
12 min
0.27 days
2.9 min
0.18 days
7 min
0.27 days
8.58 min
0.15 days
5.06 min
0 days
Lead Time
Value Adding Time


Customers
Single Layer: 26/day
Double Layer: 24/day
Multilayer: 25/day
(1-9 feb 2017)
Daily
?**
Daily - Extress and standard orders
Customer loop:
Internal & external
17
Pretreatment
Photo
PT: 11.8
CT: 2.9
Batch: 4
14
Solder mask
Photo
PT: 28
CT: 7
Batch: 4
20
Solder hardening
Photo
PT: 34.35
CT: 8.58
Batch: 4
11
Solder mask text
Photo
PT: 20.25
CT: 5.06
Batch: 4
0
Text hardening
Photo
PT: 14.8
CT: 3.7
Batch: 4
1
HOT
Chemical
PT: 21.6
CT: 5.4
Batch: 4
Alternatively Nickel/ Gold plating (3-5 / day)
PT: 85
CT: 42.5
Batch 1-3
(Depends on product)
0
Single layer skips Conductivity test
Conductivity testing
Packing
PT: 5-30
CT: 12
Batch: 1
Varying process
58
Milling - Routing
Mechanical
PT: 10-120
CT: 10
Batch: 3
12 slots
24 h prod.
Varying process
On order, if V-Cut add CT: 2 min/ panel
Batchsize on thickness
6
Separating
Packing
End of production per panel, units in PCBs. Packing is in-house customer
0**
Cell layout
Packing
Packing
% Value adding time
Lead time
Value Adding
VA/LT
Single layer
2.02 days
92.45 min
3.2 %
Double layer
2.65 days
165.35 min
4.3 %
Multi-layer
5.50 days
231.35 min
2.9 %
Lead Time
Value Adding Time
0.18 days
7 min
0.27 days
8.58 min
0.15 days
5.06 min
0 days
3.7 min
0.01 days
5.4 min
0 days
12 min
0.77 days
10 min
0.08 days
Single layer
Double
Multi-layer
Department
Abbreviations
(IL) Inner Layer
(*) Number of IL used in multi-layer PCB
(**) Finished PCBs, not per production panel
Mechanical
Chemical
Photo
Packing
Date of collection
Monday 7/2 15.00
Total Work in Progress
• 183 Panels
+ 72 Inner layers
Title
Cogra Pro Current State: Panel Production non stock orders - VSM CUDL example
Rev
3
Date
2017-03-01
Drawn by
CS
Approved by
AD

E

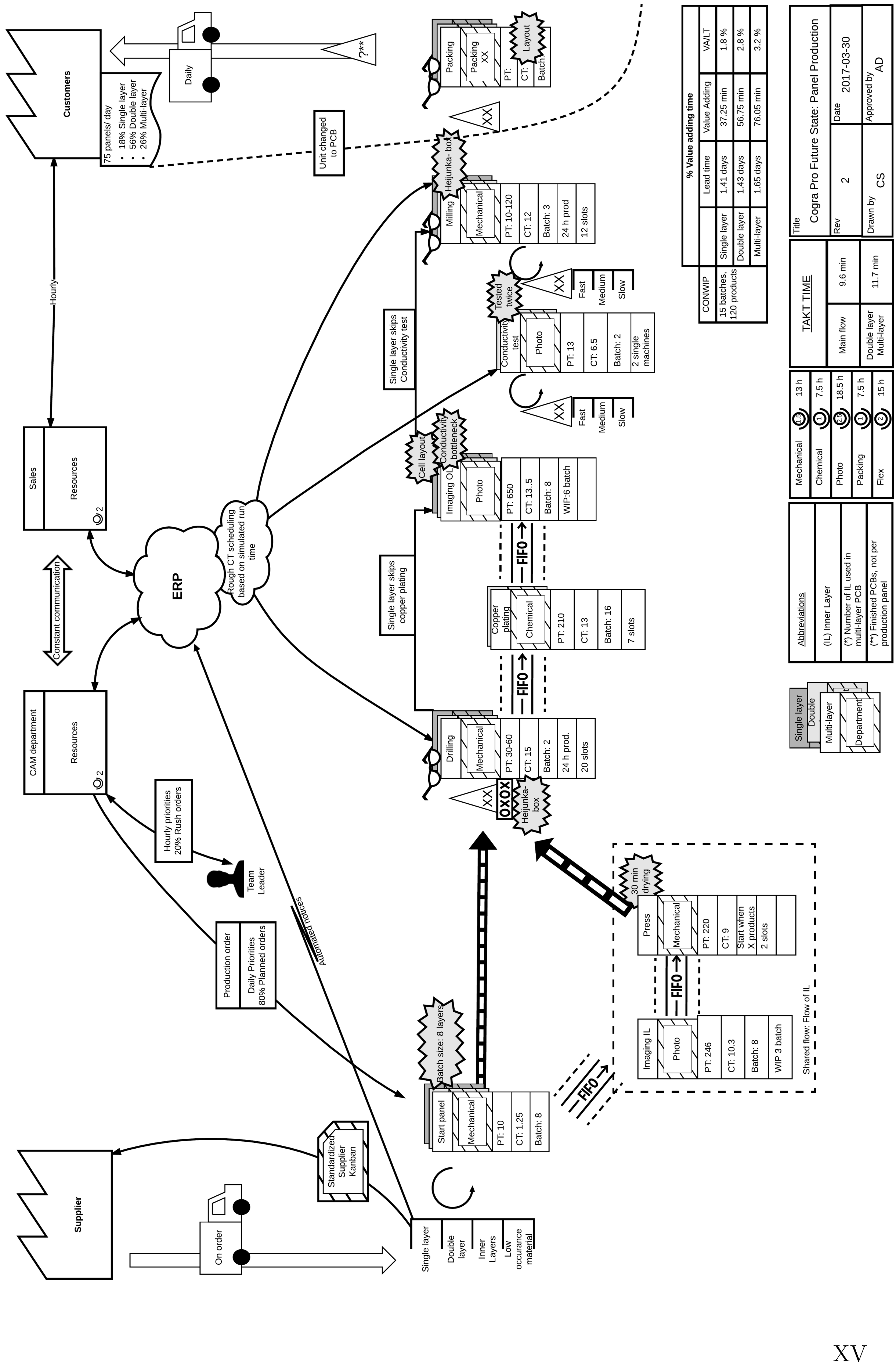
Future State Value Stream Map and Description

Ten highlighted areas of the future state:

1. Planned capacity utilization
2. Supplier kanban
3. Batch size of 8 layers
4. 30 min drying
5. Leveled drilling by heijunka box
6. Imaging as bottleneck
7. Leveled milling by supermarket
8. Two flexible workers
9. CONWIP of 15 batches
10. Rough CT scheduling for varying processes

Planned capacity utilization by splitting daily production limits in two; daily priorities and hourly priorities handled by the team leader. The team leader is a newly appointed role who tends to the whole system and overlooks key figures and arranges orders before initial production steps. Daily production orders are received planned to approximately 80% capacity of the production system. When a rush order is received, limited to 20% of capacity daily, the teal leader rearrange the daily order queue best fitting delivery dates. Hybrid make to order (Holweg & Pil, 2001) is used so that orders of mixed due-dates are in the queue enabling reprioritization in the queue, but not in the system.
Supplier kanban is used to reduce handling of frequently occurring raw material usage. Supplier connections were not part of this thesis, but is included as it is part of the VSM.
Batch size of 8 layers as described in the 8 future state questions is used for all processes to level flow through imaging department.
30 min drying is a process improvement within the press operation.
Leveled drilling by heijunka box is used by planning the drilling operation so that the imaging process downstream remain saturated. As it is a varying process with possible long cycle-times simulations enable self-control when to start operations as long as flow efficiency is maintained.
Imaging as bottleneck when grouping activities together as displayed requires process improvements to keep the takt time. Currently conductivity is the main issue in this model as double layer as multi-layer panels are tested twice, process times are long and varying. If simulated and planned by supermarket, flow can be maintained.
Leveled milling by supermarket to take account for the varying times when processing times are too long, scheduling these panels to be machined without disabling

even flow to imaging.
Two flexible workers are freed from other processes due workload analysis and improvements found in handling enabled by rearranging machinery. Additionally, two new wet-honing machines are invested to combine operations in fewer processes, reducing handling, as well as using the new solder spray together with a newly invested solder hardening tunnel. The effects as seen in the future flow map greatly reduces distances as well as enables visual management of functional areas.
CONWIP of 15 batches decreases total amount of WIP in the system, stabilizing the lead times for all products. Will help in in reducing complexity, surge effect and make problems visible.
Rough CT scheduling for varying processes becomes necessary to maintain the leveling effects of heijunka boxes and supermarkets.



Customers
75 panels/ day
18% Single layer
56% Double layer
26% Multi-layer
Daily
?**
Hourly
Sales
Resources
2
Constant communication
ERP
Rough CT scheduling based on simulated run time
CAM department
Resources
2
Hourly priorities
20% Rush orders
Team Leader
Production order
Daily Priorities
80% Planned orders
Automated notices
Supplier
On order
Standardized Supplier Kanban
Single layer
Double layer
Inner Layers
Low occurance material
Start panel
Mechanical
PT: 10
CT: 1.25
Batch: 8
Batch size: 8 layers
FIFO
Imaging IL
Photo
PT: 246
CT: 10.3
Batch: 8
WIP 3 batch
Press
Mechanical
PT: 220
CT: 9
Start when X products
2 slots
30 min drying
Shared flow: Flow of IL
Heijunka-box
OXOX
XX
Drilling
Mechanical
PT: 30-60
CT: 15
Batch: 2
24 h prod.
20 slots
Copper plating
Chemical
PT: 210
CT: 13
Batch: 16
7 slots
Single layer skips copper plating
Imaging OL
Photo
PT: 650
CT: 13..5
Batch: 8
WIP:6 batch
Cell layout
Conductivity bottleneck
Conductivity test
Photo
PT: 13
CT: 6.5
Batch: 2
2 single machines
Tested twice
Fast
Medium
Slow
Single layer skips Conductivity test
Milling
Mechanical
PT: 10-120
CT: 12
Batch: 3
24 h prod
12 slots
Heijunka- box
Unit changed to PCB
Packing
Packing XX
PT:
CT:
Batch:
Layout
% Value adding time
Lead time
Value Adding
VA/LT
Single layer
1.41 days
37.25 min
1.8 %
Double layer
1.43 days
56.75 min
2.8 %
Multi-layer
1.65 days
76.05 min
3.2 %
CONWIP
15 batches, 120 products
Title
Cogra Pro Future State: Panel Production
Rev
2
Date
2017-03-30
Drawn by
CS
Approved by
AD
TAKT TIME
Main flow
9.6 min
Double layer Multi-layer
11.7 min
Mechanical
13 h
Chemical
7.5 h
Photo
18.5 h
Packing
7.5 h
Flex
15 h
Abbreviations
(IL) Inner Layer
(*) Number of IL used in multi-layer PCB
(**) Finished PCBs, not per production panel
Single layer
Double
Multi-layer
Department

F
Future State Flow Map

Below is the future state layout flow for multi-layer production panel.

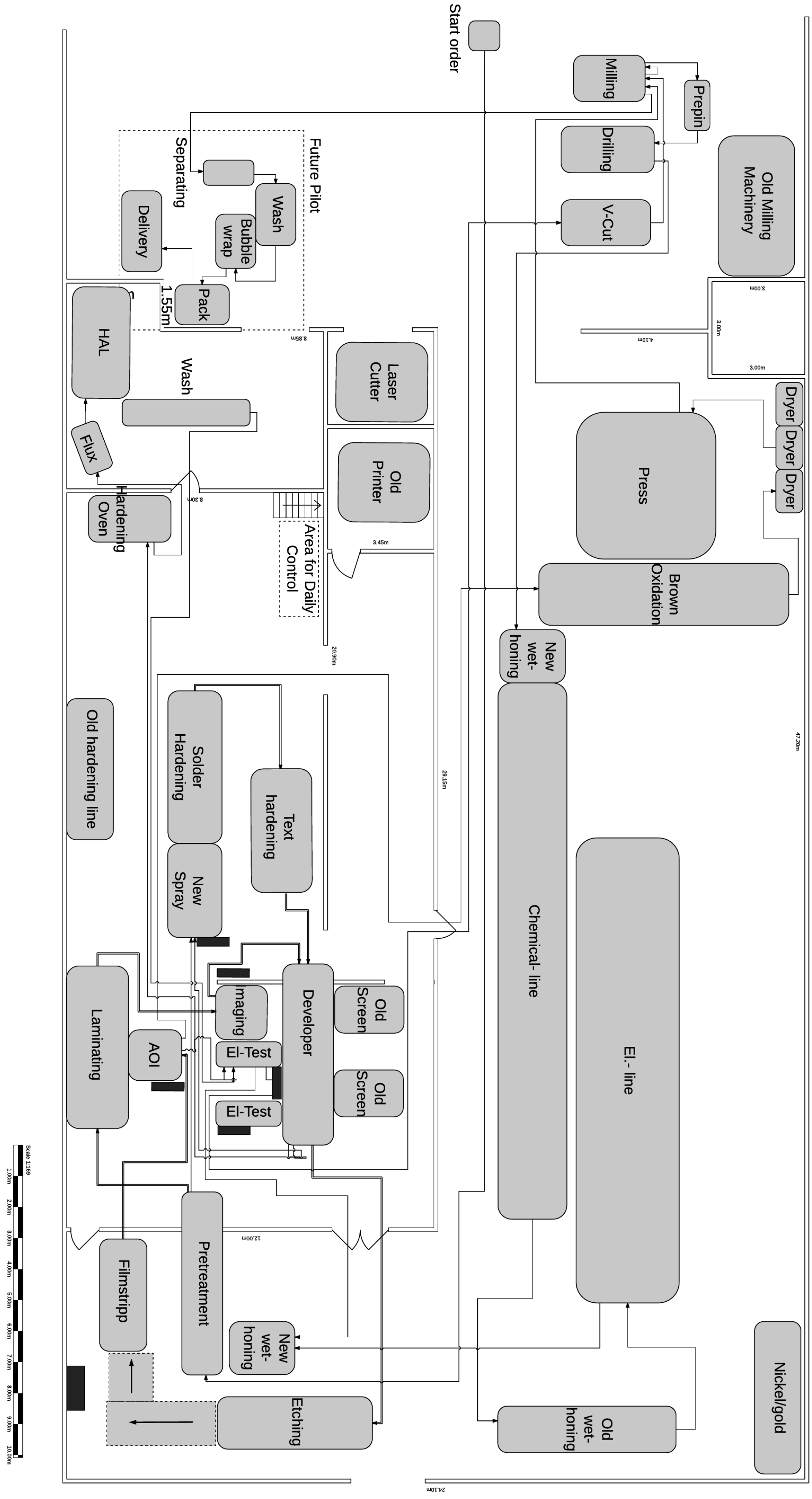


Figure F.1: Flow Map - Facility layout including flow with regard to the future state; shows the flow of a multi-layer panel. The thick lines indicates the product's path as it recirculates twice along a specific route (filmstrip - AOI).