Heine Hammersland

Order Release in Mass Customization

Can Card-Based Production Planning and Control systems be applied?

Master's thesis in Global Manufacturing Management
Supervisor: Erlend Alfnes and Kristina Kjersem
June 2019

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
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HD SOLSKJERMING
Et Hunter Douglas selskap

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Executive summary

In this thesis I investigated the applicability of four different Production Planning and Control (PPC) systems, namely KANBAN, CONWIP, POLCA and COBACABANA, to Mass Customization (MC) manufacturing. This form of manufacturing offers customizable products to their customers, while also operating with high volumes. The customization of products results in a high number of production routes, which may create planning and control problems. Hence, the Production Planning and Control systems.

The applicability of the PPC systems was analyzed through a literature study and a case study of MC manufacturer HD Solskjerming AS. While the literature was used to crossmatch the capabilities of the PPC systems with MC manufacturing characteristics, the case study was used as a validation of the findings.

As a result, the analysis suggests that COBACABANA is the most applicable PPC system, out of the four, to MC manufacturing. As the thesis only suggest this applicability, the capabilities and applicability of COBACABANA to MC should be further investigated.

Sammendrag

I denne masteroppgaven undersøkte jeg bruken av fire *Production Planning and Control* (PPC) systemer, nemlig KANBAN, CONWIP, POLCA og COBACABANA, og deres applikasjon til *Mass Customization* (MC) produksjon. Denne formen for produksjon tilbyr kundetilpassede produkter samtidig som de opererer med høye volum. Kundetilpassingen resulterer i et stort antall produksjonsruter, noe som kan skape problemer og utfordringer i produksjonskontroll og -planlegging. Dette er grunnen til at PPC systemene undersøkes i slik et produksjonsmiljø.

Anvendbarheten av PPC systemene ble analysert gjennom at litteraturstudie og et case-studie av MC produsent HD Solskjerming AS. Litteraturstudie sammenlignet egenskapene til PPC systemene med MC produksjonens egenskaper, mens case-studiet ble brukt som en form for validering av oppgavens funn.

Oppgavens analysedel tyder på at COBACABANA er det mest anvendelige PPC systemet til bruk i MC produksjon. Denne anvendbarheten er kun antydet, og det er min oppfatning at kapasiteten og anvendbarheten av COBACABANA i MC produksjon bør undersøkes nærmere.

Preface

This thesis was completed during the Spring of 2019 at the Norwegian University of Science and Technology (NTNU), Department of Mechanical and Industrial Engineering (MTP) and study program Global Manufacturing Management (GMM). The thesis was completed in cooperation with HD Solskjerming AS and Møre Forskning Molde.

I would like to thank my supervisors, Associate Professor Erlend Alfnes (NTNU) and researcher Kristina Kjersem (MFM) for the support and feedback during the thesis work. I would also like to thank Torbjørn Lund – Production manager – and Christian Michaelsen – Production Department manager – (both HD Solskjerming) for providing valuable information and material.

Molde, June 11th, 2019

Heine Hammersland

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List of Abbreviations

ATO	Assembly to order
CBPPC	Card-Based Production Planning and Control
COBACABANA	Control of Balance by Card-Based Navigation
CODP	Customer order decoupling point
COWIP	Constant Work in Progress
CTO	Configure to order
ETO	Engineer to order
LM	Lean Manufacturing
MC	Mass Customization
MTO	Make to Order
MTS	Make to Stock
OR	Order Release
ORR	Order Review and Release
POLCA	Paired-cell Overlapping Loops of Cards with Authorization
VSM	Value Stream Model

1 Introduction

The introduction chapter serve to introduce the reader to the contents and the purpose of the thesis, it answers the *what*, *why* and *how* questions the reader may have.

For the past hundred years mass production has been the most effective strategy, however, in recent years production has taken a shift towards customized production. Some authors on the field of customization state that the shift from standardized production towards customization is a result of technological growth, increasing customer demands and competition (Gilmore, 1997, Lampel and Mintzberg, 1996, Pine and Davis, 1993).

As a result of this shift Mass Customization (MC) has become a realistic and applicable production method. MC is the act of mass-producing customized products at a cost-efficient way as if it was mass produced. Fogliatto et al. (2012) stated in their review that MC is a paradox between scale production and customization, where scale production favors standardization and customization favors lower volumes of production.

This thesis contains a literature study on Card-based Production Planning and Control (CBPPC), Order Release (OR) and MC and a case study of a MC manufacturer. The theoretical part is analyzed in the final chapter, applied to the case study, and further discussed. The thesis highlights the use of CBPPC systems in MC environments and how the OR process affects the shop floor.

This introduction chapter provides the following; background of the study, a problem description, research contribution, research questions, objectives, project scope, limitations, and the structure of the thesis.

1.1 Background and motivation

The high mix, high volume production of MC manufacturing can pose a planning and control challenge. This is observed at MC manufacturer HD Solskjerming (HD Sol), where their high production mix, options and production routings result in high throughput time variety, Work-In-Progress (WIP) inventory and waiting which also leads to low utilization. HD Sol is a company located in Molde, Norway and is part of a larger group, Hunter Douglas (HD). HD Sol manufactures and install solar screening products to customers all over Norway and has experienced a great upswing, with a yearly turnover of approximately 750 MNOK.

Production Planning and Control (PPC) systems are an effective tool in mitigating such challenges. The objective of such systems is to plan and manage capacity and materials in order to achieve an effective production. The release of orders (OR) to production is one of the main functions of any PPC system, which can be triggered in many different ways. Some PPC systems has a continual release of orders in order to feed the system and maximize utilization, while some store and sort orders in a Pre-Shop Pool (PSP) and release the orders based on a sequence rule.

MC manufacturing and the OR mechanisms in CBPPC systems was chosen as the topic of this thesis as it was found to be lacking in literature. KANBAN, CONWIP, POLCA and COBACABANA are proven CBPPC systems (Thürer et al., 2016b), and are in this thesis investigated, and how applicable they are to MC environments.

1.2 Problem Description

HD Sol is a MC manufacturer that produces customized solar screening products. The mapping process performed at the case company revealed a high level of lead time variation. This variation was attributed to the timing of order release, where an inadequate release of orders would result in semi-processed jobs and WIP. WIP takes up storage space, stresses the production system, and most importantly is the result of inadequate order release.

The problem occurs when orders are released at the *wrong time*, i.e. release of orders at a time that negatively affects the production system, resulting in WIP, semi-finished products, increase in lead time and/or lead time variations. So, how can one assure that orders will be released at the right time? This thesis investigates the possibility to use a CBPPC system to mitigate the negative effects of inadequate order release by using CBPPC order release mechanisms.

To the best of my knowledge, there has not been any study on CBPPC systems in MC manufacturing, and how their OR mechanisms affect MC. This raises the question: which OR mechanism found in CBPPC systems are most applicable to MC production - KANBAN, CONWIP, POLCA, COBACABANA? In response, this thesis seeks to investigate the applicability of CBPPC systems OR mechanisms in MC manufacturing environments.

There are multiple PPC methods covered in literature, but in the context of MC Card-based PPC methods are found to be most appropriate, because MC manufacturers often are smaller businesses, and CBPPC are simple and visual method of production control. Other PPC methods are often costly and complicated, while CBPPC methods are simple and easy to implement (Thürer et al., 2016b).

Typical for MC is high variety products, customized to customers' needs based on prototype products. The production volume is high and production routes vary, this results in WIP (Lampel and Mintzberg, 1996). The aim is to address this issue by studying CBPPC systems in order to find the CBPPC methods which leads to the best order release process (Order Release TIMING), and thus reduce WIP inventories, etc. A reduction in "unnecessary" jobs being released, will reduce WIP inventories, and thus reduce production lead time and strain on the shop floor.

1.3 Gap in literature and research contribution

Even though MC manufacturing and CBPPC systems are well covered in literature, a gap between them was found, and in combination of these fields, this thesis investigates the applicability of CBPPC systems to MC and how it affects OR.

This thesis contributes to literature by providing an assessment of CBPPC systems to MC manufacturing. A good match between MC and CBPPC could result in reducing WIP inventory, production lead time and lead time variation. This research is therefore important, contributes to literature and MC production managers.

In summary, this thesis differs from previous literature in the following ways:

- A theoretical background of CBPPC, MC and OR in one thesis,
- An analysis of the interrelationship and effects CBPPC systems have on OR and MC.
- A case study on a MC manufacturer is conducted, providing them with a suggested solution based on a CBPPC system.
- Workshop with case company to assure validity of any results or findings

1.4 Research questions

The Research Questions of a thesis or project serve to focus the work and research methods with a particular goal or answer in mind (Bryman, 2016) . Meaning that the formulation of research questions designs the research, in selecting research methods and strategies. Blaikie and Priest (2019) stated in their paper that “a research project is built on the foundation of research questions”.

The Research Questions in this thesis are:

RQ1: What are the main characteristics of MC?

RQ2: What CBPPC systems are applicable to MC?

RQ3: How does the CBPPC systems OR mechanisms affect MC?

1.5 Objectives

The objective of this thesis is to investigate CBPPC systems, i.e. KANBAN, COMWIP, POLCA and COBACABANA, their OR mechanisms and how they perform in a MC manufacturing environment. The methodology used in order to reach these objectives is presented in a later chapter.

This objective includes the following activities:

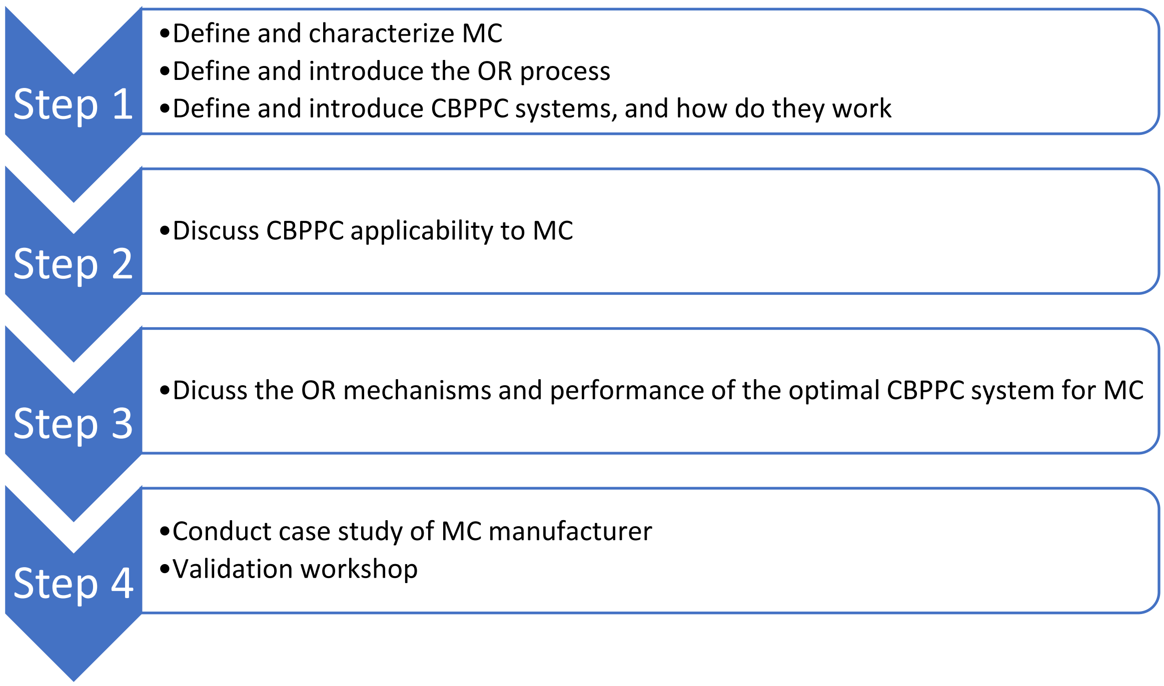

Figure 1 Thesis objectives

Step 1 gives a theoretical introduction and background on the topics of production types, the OR process and PPC. Moreover, MC and CBPPC systems (KANBAN, CONWIP, POLCA, COBACABANA) are defined and introduced. The objectives in Step 1 addresses the first research question. The second and third research question are answered in step 2 and 3, respectively. Research question 2 identifies applicable CBPPC methods - those not applicable are eliminated from the discussion in research question 3. Step 4 in the thesis is a case study of a MC manufacturer, where the cumulated results of the previous steps will be tested and tried.

1.6 Project scope

This thesis is a continuation of a project thesis completed in 2018 (Hammersland, 2018) and study the CBPPC systems effect on MC production environments. Therefore, the scope will be restricted to CBPPC systems only. Specifically, I review two areas: (1) The CBPPC systems OR mechanisms, and (2) assess the applicability of CBPPC to MC.

1.7 Limitations

The research limitations of a study are the biases that sets limitations or hinders that the researcher didn’t or couldn’t control, and could affect the results in some way or another (Price and Murnan, 2004). This thesis was limited to the extent of the literature study and the available literature, the use of a single case study and the data collected in the case study.

1.8 Structure

The structure of the thesis is as follows; the methodology used in completing the project is presented in chapter 2, chapter 3 presents the theoretical background and fundamentals which the report is based on. Chapter 4 is distributed to the case study of the report. The theory and findings of the case study is analyzed in chapter 5. A discussion of the results of the theoretical and empirical part of the thesis is found in chapter 6. Chapter 7 concludes the thesis.

2 Methodology

It is important to have a clear plan in order to achieve the objectives of a thesis and answering the research questions. This plan can be defined as a methodology and should fit the purpose of the project. This chapter describes, in detail, the methodology used in the completion of this thesis. Section 2.1 gives a brief overview of the methodology used. Section 2.2 introduces the concept of research methods and the differences in qualitative and quantitative research methods and data. In section 2.3 and 2.4 the literature study and the case study are presented, and how these methods were used in the thesis.

2.1 Methodology overview

Figure 2 gives the reader an illustrated representation of the research methods used in the completion of the thesis and how they are related to the Research Questions introduced in the previous chapter.

The methodology is twofold, containing a literature study and a case study. The literature study is used as a foundation of the thesis (theoretical background) and to answer research question 1,2 and partly 3. The case study, which is introduced in chapter 4, aims to apply the gathered information and insight from the previous steps, and apply it to in step 4.

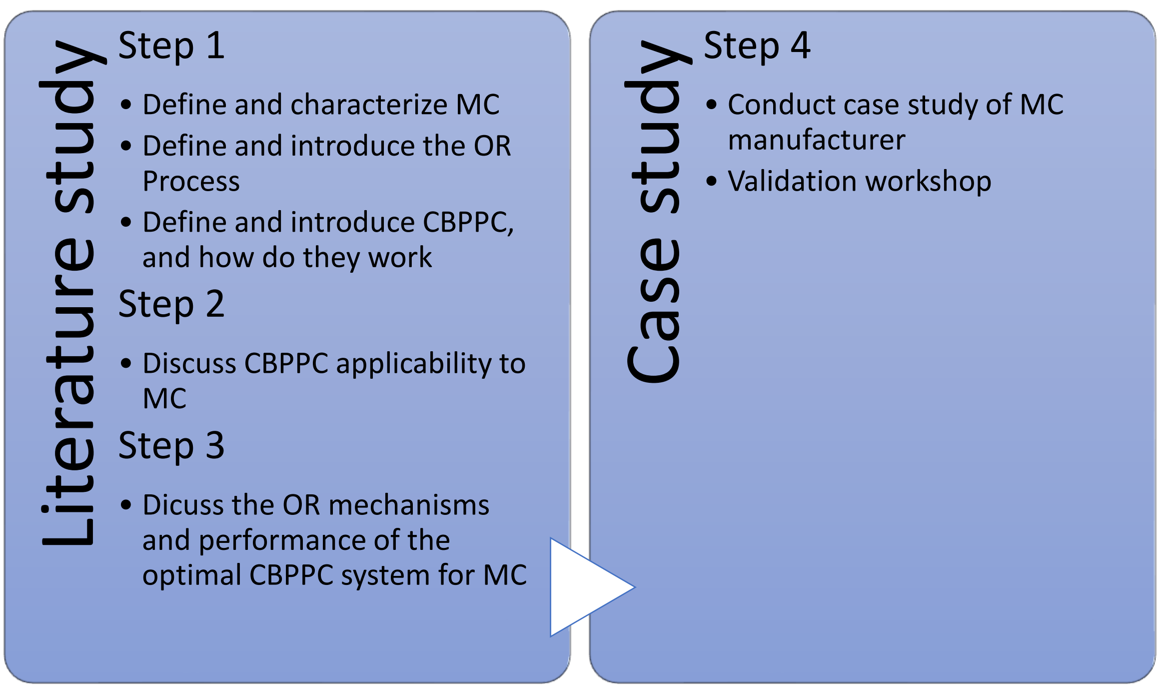

Figure 2 Methodology and research objectives

2.2 Research methods

A methodology is, according to Macquarie Dictionary, the science of methods (Mackenzie and Knipe, 2006). Somekh and Lewin (2005) defined a methodology as” the collection of methods or rules by which a particular piece of research is undertaken" and that a method is a research approach. So, the methodology is the collection of research methods or approaches used in the completion of a research work. Simply put, the methodology describes the approach to research a particular issue, situation, etc. (Iakymenko, 2018). These research methods are many and are often divided into two types; qualitative and quantitative research methods.

Quantitative research methods are used to quantify a problem or issue, generating numerical information of the research objective. Quantitative data is measurable, and the methods uses larger samples of information in order to formulate reliable facts or to uncover patterns (Guthrie, 2010).

Qualitative research methods produce information that often is represented in words, unlike quantitative data. Qualitative research methods are subjective and often involve describing, classifying or interpreting information, data or observations (Guthrie, 2010). An example of a qualitative research method could be a literature study, interviews, observations, or even a case study.

Table 1 Qualitative vs Quantitative research

Quantitative research methods	**Qualitative research methods**
Numerical	Non-numerical
Objective	Subjective
Data collection is rigid and structured	Data collection is flexible and subjective
Analysis of data	Analysis and interpretation in parallel with data collection
Usage of statistical analysis techniques	Non-standard analysis techniques

Table 1, which is inspired by Guthrie (2010), presents the characteristics and differences between quantitative and qualitative research methods.

2.3 Literature study

In her book, Ridley (2012) discusses the many meanings and scopes of a literature review and states that a literature review for a MSc thesis is: "Analytical and summative, covering methodological issues, research techniques and topics"

A literature review might consist of two literature chapters, one on methodological issues in the literature, which demonstrates knowledge of the advantages and disadvantages of methods used. And the other chapter on theoretical issues relevant to the topic or problem (Ridley, 2012).

A literature review can cover historical background, overview of current context, relevant theories, terminology and definitions. It can describe challenges, literature gaps, or underline the significance of a issues or problem (Ridley, 2012).

Simply put, the literature review encompasses as much literature as possible around a subject. A literature study on the other hand, is an analysis of a published body of knowledge. In other words, a literature study is not as comprehensive as a literature review. The literature study includes elements like literature searches, detailed review of selected research papers, writing up related work to your research.

In this thesis, a literature study was conducted, studying the topics of OR in MC production environments. The goal of the study was to identify a literature gap and to attempt to fill it.

2.3.1 Literature search

A literature search is "a systematic and thorough search of all types of published literature in order to identify as many items as possible that are relevant to a particular topic" (Gash, 1999).

The literature searches are a tremendously important part of any research, as it forms the basis of your reading and thus the basis for your product, i.e. MSc Thesis. The literature search can have multiple purposes; like an exploratory literature search, literature searches to gain insight into the topic, terminology, methodology, previous work to avoid duplication, identifying key authors, journals, and literature gaps (Ridley, 2012).

2.3.2 Search types

After an exploratory literature search key words on the topic are identified and a more focused literature search can be conducted, i.e. Keyword searches. In literature different terminology tends to be used to describe the same thing. This makes literature searches more difficult, and since no common agreement on the meaning of words and phrases exist keyword searches with synonyms and alternative descriptions is used in the searches (Ridley, 2012).

The table under (Table 2) presents key words I have used in my keyword searches and which research question they are related to. The key words are used by themselves and in combination with other keywords and synonyms using the Boolean logic.

Table 2 Literature searches based on keywords and research questions

Research question	Keyword set 1	Keyword set 2
What are the main characteristics of MC?	MTO Make to order Mass customization Customization High variety High mix	Definition Types Classification Typology Taxonomy Levels Production Strategy Manufacturing Continuum
What CBPPC systems are applicable to MC?	Production control Production planning Planning methods	Definition Explanation
		Types characteristics Classification KANBAN CONWIP POLCA COBACABANA
		Mass customization Customization High variety High mix
How does the CBPPC systems OR mechanisms affect MC**?**	KANBAN CONWIP POLCA COBACABANA	Order release Order release mechanism

2.3.3 Search engines

Oria, NTNUs online literature search engine, has been the most used search engine in my research. Oria can be used to find printed and electronic collection of books, articles, journals, thesis's, music, films, and more from journals like the "International Journal of Production Economics", "Journal of Manufacturing Systems" and the "International Journal of Production Research".

Table 3 Oria search engine. Table translated from: https://bibsys-almaprimo.hosted.exlibrisgroup.com/primo-explore/search?vid=NTNU_UB&sortby=rank&lang=no_NO

To find	Use	Example
All words		Internet privacy Larsen
Phrase	“”	“wave energy”
Words starting with	*	Industry*
At lease on of the words	OR	“child protection” OR “child welfare”
Exclude words	NOT	Music NOT Blues
Group Keywords	()	(buprenorphine OR methadone) treatment

Other than Oria, Google Scholar was used when a broader or more exploratory search was appropriate. Oria gives the user, a NTNU student, accessible and available sources, while Google Scholar gives the used all results, even the ones you don’t have access to.

2.3.4 Execution of literature study

This section is dedicated to the description of the execution of the literature study conducted in the completion of the thesis.

The selection process of the literature to be read, based on the literature searches, was as follows:

1. Execute literature search
2. Choose literature based on relevance of title. Does the title include key words?
3. Is the journal or publication credible? If not, discard it.
4. Read the abstracts of the chosen literature in order to determine if the literature was worth reading. If the article still seems relevant, read it. If else, discard it.

Table 4 presents the identified key books, articles, journals and authors from the literature searches.

Table 4 Key information from literature search. Inspired by Ridley (2012)

Key books/articles which I have identified for my research	- Card-Based Control Systems for a Lean Work Design: The Fundamentals of Kanban, ConWIP, POLCA, and COBACABANA - Card-based production control: a review of the control mechanisms underpinning Kanban, ConWIP, POLCA and COBACABANA systems
Key journals which I have identified for my research	- Int. J. Production Economics - Int. J. Production Research - J. Manufacturing Systems
Important authors/researchers in my field	- Matthias Thürer - Mark Stevenson - Nuno Fernandes - Mark J Land

After reading the literature in detail, some notes were taken in order to extract key information and as to avoid having to re-read literature at later stages. A logbook was created in Microsoft Excel in order to keep all this information in one place (see Table 5,6 and 7).

Table 5 Logbook entry of literature searches

#	Date	Database	Search strategy	Search terms	Notes	Hits	Items selected	Comment
1	16.01.2019	Oria	Keyword search	“make to order” OR “Mass customi?ation” OR “High mix” OR “high-mix” OR “high mix low volume” OR “high variety” AND “order release” OR “order release methods” OR “planning methods” OR “order release mechanism”. From the last 10 years	Revised keywords, Two keywords	314	20	a lot on "WLC" and "flow shop"

Table 6 Logbook entry of chosen literature

#	Title	journal	author	year	Relevant?
1	Card-based delivery date promising in high-variety manufacturing with order release control	Int. J Production Economics	Thurer, Land, Stevenson, Fredendall	2016	yes

Table 7 Logbook entry of literature summarization

#	Title	Journal	Author	Year	Key words	Purpose	Methodology	Results	Conclusion
1	Enterprise Design for Mass Customization: the control model methodology	Int. J. Logistics	Alfnes & Strandhagen,	2000	Mass customization	Achieving mass customization (MC) is a challenge	Therefore, the Control Model (CM) methodology was applied to HÅG.	The result of the implementation of CM to HÅG was improved performance (sales volume, inventory turnover, delivery time and precision)	The CM is effective for creating flexible and competitive enterprises that provide MC-ability

First, I made a log entry of research searches (table 5), then a log of the chosen literature based on the title or suggested literature from supervisors (table 6), and in table 7 a summary of the literature.

2.4 Case Study

This section describes the case study and the case study methodology. Section 2.4.1 covers the case study design, the methodology is described in section 2.4.2, in the remaining sections data collection, structuring, analysis and validation is covered.

The case study enables the researcher to explores and investigates a real life phenomenon by closely examining data and detailed analysis of it (Zainal, 2007). Karlsson (2010) stated that a case study is a description of a phenomenon, event or organization. Another author describes the case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin, 1984).

Yin (1984) classifies the case study research method into three categories; (1) *explanatory* which examines data closely in order to explain it, (2) *exploratory* which the name suggests is aimed to explore a phenomenon, and (3) a *descriptive* case study. The descriptive case study has the goal of describing a phenomenon as it occurs.

Zainal (2007) describes the advantages and disadvantages of the case study in his paper. One of these advantages is the examination of the data or phenomenon in the context of its use, i.e. where the activity takes place. The case study also allows for qualitative and quantitative modes of analyses, although this is not always the case. In addition, the case studies shed light on the real-life complexities of phenomenon which might not be captured by other research methods. Disadvantages of case studies are lack of rigor, scientific generalization, and producing a massive amount of data.

Yin (1981) stated that "the use of case studies allows one to examine the knowledge utilization process, and ultimately to recommend and design appropriate policy interventions". In other words, the assessment in a case study can be used to recommend and design change. Yin (1981) also state that a single-case design, like in this thesis, "can be used to test theory, especially in a disconfirming role". This is relevant to this thesis as it seeks to investigate the applicability of CBPPC systems to MC manufacturing, i.e. the case study might reject the applicability of some or all CBPPC systems.

2.4.1 Case study design

Yin (2017) recommends focusing on five important components when designing a case study: "the study's questions, its propositions, if any, its unit(s) of analysis, the logic linking the data to the propositions, and the criteria for interpreting the findings".

a) The study's *questions* are the most relevant clue as to what research strategy to pursue and is therefore important to formulate precisely. Precise and accurate study questions foster the correct use of research methods (Yin, 2017). For this thesis, the study questions are presented in section 1.4.

b) The *propositions*, if any, of a case study directs attention towards something. A "misplaced" proposition can derail the study, by studying the wrong thing or something completely irrelevant. Moreover, a study is more likely to stay within feasible limits if it contains specific propositions (Yin, 2017). The propositions of the case study completed in this thesis are workshops, informal conversation, direct observations

c) The selection of the appropriate *units of analysis***,** relate to the research questions. If the questions are vague and numerous, it may not favor any unit of analysis over the other. In turn, a mixture of uninterchangeable units, or indicators, are measured which may result in useless data and trouble when conducting the case study (Yin, 2017). In order to answer the Research Questions, the unit of analysis of this case study is the characteristics of screen production, and the challenges they may have. The characteristics and challenges are analyzed in relation to the CBPPC systems and their applicability

d) The fourth and fifth components of the case study is *linking data to propositions*, and *criteria for interpreting the findings.* The two components represent the analysis stages of a case study and is influenced by the case study design of the previous three components (Yin, 2017). Linking data to propositions, i.e. the methodology used in the analysis of the data collected in the case study, is explained in section 2.4.5. While the interpretation of the findings is found in chapter 4 and 5.

2.4.2 Case Study method

The methodology used in the case study mainly depends on the type of data and analysis used in the research. In the thesis the research design for the case study is considered to be primarily qualitative empirical data, since the study is related to a case company. Thomas (2003) states that the analysis of qualitative data encompasses a wide variety of empirical data from personnel interviews, observations, history, interaction, etc. This empirical data is often expressed verbally, which can create a broad understanding of relationships and complex systems (Ellram, 1996).

For this thesis the case study methodology was comprised of workshops, direct observations and informal conversations with production personnel while working. The case study approach is considered as an examination of a MC manufacturer and the possibility of CBPPC applications. The approach selected is a single case study of the manufacturing system of product type *Screen*. The main objective of the case study is to assess the applicability of CBPPC systems in MC manufacturing.

In case studies there are six sources to data, according to Yin (1994); interviews, participant observations, direct observations, documents, physical artifacts and archived records. The collection of data and evidence is described in the next section.

2.4.3 Data Collection

There are two types of data sources, primary and secondary data. The primary data are original in character, i.e. collected for the first time, while secondary data has already been collected (Kothari, 2006). Data (primary and secondary) can be further divided into qualitative and quantitative data, which is described in section 2.2.

The nature of primary and secondary data determines the sources of these data. Primary data, which is fresh data, is collected from interviews, surveys, observations and questionnaires. And the secondary data sources are books, literature, documents, e-mails, business records, etc. (Pawar, 2004).

2.4.3.1 Study propositions

In this section the study propositions of the case study are presented, like stated in section 2.4.1 b).

Direct observations and informal conversations

Direct observations are a primary and qualitative data source, like stated in section 2.2 and 2.4.3, and is according to Kothari (2004) a scientific tool and data collection method when observations serve a research purpose and the observations are systematically planned, recorded, and controlled.

While working a summer job in the screen production fabric department at the case company I collected data using a direct observational approach. The goal of this was to learn the ins and outs of the production while also working there. Moreover, informal conversations with employees provided more data, insight and enabled me to control the data collected through observations.

Direct observations become a research and data collection method when it is systematically completed and with intent, this is not the case with informal conversation. It is possible to learn, obtain information, collect data, etc. from informal conversations but the nature of the informal conversation disables it from becoming a systematically planned, recorded and controlled research method.

Workshops

A workshop is "an arrangement whereby a group of people learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-specific issue". Workshops used as a research method focuses on the context of the case using a workshop format as a research methodology. The workshop tries to achieve two things; (1) fulfill the participants expectations in their own interest, and (2) fulfill the research purpose, which is reliable and valid data in the research context (Ørngreen and Levinsen, 2017).

Two workshops were completed, where key personnel from the production management was presented their production system to the workshop members, with the goal of acquiring knowledge on HD Sol screen production system, making a VSM model and use this to locate challenges that HD Sol may be facing. MFM lead the workshops, as they have their own project in parallel with mine.

From these workshops qualitative and quantitative data was collected. Qualitative data was acquired in the form of verbal descriptions of the production of screen products, and quantitative data in the form of processing and waiting times between production processes and steps.

A third workshop was conducted with HD Sol and myself, with the purpose of presenting CBPPC systems to the production management, discussing their capabilities, and their applicability to MC manufacturing and HD Sol. Qualitative data on CBPPC applicability to MC manufacturing was collected, and laid the foundation for a TO-BE model of the screen production system at HD Sol.

2.4.4 Data structuring

The use of multiple data sources increases the credibility of said data and is one of the hallmarks of the case study research method (Patton, 1990, Yin, 2003). These sources are mentioned in the previous section (2.4.3). Baxter and Jack (2008) stated that the "convergence [of data from multiple sources] adds strength to the findings as the various strands of data are braided together to promote a greater understanding of the case". Although this is a great advantage of the case study, it can become a disadvantage when the amount of data exceeds a certain limit. To mitigate this disadvantage and bring order to the data collection Baxter and Jack (2008) suggest that structuring the data in a database is an effective approach to manage the volume of data.

Structuring the data and data sources, like notes, documents, narratives, photos, audio files, drawings, etc., improves the reliability of the case study, and enables the researcher track, organize and access it with ease (Baxter and Jack, 2008).

For this thesis, data collected in relation to the case study was stored and organized in computer-files, photographs and folders in the NTNU OneDrive (and online cloud-based storage application). Notes from workshops, observations, informal conversations, etc. that were taken with pen and paper was either scanned and uploaded or written in a word-file before being uploaded to OneDrive.

2.4.5 Data analysis

According toYin (2003) there are five techniques to analyze data in a case study research; pattern matching, linking data to propositions, explanation building, time-series analysis, logic models, and cross-case synthesis. He also recommends returning to the propositions in the analysis of a case study, in order to focus the scope of analysis towards to research questions. Another benefit of this practice is investigating rival propositions and alternative explanations. Lastly, addressing, accepting or reject the propositions in the analysis strengthens the confidence in the findings (Yin, 2003).

In the case study of HD Sol, the first objective was to collect data on their screen production and locate any challenges they faced. This was accomplished by the analysis of the data, structured as a VSM model. It showed high production lead time variations, which lead to my interest in OR methods and the possibility to mitigate this variation using CBPPC systems.

From here the case study's research objectives was to investigate and validate the capability and applicability of CBPPC systems to a MC manufacturer using HD Sol as case company. This was accomplished by collecting data on the characteristics of HD Sol, cross-matching them with characteristics of CBPPC systems, and having HD Sol reject or confirm the applicability of the CBPPC systems. Based on the findings a future state model of the screen production system is created.

2.4.6 Reliability and Validity

Reliability is the idea or embodiment of replicability or repeatability of results (Golafshani, 2003). Meaning that a result in a case study is reliable if the case study is repeatable and produce the same result. Validity on the other hand, described by Joppe (2000) "determines whether the research truly measures that which it was intended to measure or how truthful the results are".

In order to prove the reliability and validity of the data and research the triangulation method was used, which is "typically a strategy (test) for improving the validity and reliability of research or evaluation of findings" (Golafshani, 2003).

For this thesis multiple sources were used as a triangulation method. The data collected in the case study came from the workshops with HD Sol, the reliability and validity of this data comes from the collective perception, observation and experience of the production management and me. In other words, using multiple sources strengthen the validity and the reliability of the findings.

3 Theory

This chapter introduces the reader to the theoretical background of the thesis, i.e. Production Strategies, MC, the processes of OR and PPC systems. The theory is analyzed in chapter 5.

3.1 The Supply Chain

The supply chain is the system between actors, departments, information, people and resources involved in providing a service or product to a customer. The supply chain can be divided into two; (1) the part that responds to a customer order and (2) the part that anticipates customer orders. The former is called “PULL” and the latter “PUSH”. Figure 3 represents the division of push and pull processes in the supply chain. This boundary is also called the Customer Order Decoupling Point (CODP) (Chopra and Meindl, 2016).

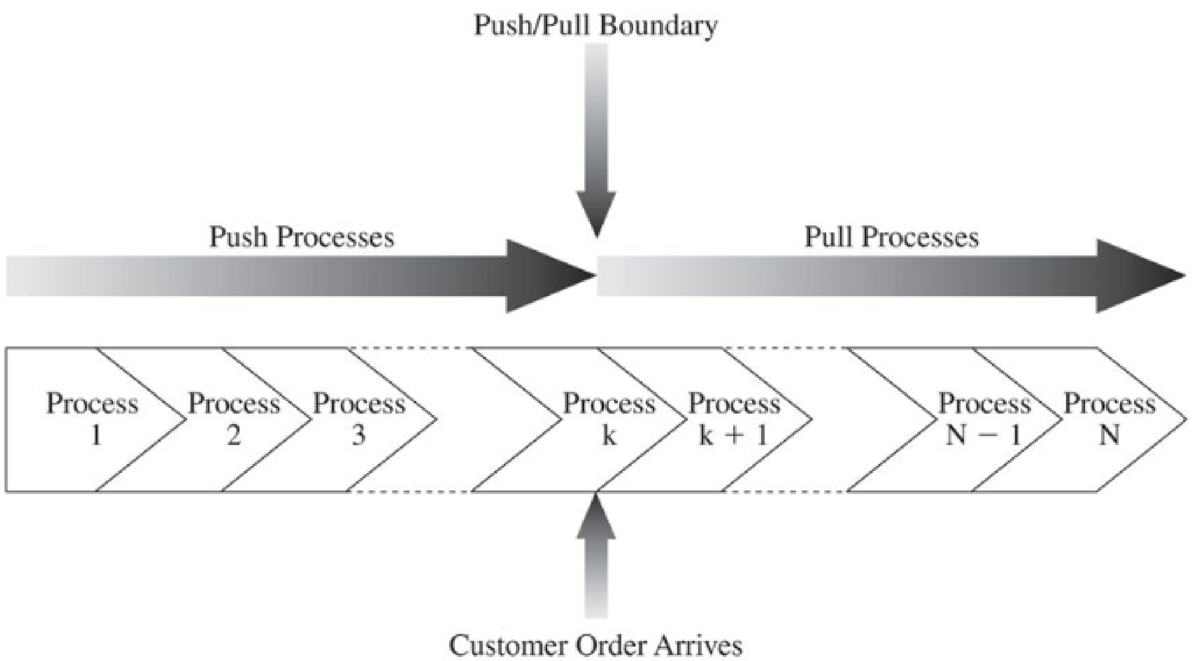

Figure 3 Push/Pull view of Supply chain processes (Chopra and Meindl, 2016)

The figure places the CODP at ‘Process k’, i.e. where the customer order arrives. All previously completed processes (k-1, -2, -3, etc.) in advance of the CODP are push processes. The pull processes are completed after the arrival of customer orders. Push processes will reduce lead time and are based on anticipation of customer order, while pull processes are based on actual customer orders.

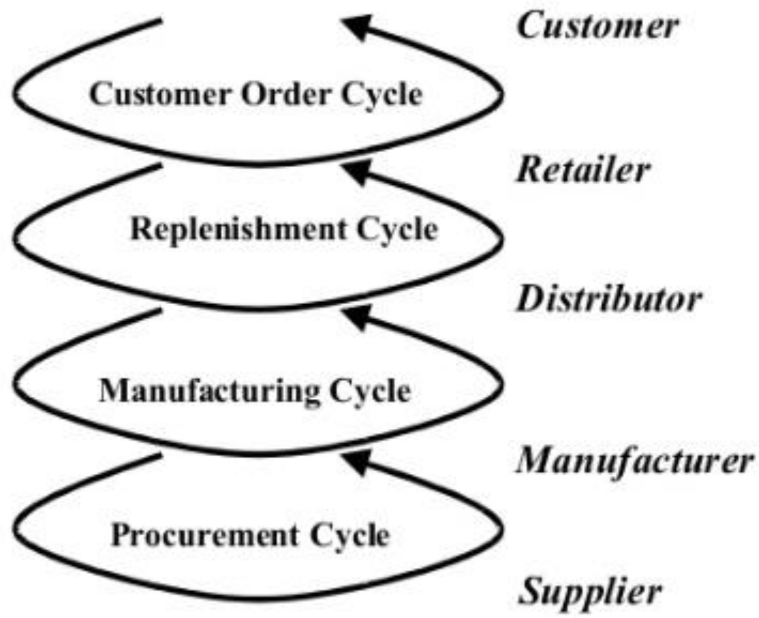

Figure 4 Cycles of the Supply Chain (Chopra and Meindl 2016)

Figure 4 presents the actors involved in supply chains, and the cycles between them. The manufacturer is the link between supplier and distributor, and is affected by all actions involved in the manufacturing and procurement cycles (Chopra and Meindl, 2016).

In this thesis the I take a look at the manufacturer and the manufacturing cycle. In the next section different manufacturing strategies are presented.

3.2 Manufacturing strategies

In order to achieve fast deliveries, provide satisfaction to customers and gain a competitive edge over competing companies, following a winning manufacturing strategy is paramount. Chapman et al. (2017) present in their book “Introduction to Materials Management” the four most mentioned strategies in literature; Engineer-to-order (ETO), Make-to-order (MTO), Assemble-to-order (ATO) and make-to-stock (MTS).

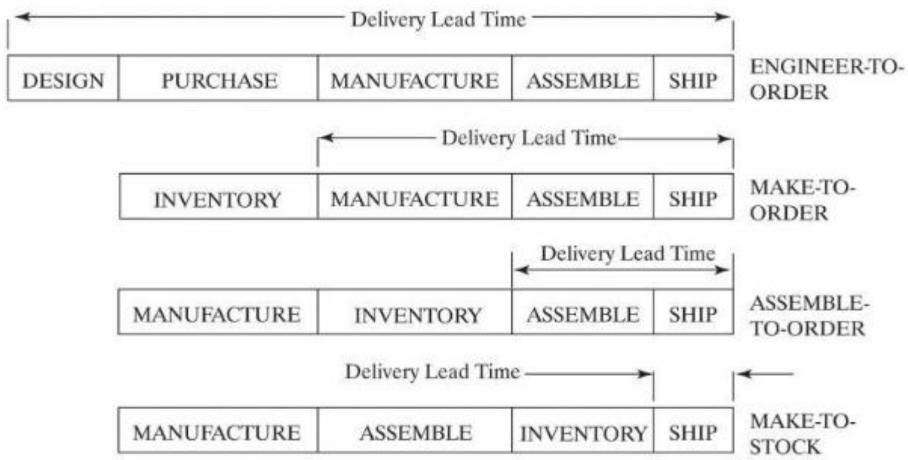

Figure 5 Manufacturing strategy and lead time (Chapman, Arnold et al. 2017).

Figure 5 presents these manufacturing strategies from the perspective of lead time, in decreasing order from top to bottom where ETO has the longest lead time and MTS has the shortest. The figure also depicts the supply chain of the manufacturing strategies.

The CODP is the distinctive feature of these strategies and is what makes these lead times possible. In ETO production for example, there can be no push activities, since the products or services needs to be designed to customer demand and needs. Thus, the CODP is before the Design phase is this ETO supply chain (Chapman et al., 2017). Figure 6 provides a better representation of the CODP's of each manufacturing strategy

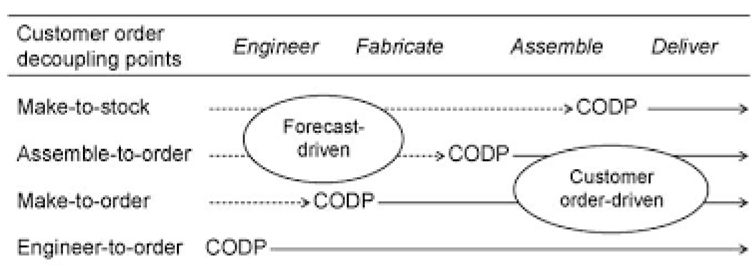

Figure 6 Customer Decoupling Point (Chapman et al., 2017)

Engineer to Order (ETO) manufacturing involves that the whole supply chain, i.e. Design, Purchase, Manufacturing, Assembly and Shipping is initiated after receiving a customer order. Meaning that the ETO strategy is purely a pull strategy, this also means that one can expect the longest lead times from ETO manufacturing (Chapman et al., 2017).

Make to Order (MTO) manufacturing, like with ETO, is customer driven, but with the distinction that the Design is already in place, thus making the procurement phase part of the push part of the supply chain. The CODP is MTO manufacturing is located between inventory and manufacturing. Lead time is reduced since there is no design time and raw materials needed are held in inventory in anticipation of customer demand (Chapman et al., 2017).

Assembly to Order (ATO) means that the manufacturing part of the supply chain is completed, and the finished components and parts are all stored in anticipation of customer demand. Since assembly and delivery is initiated by demand, the lead time is reduced compared to ETO and MTO (Chapman et al., 2017).

Make to Stock (MTS) is the manufacturing strategy with the shortest delivery lead time. This is made possible by forecast based manufacturing, i.e. producing in anticipation of customer demand. Here finished products are stored and delivered when a customer order is received. This form of manufacturing is well suited for mass production (Chapman et al., 2017).

Another manufacturing strategy that isn't mentioned too much when talking about manufacturing strategies is **Configure to Order (CTO).** It might look identical to MTO based on figure 5 and 7, but this form of manufacturing means that the customer can configure the product based on provided options. This means that each customer and order may be entirely different each time. The configuration will take place when the customer order is placed. The delivery lead time is reduced because there is no design phase, and all the configuration options already is available in inventory (Chapman et al., 2017). CTO is similar to MC, which is described next.

Figure 7 Configure to order (Chapman et al., 2017)

3.3 Mass Customization (MC)

Production has seen a shift from repetitive mass production, towards customized products and services, this in turn led to the introduction of MC. The broad definition of MC is that it offers customized goods and services at mass production costs (Pine and Davis, 1993, Da Silveira et al., 2001, Stump and Badurdeen, 2012). From what is known about manufacturing strategies, mass production is well fit for MTS manufacturing, while MTO is a better fit for customized products. This creates a paradox in MC, between mass production and customizable goods. The MC manufacturers can achieve these prices and costs by operating with flexible and highly responsive production systems (Fogliatto et al., 2012).

3.3.1 Classifications

MC is debated by authors, and many classifications and typologies are available in literature (Duray et al., 2000, Gilmore, 1997, Lampel and Mintzberg, 1996, Pine and Davis, 1993). Some of these are presented in figure 8. The table list the different MC approaches, strategies, stages and types in relation to the customer involvement in the customization and the supply chain. It's safe to say that MC is a broad term, and authors present narrower terms of a *MC-spectrum*.

MC generic levels	MC approaches	MC strategies	Stages of MC	Types of customization
8. Design	Collaborative; transparent	Pure customization		
7. Fabrication		Tailored customization		
6. Assembly		Customized standardization	Modular production	Assembling standard components into unique configurations
5. Additional custom work			Point of delivery customization	Performing additional custom work
4. Additional services			Customized services; providing quick response	Providing additional services
3. Package and distribution	Cosmetic	Segmented standardization		Customizing packaging
2. Usage	Adaptive		Embedded customization	
1. Standardization		Pure standardization		

Figure 8 Generic levels of mass customization (Da Silveira, Borenstein et al. 2001)

Gilmore (1997) presented in his paper "the four faces of mass customization" four approaches to MC. Namely, collaborative, transparent, cosmetic and adaptive in order of level of customization. Lampel and Mintzberg (1996) outlined five MC strategies based on the level of customization, ranging from pure customization to pure standardization. Five stages of MC was covered by Pine (1993): customized services (standard production, customized marketing), embedded customization (customer customize production after received), point-of-delivery customization (customization at point of sale), providing quick response, and modular production (Products and services customized using standard components). Spira (1993) developed a typology similar to Pines' five stages, i.e. four types of customization: assembling standard components into unique configurations, performing additional custom work, providing additional services, and customizing packaging. More classifications of MC and Customization are presented in literature (Alford et al., 2000, MacCarthy et al., 2003, Ross, 1996).

The type of MC production and customization I'm interested in in this thesis, and that is covered by the case study, is customization in the Manufacturing stage of the supply chain. This means that the product design is ready, changes can be made, and the customer can customize the product using standard components, similar to CTO manufacturing mentioned in the section on manufacturing strategies.

3.4 Lean Manufacturing (LM)

Lean manufacturing was developed by automobile manufacturer Toyota, and is originally called the Toyota production system (TPS), and can be described as a flexible system which produce high quality services and production using minimal resources (Stevenson, 2014). This is achieved by following the five principles that encapsulate the LM approach (Stevenson, 2014):

1. Identifying customer values
2. Focusing on processes that create value
3. Eliminate waste to create flow
4. Produce only according to customer demand
5. Strive for perfection

Waste reduction and continuous improvement are the hallmarks of LM. In Lean theory there are 7 types of waste; Transport, Inventory, Motion, Waiting, Over-production, Over-processing, and Defects.

Reduction in these wastes will according to Lean result in better flow and productivity (Stevenson, 2014, Chapman et al., 2017). Other LM traits are (Stevenson, 2014):

- Cellular layout
- Visual operation controls
- High quality processes and output
- Minimal inventory
- Pull production
- Quick equipment changeovers
- Small lot sizes
- Use of interdisciplinary teams
- Lean culture
- Takt time
- Heiljunka

3.5 Value Stream Mapping (VSM)

Value Stream Mapping is a LM tool used to map and understand material and information flow of value-adding and non-value adding processes in a value chain. The VSM provides an understanding of the current state of a system and can be used to develop a future state that reduce wastes and non-value adding processes (Chapman et al., 2017).

Stevenson (2014) describes in his book "Operations Management" VSM as "a visual tool to systematically examine the flow of materials and information".

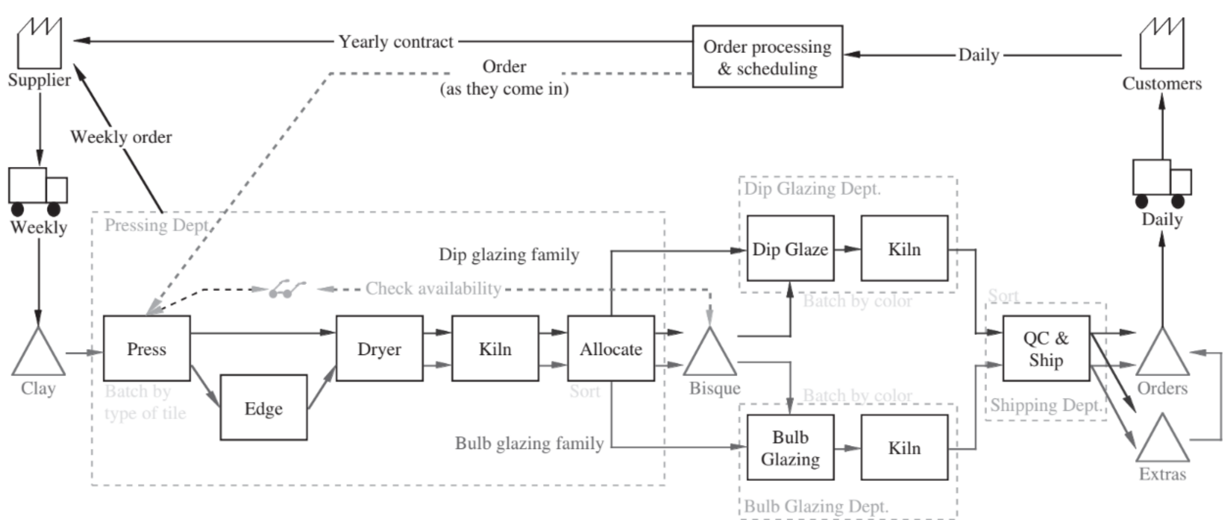

Figure 9 Example of Value Stream Model (Lander and Liker, 2007)

Figure 9 gives a visual representation of how a VSM can look. The model maps actors (supplier, customer), operations (transportation, press, dryer, etc.), inventories (triangles), material flow (solid arrows), information flow (dotted arrows), departments (dotted boxes) and the frequency (weekly, daily, yearly or as they come).

3.6 Job shops

Job shops are manufacturers of job production, i.e. customized manufacturing, of customer orders or batch jobs. Job shops can be described as highly flexible both in production and in volume, and the use of multipurpose machines make them robust to machine downtime and provides low obsolescence. On the other hand, high flexibility, variability and production mix provides a complex planning and scheduling problem. Low capacity utilization is also seen as a disadvantage in job shops (Stevenson, 2014).

MC job shop PPC is, as stated previously, the center-piece of this thesis. The production control of job shops consists of three parts; due date setting, order release (input control), output control (Thürer et al., 2018c, Bertrand and Wortmann, 1981). Order release and Production planning and control is presented in the next two sections of this chapter.

3.7 Order Review and Release

Order review and release (Bergamaschi et al., 1997, Melnyk et al., 1988, Melnyk and Ragatz, 1989), is one of the main functions of PPC (Bertrand et al., 1986, Zäpfel and Missbauer, 1993). When order release control is applied, jobs do not enter the shop floor directly – they are retained in a pre-shop pool and released in accordance with certain performance targets, e.g. to restrict the level of WIP and/or maximize due date adherence. In other words, order review and release is the process of controlling the order from planning to releasing it to the shop floor (Melnyk et al., 1988).

Thürer et al. (2018c) showed through simulations that order review and release has a strong impact on the throughput time of the shop floor, a weak effect on the total lead time, and a weak effect on the timing of jobs on the shop floor through the sequencing of jobs. This is due to the use of PSP, where the total lead time is not affected that much on the grounds that it is in the PSP, but the time on the shop floor is greatly reduced.

3.7.1 The Process

Order release is an approach to controlling the shop floor. When order release is applied to a production system, the work orders will not enter the shop floor on arrival. Instead, orders will be “screened” and picked/released in order to the control shop floor and to meet certain production performance measures, such as due date adherence, throughput time, WIP levels, etc. (Thürer et al., 2017b).

The order release process consists of three phases; (1) Order entry, (2) pre-shop floor, and (3) order release.

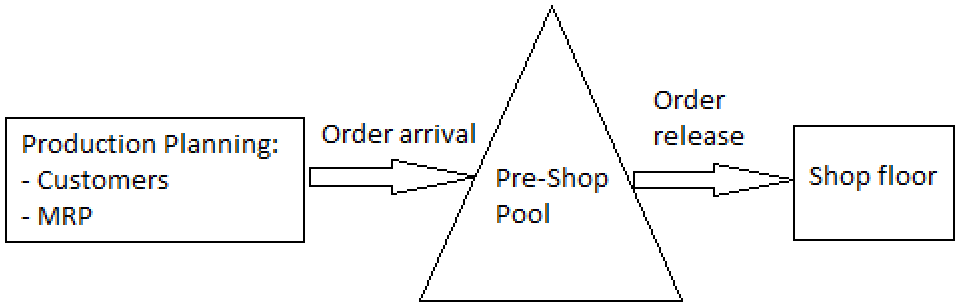

Figure 10 The Order Review and Release Process. Inspired by Melnyk and Ragatz (1989)

OE – Order entry: In the order entry phase, the production manager determines which orders is accepted or not. After an order is accepted it is backlogged into the PSP.

PSP – Pre-shop pool: When an order is backlogged in the PSP, the most important steps towards controlling the shop floor can commence. The PSP decouples the order planning system from the shop floor. Three important aspects with the PSP and control of the shop floor are the *timing convention*, the *triggering mechanism*, and the *dispatching rules* (Melnyk et al., 1988).

The timing convention of the PSP controls the **when**, which can be continuous or periodic. The triggering mechanism controls **when** an order is released, and like the name suggests is triggered by an "event", for example that an order has been completed. The dispatching rule determines **which** order is released to the shop floor when the order release is triggered (Melnyk et al., 1988). Dispatching rules comes in many different forms, like Earlies Due Date (EDD), shortest processing time (SPT), First in First out (FIFO) etc. (Dominic et al., 2004).

OR – Order release: In the order release phase, the shop floor has triggered a release mechanism and an order is released to the shop floor based on the selected dispatching rule. The performance of the order release in job shops is according to Land (2006) based on two criteria; (1) a timing function, in order to meet due-dates, and (2) a load balancing function, to balance work between workstations on the shop floor (Thürer et al., 2012). Based on these functions there are two decisions to be made when designing the order release mechanism of your PC; (1) the timing (periodic or continuous), (2) the order sequencing and selection rule.

Continuously order release, where order release can take place at any time, has in previous studies been shown to outperform periodic order release (Sabuncuoglu and Karapınar, 1999, Thürer et al., 2012).

3.8 Production planning and control systems

Production Planning and Control (PPC) systems are used in order to meet high expectations and customer demand and gain a competitive edge in a highly competitive manufacturing environment. When talking about PPC systems, materials requirements planning, demand management, capacity planning, scheduling and sequencing of jobs are typical functions used to reduce WIP, shop floor throughput time (SFTT) and lead time (LT). The right PPC system might improve responsiveness, delivery date adherence and flexibility, and the choice of PPC system is therefore an important strategic decision (Stevenson* et al., 2005).

Production control in job shops that produce customized products to order is very challenging since finished goods cannot be stocked in advance of demand and detailed order specifications, e.g. processing and set-up times, are often uncertain as it may be the first time that an order has been placed. This makes many approaches to PPC presented in the literature unfeasible (Thürer et al., 2016a). In general, few PPC systems – card-based or not – have been developed that are suitable for job shops (Thürer et al., 2014).

Few PPC systems exist for such production environments, i.e. MC production. An exception to this statement is Workload Control (WLC), which improves job shop performance. But in order to use WLC, production managers need to make complex calculations, which has proven to be a huge challenge, and often involved investments in software and hardware (Thürer et al., 2016a).

3.8.1 Card-based Production Planning and Control (CBPPC) systems

A subdivision of PPC systems are *Card-based* production planning and control systems (CBPPC), which use information on the systems output to control the input. This makes them input/output systems, which can be characterized as *pull* systems. The information on input and output from the system in a CBPPC system takes the form of a card, hence the name. This makes CBPPC systems a simple, visual approach to controlling manufacturing (Thürer et al., 2016b).

KANBAN (Shingo and Dillon, 1989, Sugimori et al., 1977), CONWIP (Spearman and Hopp, 1996, Spearman et al., 1990) and POLCA (Riezebos, 2010, Suri, 1998) are examples of CBPPC methods, and are widely implemented and used in practice (Krishnamurthy et al., 2009, Riezebos, 2010, Slomp et al., 2009, White et al., 1999, White and Prybutok, 2001) in order to manage flow of orders between workstations and trigger order release to the shop floor. This is due to their simple and visual means of control. However, although CBPPC systems are relatively straightforward to implement and are effective in stable manufacturing environments, Thürer et al. (2014) notes that their applicability to MTO job shops are severely questioned.

In later years COBACABANA (Land, 2009) has been introduced in literature, as a card-based version of Workload Control (WLC) and has been researched multiple times by Thürer and Stevenson (Thurer et al., 2016, Thürer et al., 2016b, Thürer et al., 2014, Thürer et al., 2018b, Thürer et al., 2015).

Table 8 Card-based Production planning and control characteristics

KANBAN	**CONWIP**	**POLCA**	**COBACABANA**
Pull	Pull	Push-Pull	Push-Pull
MTS	MTO	High mix, low volume	High mix (MTO)
Decentralized production control	Decentralized production control	Decentralized production control	Centralized production control
Steady demand	Steady demand		
Takt	Backlogging	Backlogging	Backlogging
Multiple set of cards, representing a certain item and quantity	One set of cards, representing available capacity.	Multiple loop cards, representing loop capacity	Two sets of cards; workload and order acceptance
Manages production sequence	Manages system WIP	Manages flow	Manages release of orders
Standardized production and products			

Four CBPPC systems, i.e. KANBAN, CONWIP, POLCA and COBACABANA, are examined in the remainder of this chapter, i.e. section 3.8.2, 3.8.3, 3.8.4 and 3.8.5. Table 8 provides an overview of their characteristics; a more comprehensive description is presented below. These CBPPC systems are analyzed (chapter 5) and discussed in chapter 6, specifically how applicable to the MC environment.

3.8.2 KANBAN

KANBAN is a lean method, created by Toyota as the Toyota production system (TPS), with the goal to balance demand with capacity. KANBAN is a visual system, that through KANBAN-cards signals free capacity then pulls work through the system rather than pushing work into the system when received. This way, Just-in-time production can be achieved thus reducing inventory (Shingo and Dillon, 1989, Sugimori et al., 1977).

There are four types of uses for KANBAN systems; Work-in-progress KANBAN, production KANBAN, Dual KANBAN, and Common KANBAN systems (Thürer et al., 2016b). These are outlined below.

Work-In-Progress KANBAN:

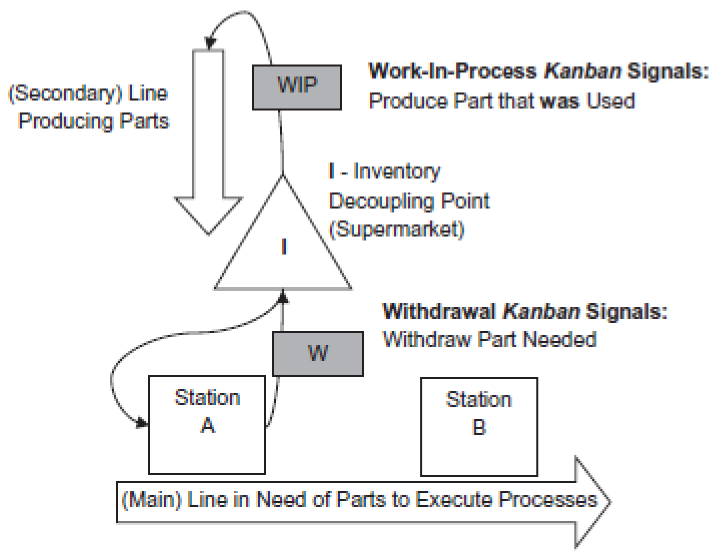

Figure 11 Work in progress KANBAN (Thürer et al., 2016b)

Figure 11 presents the work in progress KANBAN (WIP KANBAN) system. From the figure it is possible to see two KANBAN loops, decoupled by an inventory or *supermarket*.

Let's say 'item 1' is needed at 'station A'. A withdrawal KANBAN signal is then sent from 'Station A' to the supermarket, signaling the need for this particular item. The item is then sent from the supermarket to 'station A'. Now the supermarket has one less of 'item 1' in stock, therefor it will send a 'WIP KANBAN signal' to the production line of this product, resulting in the re-stocking of 'item 1' at the supermarket.

Production KANBAN:

Production KANBAN systems work similarly to the WIP KANBAN system, the only difference is that it doesn't signal what *was* used, but what *will* be used. In order to achieve this the 'production KANBAN signal' must be sent in advance. Figure 12 illustrates this. The figure shows the 'production KANBAN card' signaling that 'product 1' *will* be needed down the 'main line' and is produced and delivered to the supermarket in anticipation of the 'withdrawal KANBAN card' (Thürer et al., 2016b).

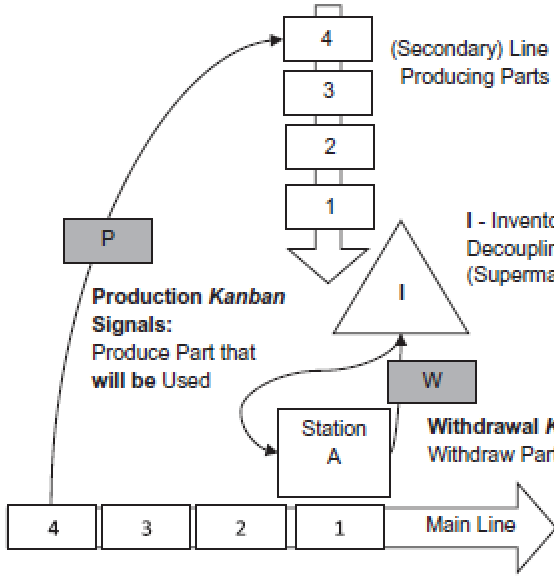

Figure 12 Production KANBAN (Thürer et al., 2016b)

Common and Dual-KANBAN:

When the above KANBAN Systems are used in coordinating a line between two stations one get the so called Dual-KANBAN system (Figure 13). In this system there are two KANBAN-loops and two WIP-inventories (Thürer et al., 2016b).

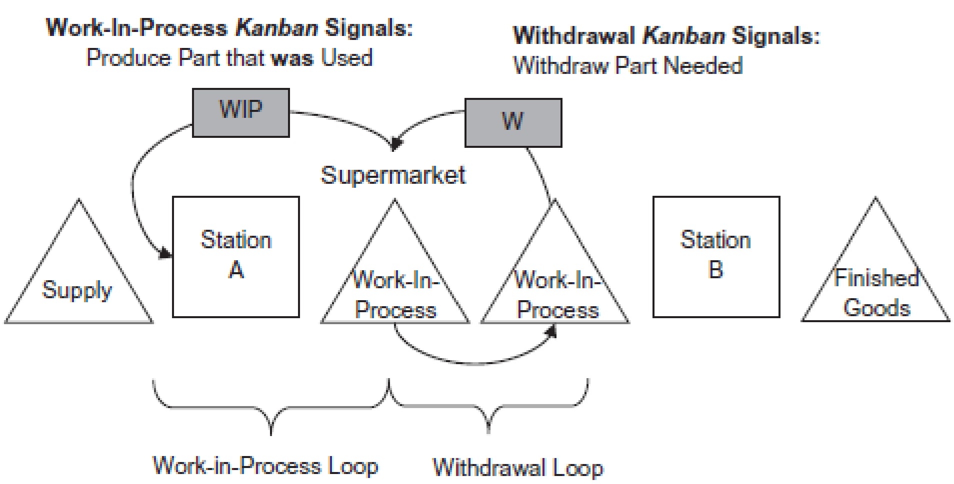

Figure 13 Dual KANBAN (Thürer et al., 2016b)

In this scenario the supermarket, or output buffer, is not necessary. By eliminating the supermarket, one also eliminate the need for a withdrawal KANBAN. Figure 14 depicts the resulting KANBAN system, i.e. the Common KANBAN system. In this system the common KANBAN can signal as a WIP KANBAN or as a Production KANBAN.

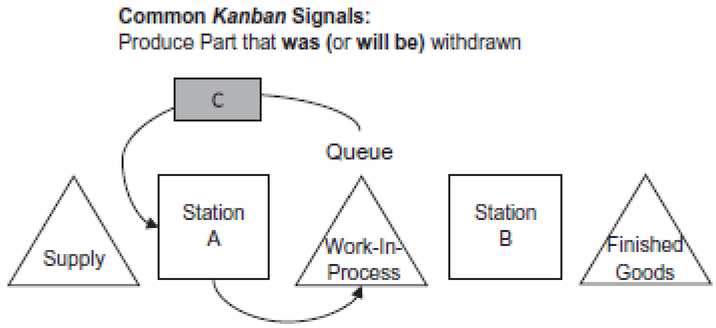

Figure 14 Common KANBAN (Thürer et al., 2016b)

3.8.3 Constant Work In Progress (CONWIP)

CONWIP was developed by Mark Spearman and Wallace Hopp in 1990 and is a pull production control system that controls the release of orders by an output and input control mechanism. By setting a limit on the WIP, or Work-in-Progress, no order will enter the production when the limit is met. When the limit is met, incoming orders will be backlogged into a pre-shop pool and released according to a dispatching rule when an order is completed (Spearman and Hopp, 1996, Spearman et al., 1990, Thürer et al., 2017a).

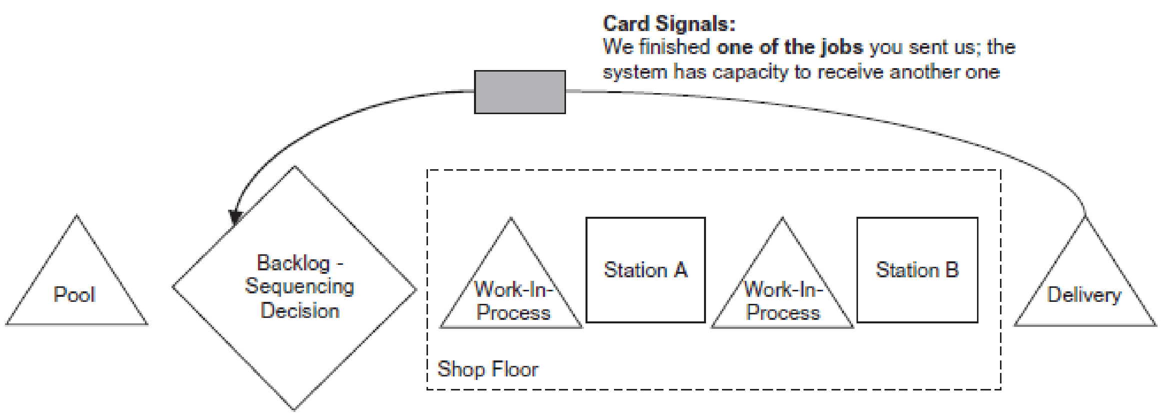

Figure 15 CONWIP (Thürer, Fernandes et al. 2017)

CONWIP is the simplest card-based PC system; when a job leaves the system a CONWIP-card is sent back to the backlog signaling free capacity. This CONWIP-card can now be attached to the next order in the backlog, and follows the order thought the production system.

While KANBAN systems used multiple KANBAN-loops, the CONWIP system is one single loop, making it simple, visual and easy to adjust by adding or removing CONWIP-cards in the loop. Another difference between KANBAN and CONWIP is the information the cards signal. CONWIP-cards only signal free capacity on the shop floor, thus making the dispatching rule in the backlog incredibly important to the sequencing of jobs (Spearman et al., 1990, Spearman and Hopp, 1996).

3.8.4 Paired-cell Overlapping Loops of Cards with Authorization (POLCA)

POLCA is different from other card-based systems because it combines card-based control with Material requirements planning (MRP) and is argued to be an alternative to KANBAN systems for Quick Time Manufacturing or time-based competition. The combination of MRP and card-based control makes POLCA a hybrid push-pull system (Riezebos, 2010, Suri, 1998).

POLCA is a push-pull system, which combines KANBAN and MRP in order to better match a high-variety production environment. POLCA is a response to the lack of fit between high-variety production and KANBAN control systems (Krishnamurthy et al., 2009).

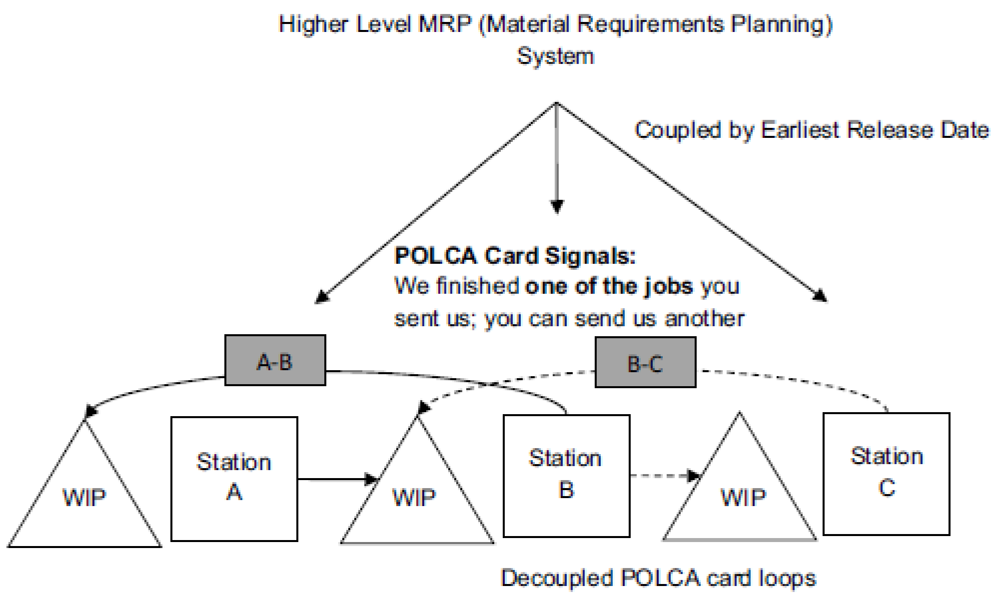

Figure 16 POLCA system (Thürer, Fernandes et al., 2017)

POLCA operates with paired stations, i.e. cells or loops, given their own POLCA-card (see figure 17). Figure 16 shows how POLCA works and is used as an example.

When the following conditions are met; (1) Station A is available, (2) 'Earliest Release Date' of the order has been reached, and (3) a POLCA A-B card is available, order processing can start. The A-B card is attached to the job-order and follows the order from station A to station B. At Station B, the same three conditions mentioned before need to be met in order to proceed. When the order has finished at station B, the card can be released from the order, sent back to station A. When moving to the last station, station C, the third condition is neglected, but the remaining two are still counting (Thürer et al., 2016b).

Advantages of POLCA:

1. POLCA cards signal capacity and is used in order to assure that jobs flow downstream without holdups in WIP. POLCA cards signal available capacity in downstream production cells.
2. By controlling the Cells, machines in the cells give room for workload adjustments. It also prevents buildup of WIP
3. POLCA cards flow in loops, which assures flow, and provides flexibility

4. POLCA cards provides information on the production routings, where the overlapping of loops signal that a cell is a supplier or customer of another cell.
5. By only returning POLCA cards after the downstream job in the cell is complete, POLCA ensures that workload on the shop floor don't build (Krishnamurthy et al., 2009).

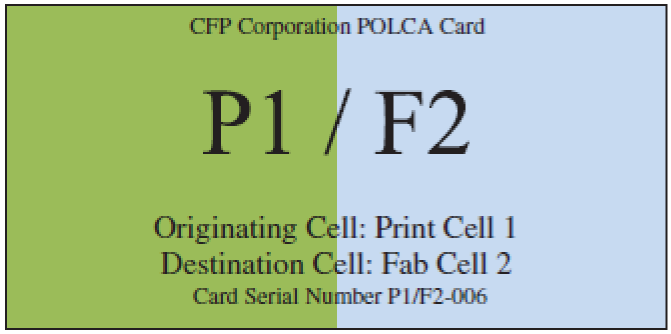

Figure 17 POLCA card (Krishnamurthy et al., 2009)

3.8.5 Control of Balance by Card Based Navigation (COBACABANA)

COBACABANA is a card-based version of the Workload Control (WLC) system, first introduced by Land (2009). WLC is a suitable control method for job shops, but calculations and high investment costs impedes its usability. Since COBACABANA replaces the calculations and software investments with a simple card-based control system, it makes for a suitable control system for job shops (Thürer et al., 2016b).

Figure 18 illustrates COBACABANA, where you have a 'planning table' and 'shop floor'. The planning table controls the workload on the shop floor using 'release cards', thus creating a centralized planning station. The centralized planner manages the workload by placing the released orders on the 'planning table' to visualize the jobs workload on the shop floor. When the orders are released to production, by the planner, an 'operation card', which follows the order, is sent to the shop floor and to the corresponding station. The size of the cards represents the workload of the operation. When the operation is complete, the operation card is returned to the planner. This way, the planning table is a complete representation of the workload on the shop floor and its stations (Thürer et al., 2016b).

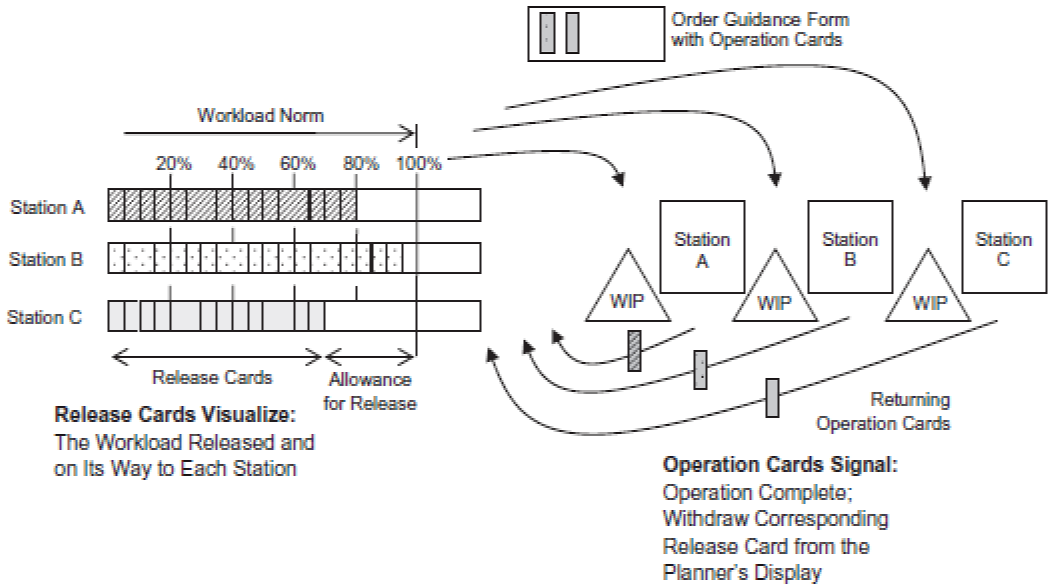

Figure 18 COBACABANA order release (Thürer et al., 2016b)

Orders are pooled in a pre-shop pool (PSP), where they are sequenced by a dispatching rule, e.g. earliest due date. When the planning table indicates free workload/capacity on the shop floor, the first order in the sequence is released, and the planner places the corresponding release card on the planning table for each station in the orders route. If the workload of an order, for any station, exceeds the 100% limit on the planning table, the order is retained in the PSP. When the orders are released, the corresponding operation cards follows the order to the shop floor. When an operation is completed, the operation card is returned to the planner, this signals that the planner can remove the release card for that operation on the planning table (Thürer et al., 2016b).

Order release can occur continuously or periodically with COBACABANA. For job shops the latter is preferred, while for flow shops the former is preferred. Thürer et al. (2012) proposed a starvation avoidance trigger, in order to avoid premature idleness at operation stations. This trigger releases jobs that can be processed directly to a station is starved regardless of a jobs load on the shop floor.

In a study by Thürer et al. (2016a) they proposed a customer enquiry management loop to compliment the order release loop in COBACABANA. Here, the PSP decouples the customer from the production, creating two card-loops, one for customer enquiry management, and one for order release. This is shown in figure 19 below. The customer enquiry management loop is a useful tool in managing the incoming orders, and declining jobs when a limit it exceeded.

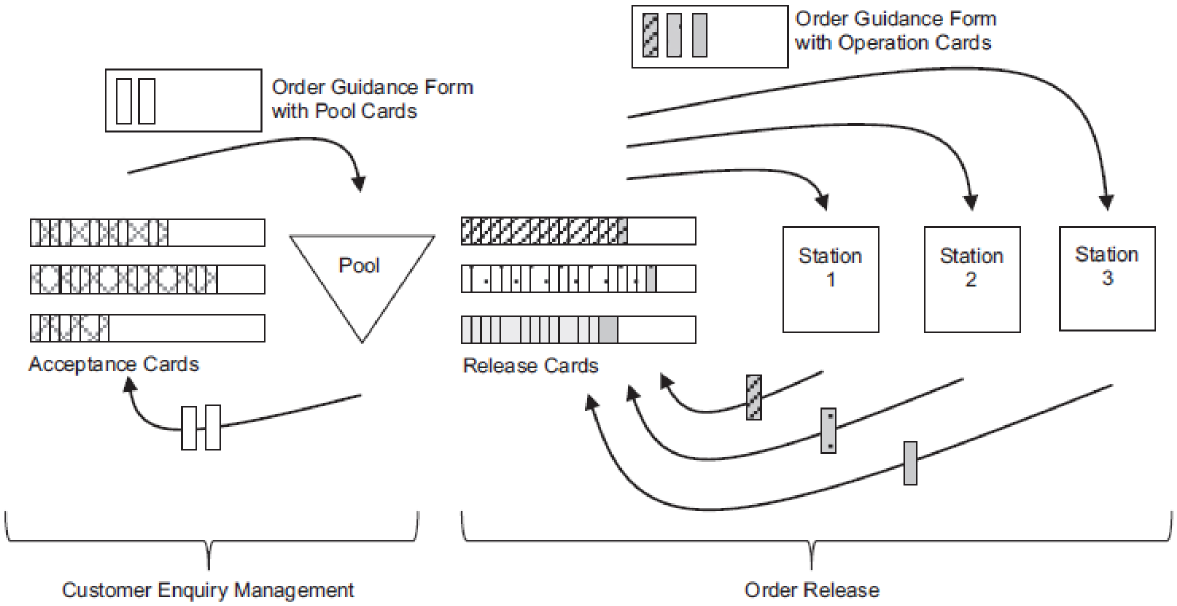

Figure 19 COBACABANA card loops between sales personnel and production planner (Thürer, 2016)

4 Case Company

This chapter is dedicated to the case study of a MC manufacturer, HD Sol, which will be introduced in section 4.1, then a AS-IS control model of the current state of the production of product type Screen will be presented in section 4.2. Based on this AS-IS model and the theoretical insight gained from the previous chapter a TO-BE control model will be proposed in section 4.3.

4.1 Introduction: HD SOL

HD Sol is a MC manufacturer (and transporter and installer) of solar screening products, based in Molde, with a yearly turnover of over 750 MNOK, making it Norway's largest manufacturer of solar screening products. They offer predesigned products, which are made to order and tailored to each customers' needs and preferences. Each product is tailored to size, i.e. fitted to window sizes. HD Sol also offer their customers the opportunity to select product components from a variety of options in storage. HD Sol offers several types of products among them, the screen product group, which is the focus of this thesis.

The "Screen" product plant is responsible for manufacturing of the screen product series. There are 11 types of "screen" products, divided into two product families. Common for most products is that they are comprised of the same type of components; fabric, guide rails, structural rails, cover, and a motor (see figure 20). These components are offered in different variants and is the difference between the types of "screen" products.

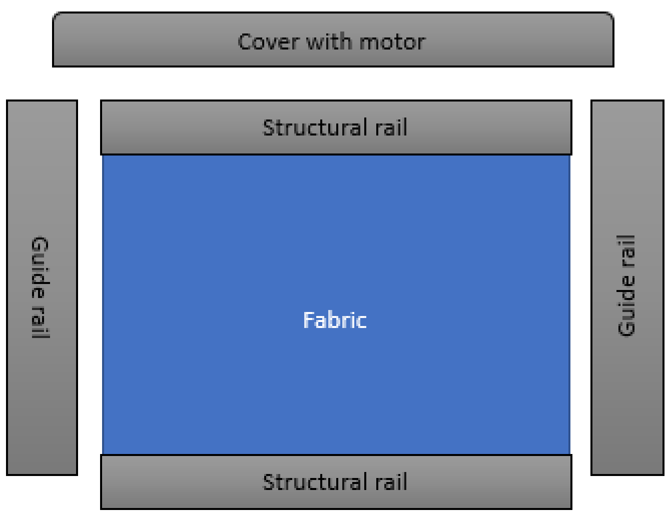

Figure 20 Screen product main components

HD Sol's screen production plant is divided into four departments; (1) *Fabric department*, which is responsible for the cutting and treatments of the fabric for all products. (2) *The profiles department*, which is responsible for the metal components of the products, cutting it into covers and rails. The smaller prefabricated parts and components are purchased and stored in the (3) *Small-part storage* and are picked and made ready for assembly in (4) the *assembly department*.

4.2 AS-IS

As an introduction to the case study of HD Sol, a workshop was conducted in cooperation with MFM and HD Sol (22.02.2019) where we attempted to create a Value Stream Map (VSM) of the Screen production at the HD Sol Plant.

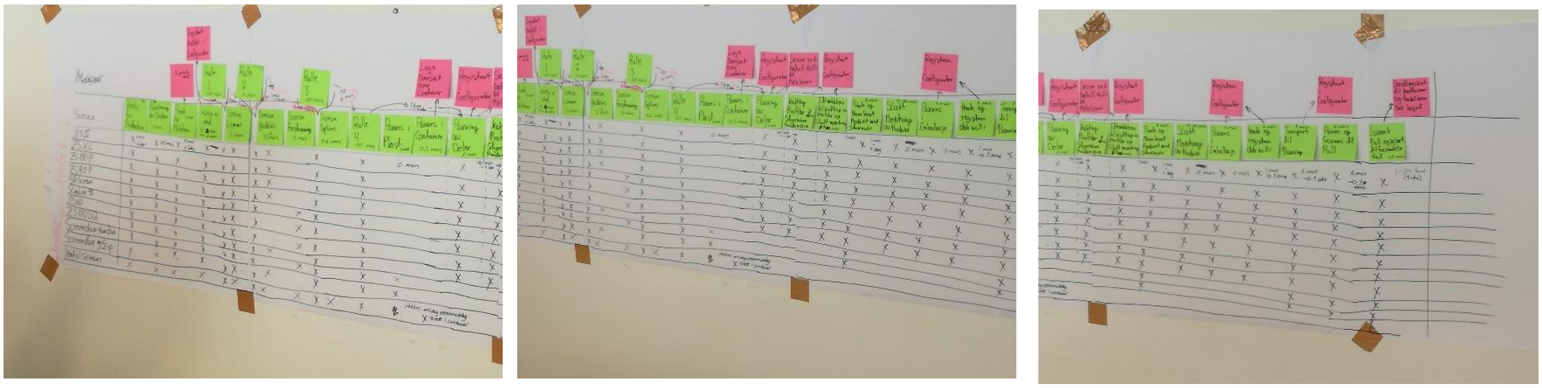

Figure 21 VSM model using post-it notes

MFM was in charge of the VSM process, using post-it notes for each process in the production chain. The production department of HD Sol gave MFM the information they needed; i.e. physical activities, informative activities, processing and waiting times, products, product families, etc.

Screen production is divided into four stages (table 9), dealing with two product families (table 10).

Table 9 Screen production departments

Stage 1	Fabric department
Stage 2	Parts and Components
Stage 3	Metal department
Stage 4	Assembly department

Table 10 Product families

Production family 1	- ZS2 - ZSXL - ZS100P - ZS80P - SR-Screen - SLimeLine90 - MS60 - ZS100SQ
Production family 2	- Screenduk - Screenduk Zip - Vental Screen

The stages of screen production are presented in the gray numberings on the VSM below (figure 22), while the product families are divided into matt red and blue colors.

The VSM model (see appendix 1 for a larger version of the model) show that HD Sol is operating with many variations, particularly in the waiting times between operations, with variations ranging from a few minutes up to 2 weeks! This might be due to poor production planning and scheduling and points to the importance of the research direction of this thesis.

Production family	Products	Ready for production	Prioirtising orders	Printing production papers	Fabric cutting	Rolling 1	Welding Pockets	Rolling 2	Welding Zippers	Welding Reinforcement	Rolling 3	Welding Spline	Rolling 4	Packing (plastic)	Packing (container)	Packing Parts	Cutting profiles	Print and attatch barcodes	Assembly	Packaging	Pick and regsiter fabrid kolli	Transport to packing	Pack and scan to Pallet	Close Pallet and move to transportation hall	Final transportation
1	ZS2	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZSXL	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZS100P	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZS80P	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	SR-Screen	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	SLimeLine90	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	MS60	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	ZS100SQ	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
2	Screenduk	x	x	x	x	x	x	x		x	x		x	x				x				x	x	x	x
	Screenduk Zip	x	x	x	x	x	x	x	x		x		x	x				x				x	x	x	x
	Vental Screen	x	x	x	x	x	x	x	x	x	x	x	x		x									x	x
	Processing time	0	1 m	1 m	4 - 6 m	0,5 m	3 m	1 m	3 - 4 m	5 m	0,5 m	1 - 2 m	0,5 m	1 m	0,5 m	1 m	7 m	1 m	15 - 20 m	1 m	2 m	1 m	2 m	0,5 m	1 d
	Waiting time	5 m - 2 w	0,5 m	5 m - 1 w	1 m	1 m - 3 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	0	0	1 h - 2 w	1 m - 1 w	1 m	1 m - 1 d	0	0	1 m - 1 h	1 m - 1 w	10 m - 1 h	1 h - 1 w	0

Figure 22 Value Stream Map

Operating times are roughly between 50-60 minutes excluding transportation. Waiting times on the other hand vary between 2,5 hours and up to 2 months in total!

The processes with the most variations are; (1) “ready for production” which means that the order is approved for production, (2) “printing production papers” which means that the order is released to production. (3) “Packing in container” which means that the finished treated fabric is packed in a container before being shipped to the customer. (4) “Packing parts” at the small-parts storage, (5) “transport to packing” meaning transporting finished products to the packing area in the assembly department. And lastly, (6) “closing pallet and moving it to the transportation hall” awaiting transport to final destination. A more detailed description of the processes in the screen production is available in table 11.

Table 11 Process description

Process	**Description**
Ready for production	The order is approved for production.
Prioritizing orders	Orders in the backlog are prioritized before they are released.
Printing production papers	The order is released.
Fabric cutting	Fabric is cut into pieces as described in the production papers.
Rolling 1	After the fabric is cut, it is rolled and placed in a WIP.
Welding pockets	Pockets are welded on the width sides of the fabric. The structural rails are going into these pockets in Assembly.
Rolling 2	The fabric is rolled and placed in WIP.
Welding Zippers	Zippers are welded in the height sides of the fabric. These are used to guide the screen up and down and prevent the fabric from bulging
Welding Reinforcement	A reinforcement tape is welded on the height sides of the fabric.
Rolling 3	The fabric is rolled and placed in WIP.
Welding Spline	A “spline” (plastic “rail”) is welded on one width side of the fabric.
Rolling 4	The finished treated fabric is rolled and placed in WIP, awaiting signal from Assembly.
Packing (plastic)	The finished treated fabric is packed in a plastic tube bag. Only for “Screenduk” and “Screenduk Zip”
Packing (container)	The finished treated fabric is packed in a container. Only for “Vental screen”
Packing parts	*The small-parts storage department* packs and readies parts and components for assembly.
Cutting profiles	*The profile department* cuts the covers and railings for assembly
Print and attach barcodes	Barcodes are printed and attached to order
Assembly	Components from the fabric department, small-parts storage and profile department are assembled.
Packaging	Assembled products are packed
Pick and register fabric kolli	The order is picked and registered as finished and ready for transportation
Transport to packing	Orders are transported to packing station
Pack and scan to pallet	Orders are scanned and packed in pallet
Close pallet and move to transportation hall	Pallet is closed and moved to transportation hall, awaiting transport to destination.
Final transportation	Orders are transported to final destination, before being installed at customer

HD Sols’ production is transportation based, meaning all production is based on the transportation schedule in table 12. The reason for the large production lead time variations is mostly based on the transportation schedule of HD Sol, see table 12, meaning that if an order misses its transportation departure it will have to wait a full week for the next one. Waiting for the approval of an order in the backlog is also a source for the long waiting times.

Table 12 HD Sol transportation schedule

Weekday	**Locations**
Monday	Romsdal
Tuesday	Vestlandet
Wednesday	Østlandet 1
Thursday	Trøndelag
Friday	-
Saturday	Østlandet 1

Based on the data collected in the second workshop (Appendix 2), there is evidence that there is most need for improvements in the procurement and installation stages of the supply chain. Storage and warehouse management is also a challenge for HD sol. This is not part of the thesis but is merely stated as opportunities for HD Sol to improve upon. This project focuses on production.

Based on the data collected the resulting AS IS model of the HD Sol screen production was created (see figure 23). It shows how a customer order moves through the value chain (information flow), and proceeds to be produced, from supplier to finished product is delivered and installed at the customer (physical flow).

Information flow is found between customer, Configurator (their ERP system), production manager, and the suppliers. The customer communicates their needs online or in cooperation with an inspector whom will enter the customer order into Configurator. When the order is confirmed the production-manager is free to release the order to production, based on inventory levels and transportation schedule. When the production manager detects an upcoming shortage of materials, she will contact the actual supplier with an order.

The physical flow of the screen production starts when the delivery of supplier materials, which MFM found to have the longest lead time. When the materials are available in inventory, the PSP of customer orders are approved for production, and the production manager releases orders the order will be executed accordingly. The production manager release orders cumulating approximately 100 products for each shift, and according to the Earlies Due Date (EDD) principle, with the exception of express orders. Some orders move through all departments (dotted boxes, figure 23), while others are only processed at the fabric shop floor. The figure illustrates multiple different processing routes in the fabric shop floor, making it the most stressed department. All orders move through here (fabric department).

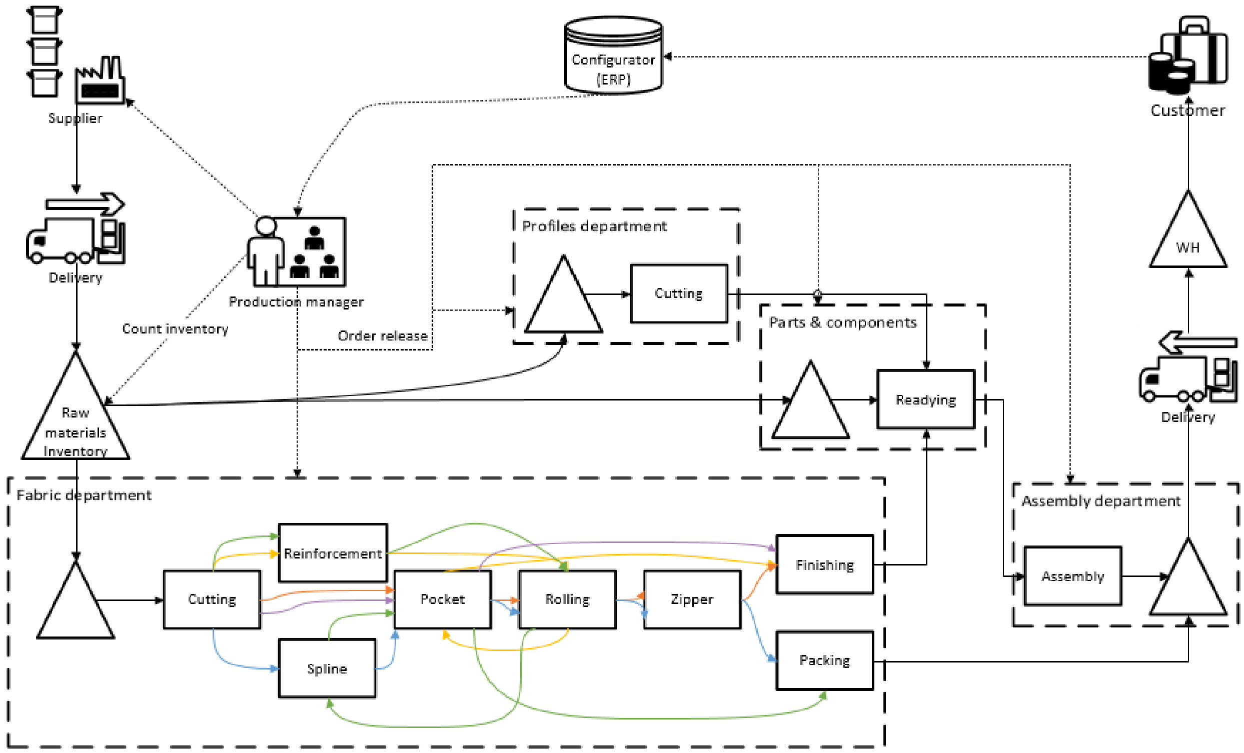

Figure 23 Simplified AS IS model of HD Sol screen production system

After the order has been processed it will be packed and readied for transportation at the end of the day. The transportation will follow the schedule previously presented. In most cases the products are delivered to a centralized warehouse or to an installer before being installed at customers home, office, etc. A more detailed description of the production processes can be found in the Appendix.

4.2.1 Fabric Department

The fabric shop floor of HD Sol consists of two multipurpose machines (M1 and M3), two cutting machines, one welding machine (M2) for pockets and a rolling table (RT). There are also multiple WIP storages between machines (see figure 24). Cutting machine 1 (CM1) is responsible for the majority of cutting, while Cutting Machine 2 (CM2) can be used for rolling, finishing, packing, as well as cutting.

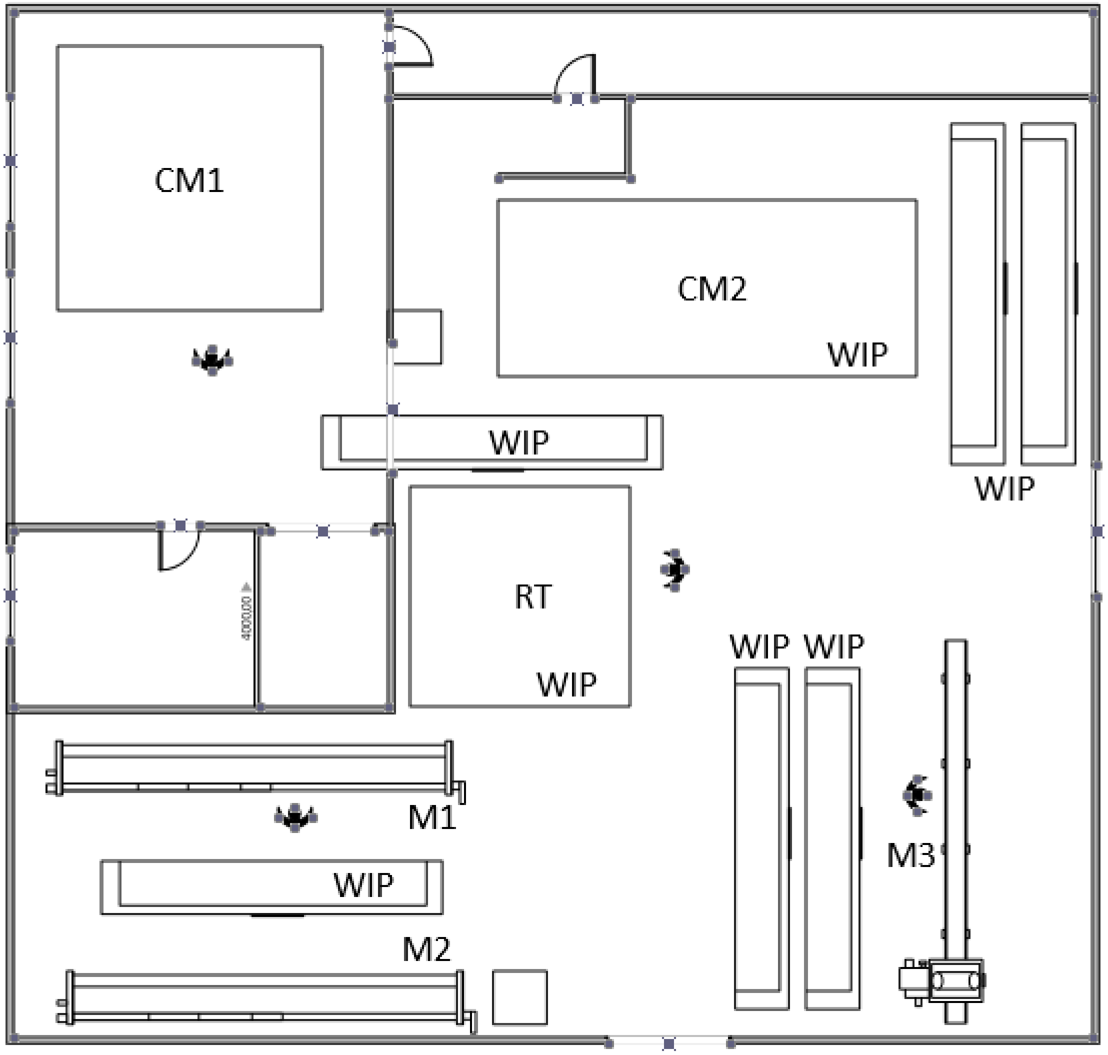

Figure 24 Fabric Department shop floor

The high product mix and production variation on the fabric shop floor make machine utilization and management of production routes challenging. Figure 25 illustrates the workstations and what operations are available for utilization at said workstation. From the table below (table 13) the frequency of workstation activity can be seen. A description of these processing activities is covered in table 11.

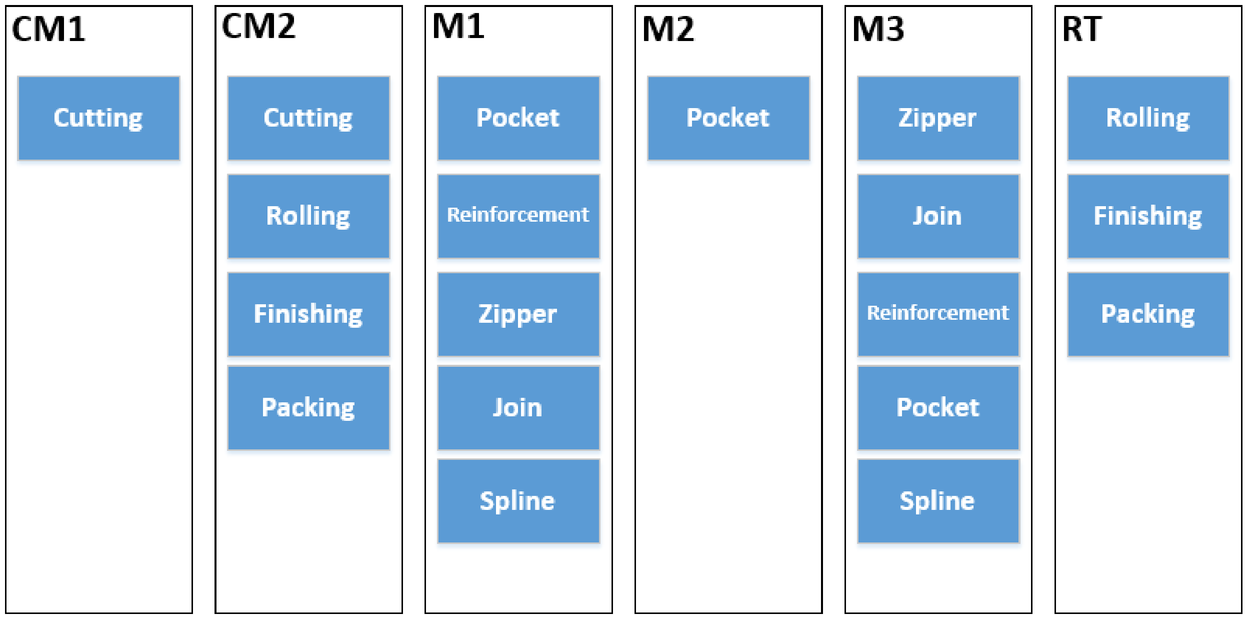

Figure 25 Workstation activity

Figure 25 illustrates the machines and workstations on the fabric department shop floor, and what processes they are able to carry out. CM1 is only cutting, while CM2 is also used as a Rolling Table (RT). M2 is only capable to weld pockets on the fabric, while M1 and M3 are multipurpose machines and able to complete a spectrum of welding operations.

Table 13 Workstation activity frequency

	CM1	**CM2**	**M1**	**M2**	**M3**	**RT**
Cutting	High	Medium				
Rolling						High
Joining			Low		Low	
Reinforcement			Medium		Low	
Pocket			High	Medium		
Zipper			Low		High	
Spline			Medium			
Finishing		High				Medium
Packing		Medium				Low

Table 13 represents the frequency of processes presented in figure 25. ZS2 is the volume product at HD Sol, and it is possible to see the effects of this on the workstation activity frequency. ZS2 products will move in this sequence on the fabric shop floor: CM1 – M1 – RT – M3 – CM2. The processes with the highest frequency at these workstations are the ones needed in order to manufacture the ZS2 product.

4.2.2 Challenges

Based on the findings from the first and second workshop, i.e. (1) production lead time variations and (2) that procurement and installation stresses the production at HD Sol, it should be suggested that a more stable and reliable production environment would be beneficial to HD Sol. With the aim to maximize utilization of transportation, i.e. filling the trailers with as much goods as possible without over- or underproduction.

Moreover, most stress is put on the fabric department as it is the only department which is responsible for all screen products, from both product families. Moreover, the fabric department operates with high production mix and production variety. Therefore, less stress on the fabric department could be beneficial. Ensuring a balanced workload among stations could mitigate this stress.

There is no inventory management system, except manual counting and the use of excel spreadsheets. Better control of inventory can mitigate the negative effects of no inventory control, e.g. release of orders missing parts needed for production, resulting in WIP, interruptions, waiting and waste of time.

4.3 TO-BE

After the production of Screen products was mapped, and with the knowledge of the four CBPPC systems covered in section 3.8, another workshop with the production management at HD Sol was conducted, with the aim to validate the use and match between CBPPC systems and HD Sol. The workshop was conducted in advance of the creation of a TO-BE model, in order to get feedback from the production management on all four CBPPC systems, i.e. their capabilities and applications to HD Sols' screen production system.

The agenda for the workshop was to present and give the production management a general overview of KANBAN, CONWIP, POLCA and COBACABANA, their capabilities, pros and cons, and lastly discuss the applicably of the systems to HD Sol and MC manufacturing. The slides used in the presentation are presented in figure 26, 27, 28, and 29.

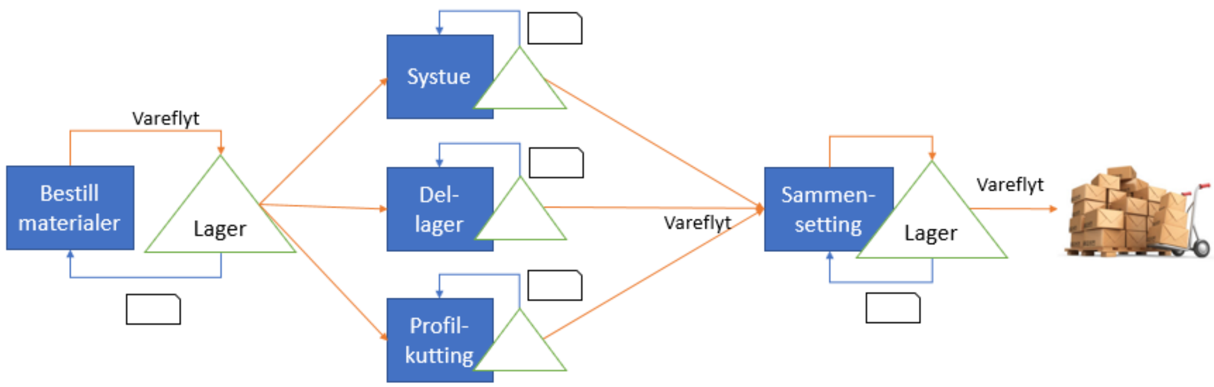

Figure 26 KANBAN and HD Sol

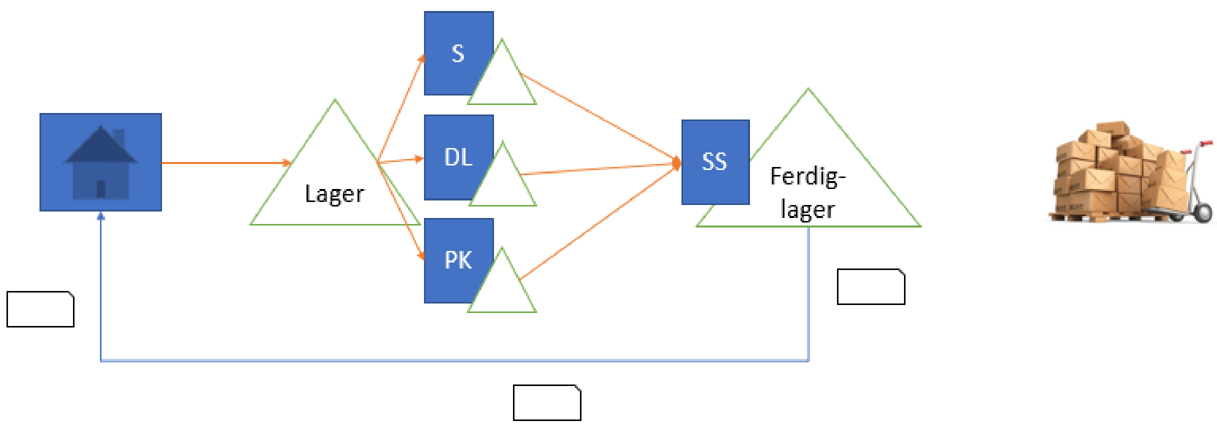

Figure 27 CONWIP and HD Sol

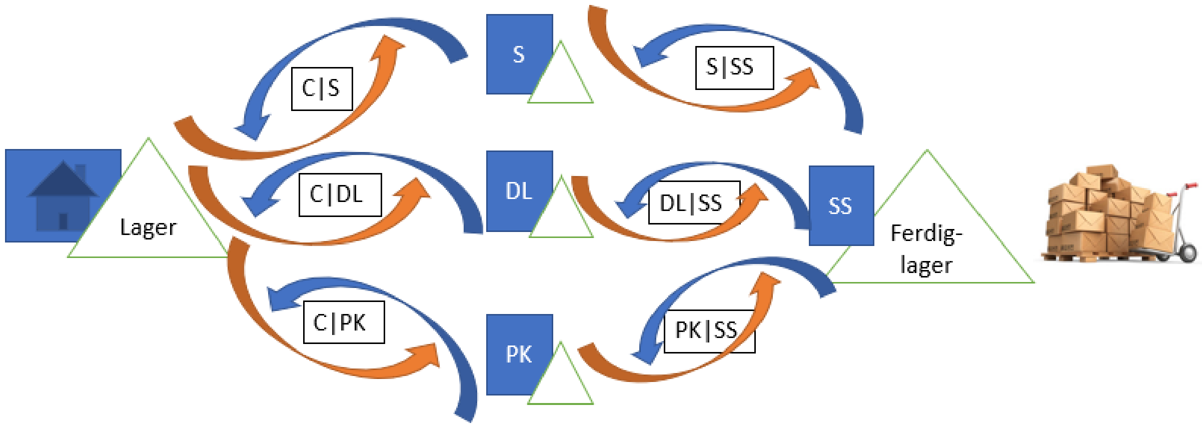

Figure 28 POLCA and HD Sol

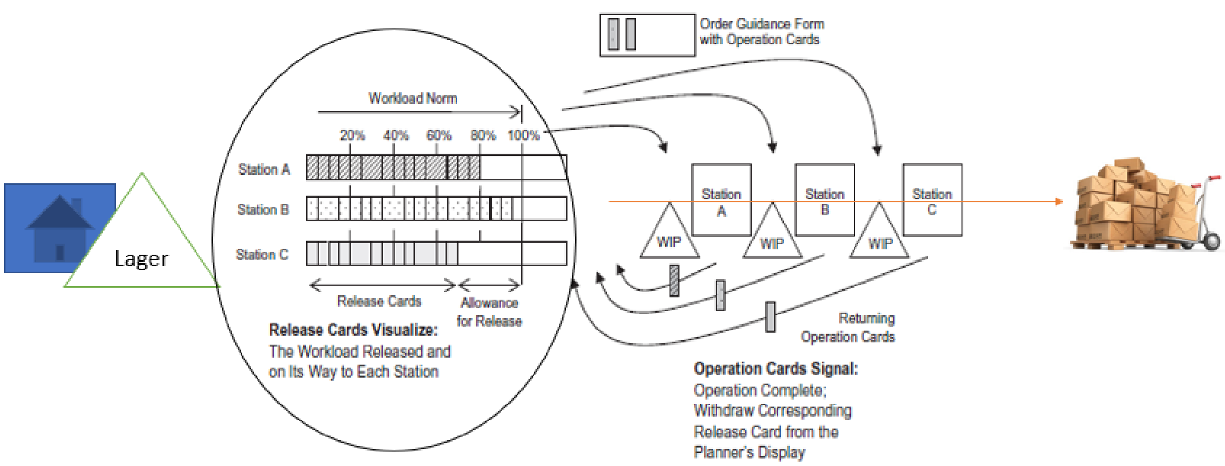

Figure 29 COBACABANA and HD Sol

HD Sol found that the COBACABANA system was most applicable and desirable, as it represented what they aimed to achieve in production. They currently use a combination of Configurator, Excel spreadsheets and “hunch” to plan and control production. Based on the feedback from HD Sol a TO-BE model of the screen production was created, using the COBACBANA system.

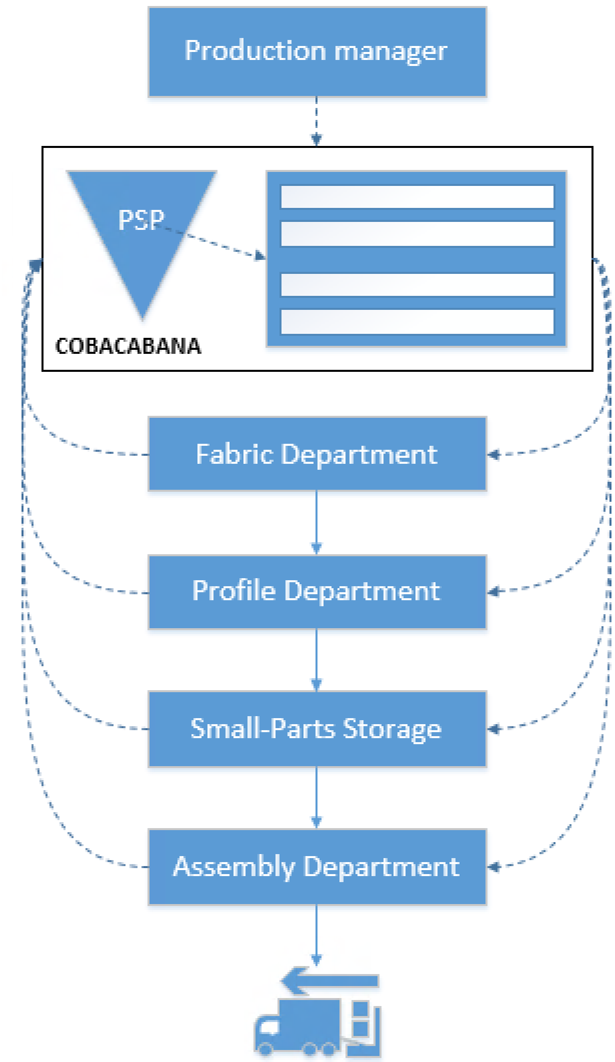

Figure 30 TO-BE Model of screen production with COBACABANA

Figure 30 illustrates the TO-BE Model of HD Sol's screen production with the use of COBACABANA PPC system. The system doesn't directly affect the production managers relationships with inventory, Configurator or Suppliers. The same goes for the transportation and installation of production to customers. And that is why the TO-BE model only covers the production manager, the COBACABANA system, the production departments and transportation.

The PSP is fed with customer orders from the Configurator as soon at the orders are approved. Now that the production manager can release theses orders from the Configurator, he will use the COBACABANA system to do so. Free capacity is illustrated in the COBACABANA 'planning table', based on a Workload norm, signaling this with free 'release-cards'. Once the order is released, the 'operations-card' follows the order, and is sent back to the 'planning-table' for each finished operation. Each order has two sets of cards, one set follows the order on the shop floor, while the other is put on the 'planning-table'. This way the production manager always knows what workload is put on the shop floor.

Let's say a ZS2 (Zip Screen) is ordered, this is the volume product. We know that this product flows though all departments, so this product-order will have eight COACABANA-cards, four following the order, the other for the 'planning table'.

When the order is released three release-cards is put up on the planning table, representing the workload released into the system. These three cards represent the fabric department, the profile department, and small-parts storage department. Since the assembly only can start when all previous departments are finished, signaled by receiving these release cards, the last set of cards is not yet released until this is signaled.

Fabric department, profile department and small-parts storage can start their processing as soon as the order is released. When they are finished, they will send their release-card back to the planning table as soon as the assembly department has received all components. Now that assembly has started, the previous three departments have freed up some workload and is ready for the next order. This way workload, waiting, WIP, lead-time is monitored and managed.

4.3.1 Fabric department

As mentioned before, the Fabric department is dealing with high product mix and processing route variations. To mitigate this, a TO-BE model of the Fabric department coupled with COBACABANA was created.

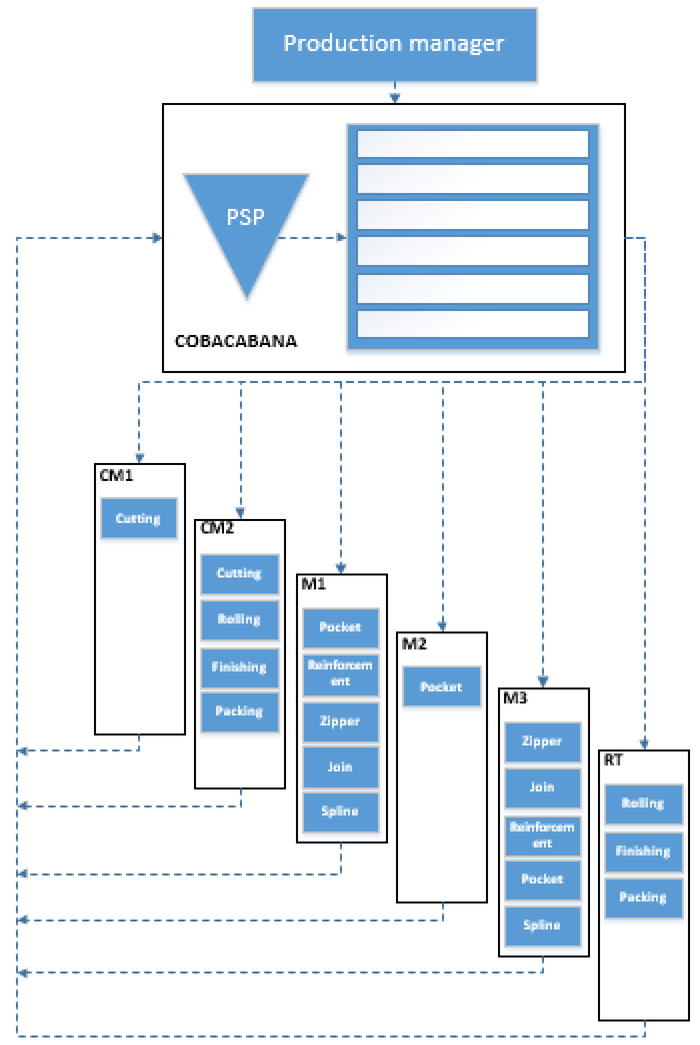

Figure 31 Fabric shop floor TO-BE Model

With this TO-BE solution, the production manager can by using the COBACABANA planning table manage the workload among workstations and distribute the workload among them. The production manager will also be able to detect if a workstation is becoming idle, and releasing orders to prevent this from happening, thus increasing utilization of the shop floor.

5 Analysis

In this chapter an analysis of the theory and case study is presented. This was done by describing and interpretation of the empirical findings and attempting to quantify the theoretical findings.

A summary on the pros and cons of the above CBPPC systems are presented in the table (14) below. This was used to gather, summarize and analyze the CBPPC systems. Based on the theory on the CBPPC systems COBACABANA seem to be the best match for MC production, providing centralized production control, management of workload, order release and its ability to manage customer enquiries. However, COBACABANA is a new system first covered in literature in 2009, and still needs to be properly proven. It should be mentioned that literature on COBACABANA is mostly conducted by researcher Thürer, and might bring some bias to its capabilities.

Table 14 Pros and Cons of Card-based Production Planning and Control systems

	Pros	Cons
KANBAN	- **High quantity, low variety production (MTS)** - Manages production sequence - Prevents overproduction and overloading - Lean production	- Not suitable for high-variety production (MTO-ETO) - Only works with continuous demand - No management of workload
CONWIP	- **Well suited for MTO** - Prevents overproduction and overloading - WIP control - Lean production	- CONWIP-cards only manage system WIP - Can struggle in MTS production - Relies heavily on production sequencing - Sensitivity to bullwhip effect - No management of workload
POLCA	- **High mix, low volume (MTO)** - Well suited for job shops - Prevents inventory building up - Reduces overall throughput time - Avoids upstream blockage	- Complex planning and scheduling - Relies on Order Release time calculations - Deadlocks - Overloading and low utilization - Low flexibility
COBACABANA	- **High mix, high volume (MTO)** - Centralized production control - Manages workload on shop floor and work centers - Manages release of orders - Manages customer enquiry, thus simple due date setting	- Complex planning and scheduling - Not suitable for MTS or low volume production - Little documented use

To better represent the applicability of the CBPPC systems to MC manufacturing a matrix (Table 15) was created matching MC manufacturing characteristics with the CBPPC systems in question. Awarding the systems 1 or 0 points for matching MC characteristics, resulted in 4 points to COBACABANA, 3 for POLCA, 2 for CONWIP and 1 for KANBAN. Thus, the table supports the assumption that COBACABANA is the most applicable CBPPC system for MC manufacturing.

Table 15 Mass Customization vs Card-based Production Planning and Control systems

	Card-based production planning and control system			
MC characteristics	**KANBAN**	**CONWIP**	**POLCA**	**COBACABANA**
CTO/MTO	0	1	1	1
High variety	0	1	1	1
High volume	1	0	0	1
Job shop	0	0	1	1
Score	**1**	**2**	**3**	**4**

The case study of HD Sol also supports this assumption, where the production management opted for the COBACABANA system in workshop 3, where the CBPPC systems were presented (see Appendix for presentation). COBACABANA was chosen because HD Sol thought it best resembled their production and what they wanted to accomplish, regarding planning and control. As of now, HD Sol uses a collection of tools to plan and control their production, i.e. Configurator, Excel, Experience and “hunch”. What seem to distinct the two are the presence of a clear pull, i.e. order release mechanism, that clearly signals the timing and free capacity.

It should also be mentioned that COBACABA never actually was implemented or tried at HD Sol, only validated by the production management as the most applicable CBPPC system to their production system. And even though HD Sol chose COBACABANA when asked, how applicable COBACABANA or even CBPPC systems in general are to MC manufacturing still needs to be proven.

Bottom line is that both the theory and case study suggest that, out of the four presented CBPPC systems, COBACABANA is the most applicable to MC manufacturing.

6 Discussion

In this chapter the theoretical part of the thesis, the case study and analysis are discussed. The chapter is structured as to attempt to answer the Research Questions stated in the introduction. The meaning of the results will be discussed, as well as the limitations of the thesis work. Section 6.1, 6.2 and 6.3 attempts to answer research question 1,2 and 3 respectively.

6.1 What are the main characteristics of MC?

From literature and the case study, it was found that the main characteristics of MC manufacturing are flexible and responsive mass production of customizable goods. Customization and customer involvement can be offered at different stages and different levels, resulting in multiple variations, approaches and strategies to MC manufacturing. The high production volume paired with customization result in high variety of products. Like in the case of HD Sol, where the product ZS2 is available in over 500 different product compositions. In addition to this, the products are tailored in size. Making the all products near one-of-a-kind. The products in MC are typically pre-designed, tailored to customer needs and preferences, while also offering them options like different components, colors, and materials types.

The products are made to order, with the CODP located at the manufacturing stage. The nature of the products necessitates that they are made based on an actual order. But inventory of materials and components are kept, in order to reduce lead time and increase responsiveness.

The main characteristics of MC manufacturing are:

- Flexible and responsive production
- High production volume
- Job shop production, with skilled workers
- Customization (CODP) at the manufacturing stage in the value chain
- Pre-designed products
- High variety of products
- Make-to-Order

6.2 What CBPPC systems are applicable to MC?

Stump and Badurdeen (2012) discussed the use of production strategies like TOC, FMS, agile, QRM and POLCA in their paper on MC and lean manufacturing. The authors stated that lean principles more easily are applicable to low-level MC environments, and more difficult with more customer involvement and customization. This speaks in the favor of Lean production strategies in MC. However, customer involvement and customization are still part of MC manufacturing and can cause limited lean applicability. CBPPC systems are based on lean principles and was analyzed in this thesis. How applicable are they to MC manufacturing? Below each CBPPC is discussed individually.

6.2.1 KANBAN

The analysis of KANBAN awarded it one point, for matching MC manufacturing's high-volume production characteristic. Are there any other aspects to KANBAN which can make it more applicable to MC?

Reasons why KANBAN isn't applicable to MC production: (1) KANBAN works in a steady pace/takt with WIP at each workstation, this is impossible in MC. (2) One cannot build inventories (WIP) at workstations in anticipation, since the specifics of the design is unknown until a customer order is placed, and (3) KANBAN is designed for repetitive, standardized production with predictable demand. (4) Enforcing takt time and heijunka (production leveling) is not practical in MC, when nothing is known until the order arrives (MTO) (Krishnamurthy et al., 2009).

In an "inventory control problem" the KANBAN systems are preferred (Thürer et al., 2016b). Meaning that when the demand is predictable, and a company must decide how much to order in order to meet demand, the KANBAN system is most applicable. This is again related to KANBANs applicability to standardized, predictable production.

From a study by Thürer et al. (2016b) they stated that there are three important factors to keep in mind when it comes to KANBAN systems: (1) Routing variability (2) processing time variability, and (3) inventory vs order control. KANBAN is less applicable with high routing variability, this is because all routing steps need to be represented by a KANBAN-loop. In order to avoid making control cumbersome It is desirable to keep the number of loops low.

Processing time variability impedes the applicability of KANBAN (Thürer et al., 2016b). This contradicts the characteristics of a MC manufacturer, which was observed at HD Sol, where the processing rime variability was high.

KANBAN systems are effective when stations are decoupled with inventories. But problems can rise when used for order control (Thürer et al., 2016b). This also contradicts the nature of MC manufacturing.

KANBAN is simply not applicable to MC manufacturing, which is a high-variety production environment. This is supported by Thürer et al. (2014) in their statement: "KANBAN is not suitable for high-variety production environments"

6.2.2 CONWIP

The analysis of the applicability of the CBPPC systems to MC manufacturing awarded CONWIP two points, for being applicable to high variety production and MTO production. Making CONWIP more applicable to MC than KANBAN.

But "According to a survey by Framinan et al. (2003), many authors insist that CONWIP outperforms KANBAN when processing times on component operations in production processes are variable. However, Gstettner and Kuhn (1996) concluded otherwise. Their results suggested that KANBAN can result in lower WIP levels than CONWIP if the card distribution in the KANBAN is chosen appropriately (Sato and Khojasteh-Ghamari, 2012).

CONWIP is not superior to KANBAN is every setting, even though it is argued by many. Sato and Khojasteh-Ghamari (2012) found that CONWIP outperforms KANBAN in serial production lines as well as variety production.

“CONWIP performs poorly in job shop production environments, because it does not provide a means of balancing workloads across resources at release; instead, this has to be achieved prior to release” (Thürer et al., 2014). This study states that CONWIP is not applicable to MC manufacturing because the system doesn’t have workload balancing capabilities. Meaning that order sequencing in the CONWIP system is the only tool used to control production.

However, a study by Thürer et al. (2017a) investigated the applicability of CONWIP to high-variety, make-to-order job shops with backlog sequencing rules (dispatching rules). The study shows, through simulation, that capacity slack-based rules provide load balancing, reduced throughout time and tardy jobs, proving that backlog sequencing extends the applicability of CONWIP to high-variety production.

6.2.3 POLCA

The analysis shows that CONWIP is more applicable to MC than KANBAN, however, it also gave POLCA three points for matching MC manufacturing in (1) MTO, (2) high variety, and (3) job shop production. POLCA lacks the capabilities of high-volume manufacturing though.

Thürer et al. (2016b) states that POLCA is equivalent to KANBAN systems, but with job anonymous cards. This means that the three *challenges* (Routing variability, processing time variability and inventory vs order control) in regard to KANBAN mostly also apply to POLCA. Routing and processing time variability, like with KANBAN, creates challenges and hinders POLCA in working as intended. This poses as a challenge in the applicability to MC manufacturing.

The authors also state that POLCA will introduce weaknesses associated with MRP. This is supported in another study, where they stated that POLCA may lead to blocking when there is high variability in routing, which is common in job shops (Thürer et al., 2014).

However, POLCA has the advantages of reduced waiting, WIP buildup, ensures flow and flexibility, and manages the workload. POLCA is the “KANBAN for high-variety production (Krishnamurthy et al., 2009).

6.2.4 COBACABANA

In the analysis, COBACABANA was awarded four points and found to be the most applicable CBPPC system to MC manufacturing. COBACBANA is well suited for MTO, high variety, high volume and job shop production. The case company, HD Sol, also found COBACABANA to be most applicable to their production system.

In a study by Thürer et al. (2014) they improved and evaluated the COBACABANA system in a job shop simulation model. Here they found that COBACABANA significantly improve throughput time, percentage tardy jobs and mean tardiness performance. Thus, COBACABANA provides an effective solution to controlling order release in job shops. This study has shown that COBACBANA is well applicable to job shops. The order release control reduces the WIP, by keeping orders in the PSP, but at some point, this will increase the total throughput time (time in PSP and throughput time on shop floor).

Thürer et al. (2016b) states that COBACABANA is the preferred PPC method in a “order control problem”. Meaning that COBACBANA is the preferred PPC system when designing a production system to minimize costs. Like with the inventory control problem, where the same dilemma is posed, but focusing on the amount of inventory to keep.

COBACABANA is a card-based approach to WLC, providing simple, visual and centralized control of job shop production. The findings in this thesis suggest that it also is the most applicable PPC approach to MC manufacturing. To further support the findings in this thesis, COBACABANA could be implemented to HD Sol and multiple other MC manufacturers.

6.2.5 Summary

So, what CBPPC systems are applicable to MC? The analysis found that COBACABANA was most applicable, POLCA, CONWIP and KANBAN follow in decreasing order. The discussion also suggests this. Thürer et al. (2014) however, noted that the applicability of CBPPC systems to MTO job shops, i.e. like MC manufacturer HD Sol, is severely questioned.

In an attempt to answer the research question, based on analysis and discussion, it can only be suggested that COBACABAN is most applicable. How applicable, beneficial and effective it is in MC needs to be further investigated. The thesis finds that CONWIP, POLCA and KANBAN systems are not applicable to MC. This is based on the characteristics of the systems and MC production, which suggest a mismatch between them.

6.3 How does the CBPPC systems OR mechanisms affect MC?

KANBAN, CONWIP and POLCA was found to not be applicable to MC manufacturing, and therefore not covered in the answer to this research question. The OR mechanisms of COBACABANA is discussed since it was found to be the most applicable CBPPC system to MC manufacturing.

Applying COBACABANA can bring benefits to MC manufacturers, as mentioned previously, like centralized production control, workload control and customer enquiry management. This is accomplished by applying the planning table which reflects the shop floor workload and releasing orders to achieve a balanced workload among workstations.

Since the COBACABANA brings the opportunity to control the shop floor, the system should be customized to the production type and environment it is applied to. In the case of MC manufacturing, COBACABANA should account for high production variety and multiple production routes.

Like in the case of HD Sol, MC characteristics resulted in high amounts of WIP inventories and production lead time variations. In order to mitigate this, COBACBANA could apply a WIP cap reducing waiting and production lead time. However, limiting the WIP with WIP cap can lead to starvation of workstations when processing times vary. Thürer et al. (2018a) suggest that lot splitting, i.e. splitting customer orders into parts, as a means of reducing starvation and managing large orders. This means that lot splitting can ensure that downstream workstations are replenished with work and avoids idleness and starvation (Thürer et al., 2018a). This OR mechanism speaks in favor of COBACABANA and could benefit the MC manufacturer with high production mix, variation and routings.

Moreover, COBACBANA systems OR mechanism affect MC by monitoring the workload among workstations and releasing orders from PSP using a sequencing rule. At HD Sol this means that when a workstation approach certain level of workload it will trigger an order release. The challenge here is knowing what this level is and could be compared with the ‘hunch’ production management operates with.

It would seem that COBACABANA could bring some benefits to MC, but this needs to be further investigated and proven. This thesis is limited by the fact that the CBPPC systems only was presented to HD Sol, and rated and validated by HD Sol. A simulation model or actual implementation of the CBPPC systems to MC manufacturing systems are potential future research possibilities.

7 Conclusion

In this thesis I investigated the applicability of four CBPPC systems, i.e. KANBAN, CONWIP, POLCA and COBACABANA, in a MC manufacturing environment. This was done through both a literature study and a case study of MC manufacturer HD Sol. Moreover, the thesis answered three research questions; (1) what are the main characteristics of MC? (2) What CBPPC systems are applicable to MC? And, (3) How does the CBPPC systems OR mechanism affect MC?

The main characteristics of MC manufacturing are a mix of MTS and MTO production, where the MC manufacturing offers customizable goods at mass production rates. The customers are involved at the manufacturing level, customizing the product to their needs and preferences. Production is initiated when an order is placed and because of the customization the MC manufacturers operate with high variety and many production routes. In order to reduce lead-time, the manufacturer keeps inventory of all offered components and options.

The analysis of literature and the case study of HD Sol suggested that COBACABANA is the most applicable of the four. Moreover, the thesis finds that CONWIP, KANBAN and POLCA systems are likely not applicable to MC. Based on this a TO-BE model of HD Sol was presented, implementing the COBACABANA system. The thesis found that the OR mechanisms of COBACABANA offers MC benefits like centralized control, workload management and workload balancing capabilities. It is also suggested that MC manufacturers set WIP caps at workstations, with starvation triggers as to reduce idleness.

The thesis suggests that COBACBANA is applicable to MC and brings beneficial OR mechanisms to MC manufacturing environments. However, this needs to be further researched and proven. A simulation model or actual implementation of the CBPPC systems to MC manufacturing systems are potential future research possibilities.

References

ALFORD, D., SACKETT, P. & NELDER, G. 2000. Mass customisation—an automotive perspective. *International Journal of Production Economics,* 65**,** 99-110.

BAXTER, P. & JACK, S. 2008. Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report,* 13**,** 544-559.

BERGAMASCHI, D., CIGOLINI, R., PERONA, M. & PORTIOLI, A. J. I. J. O. P. R. 1997. Order review and release strategies ina job shop environment: A review and a classification. 35**,** 399-420.

BERTRAND, J., WINGAARD, J. J. I. J. O. O. & MANAGEMENT, P. 1986. The structuring of production control systems. 6**,** 5-20.

BERTRAND, J. W. M. & WORTMANN, J. C. 1981. *Production control and information systems for component-manufacturing shops*, Citeseer.

BLAIKIE, N. & PRIEST, J. 2019. *Designing social research: The logic of anticipation*, John Wiley & Sons.

BRYMAN, A. 2016. *Social research methods*, Oxford university press.

CHAPMAN, S. N., ARNOLD, J. R. T., GATEWOOD, A. K. & CLIVE, L. M. 2017. *Introduction to Materials Management*, PEARSON.

CHOPRA, S. & MEINDL, P. 2016. *Supply Chain Management - Strategy, Planning, and Operation*, PEARSON.

DA SILVEIRA, G., BORENSTEIN, D. & FOGLIATTO, F. S. 2001. Mass customization: Literature review and research directions. *International journal of production economics,* 72**,** 1-13.

DOMINIC, P. D., KALIYAMOORTHY, S. & KUMAR, M. S. 2004. Efficient dispatching rules for dynamic job shop scheduling. *The International Journal of Advanced Manufacturing Technology,* 24**,** 70-75.

DURAY, R., WARD, P. T., MILLIGAN, G. W. & BERRY, W. L. J. J. O. O. M. 2000. Approaches to mass customization: configurations and empirical validation. 18**,** 605-625.

ELLRAM, L. M. 1996. The use of the case study method in logistics research. *Journal of business logistics,* 17**,** 93.

FOGLIATTO, F. S., DA SILVEIRA, G. J. & BORENSTEIN, D. 2012. The mass customization decade: An updated review of the literature. *International Journal of production economics,* 138**,** 14-25.

FRAMINAN, J. M., GONZALEZ, P. L. & RUIZ-USANO, R. 2003. The CONWIP production control system: review and research issues. *Production Planning & Control,* 14**,** 255-265.

GASH, S. 1999. Effective Literature Searching for Research. Gower Publishing.

GILMORE, J. H. J. H. B. R. 1997. The four faces of mass customization. 75**,** 91-101.

GOLAFSHANI, N. 2003. Understanding reliability and validity in qualitative research. *The qualitative report,* 8**,** 597-606.

GSTETTNER, S. & KUHN, H. 1996. Analysis of production control systems kanban and CONWIP. *International journal of production research,* 34**,** 3253-3273.

GUTHRIE, G. 2010. *Basic research methods: An entry to social science research*, SAGE Publications India.

HAMMERSLAND, H. 2018. *Order Review and Release as Production Planning and Control approach in Mass Customization.* Specialization Project, NTNU.

IAKYMENKO, N. 2018. Specialization Project, information search, literature study and research methodology. *TPK4430 Production management and Logistics*.

JOPPE, M. 2000. Validity. The Research Process.

KARLSSON, C. 2010. Researching operations management. *Researching Operations Management.* Routledge.

KOTHARI, C. 2006. Research Methodology: methods and techniques. reprint. *Dehli: New Age International***,** 14-16.

KOTHARI, C. R. 2004. *Research methodology: Methods and techniques*, New Age International.

KRISHNAMURTHY, A., SURI, R. J. P. P. & CONTROL 2009. Planning and implementing POLCA: a card-based control system for high variety or custom engineered products. 20**,** 596-610.
LAMPEL, J. & MINTZBERG, H. J. S. M. R. 1996. Customizing customization. 38**,** 21-30.
LAND, M. J. 2009. Cobacabana (control of balance by card-based navigation): A card-based system for job shop control. *International Journal of Production Economics,* 117**,** 97-103.
LAND, M. J. I. J. O. P. E. 2006. Parameters and sensitivity in workload control. 104**,** 625-638.
LANDER, E. & LIKER, J. K. 2007. The Toyota Production System and art: making highly customized and creative products the Toyota way. *International Journal of Production Research,* 45**,** 3681-3698.
MACCARTHY, B., BRABAZON, P. G. & BRAMHAM, J. 2003. Fundamental modes of operation for mass customization. *International Journal of Production Economics,* 85**,** 289-304.
MACKENZIE, N. & KNIPE, S. 2006. Research dilemmas: Paradigms, methods and methodology. *Issues in educational research,* 16**,** 193-205.
MELNYK, S. A., RAGATZ, G. L. J. P. & JOURNAL, I. M. 1988. Order review/release and its impact on the shop floor. 29**,** 13.
MELNYK, S. A. & RAGATZ, G. L. J. T. I. J. O. P. R. 1989. Order review/release: research issues and perspectives. 27**,** 1081-1096.
PATTON, M. Q. 1990. *Qualitative evaluation and research methods*, SAGE Publications, inc.
PAWAR, M. S. 2004. *Data collecting methods and experiences: A guide for social researchers*, Sterling Publishers Pvt. Ltd.
PINE, B. J. 1993. Mass customizing products and services. *Planning review,* 21**,** 6-55.
PINE, B. J. & DAVIS, S. 1993. Mass customization: the new frontier in business competition.
PRICE, J. H. & MURNAN, J. 2004. Research limitations and the necessity of reporting them. Taylor & Francis Group.
RIDLEY, D. 2012. *The literature review: A step-by-step guide for students*, Sage.
RIEZEBOS, J. J. I. J. O. P. R. 2010. Design of POLCA material control systems. 48**,** 1455-1477.
ROSS, A. 1996. Selling uniqueness. *Manufacturing Engineer,* 75**,** 260-263.
SABUNCUOGLU, I. & KARAPıNAR, H. J. I. J. O. P. E. 1999. Analysis of order review/release problems in production systems. 62**,** 259-279.
SATO, R. & KHOJASTEH-GHAMARI, Y. J. J. O. I. M. 2012. An integrated framework for card-based production control systems. 23**,** 717-731.
SHINGO, S. & DILLON, A. P. 1989. *A study of the Toyota production system: From an Industrial Engineering Viewpoint*, CRC Press.
SLOMP, J., BOKHORST, J. A., GERMS, R. J. P. P. & CONTROL 2009. A lean production control system for high-variety/low-volume environments: a case study implementation. 20**,** 586-595.
SOMEKH, B. & LEWIN, C. 2005. *Research methods in the social sciences*, Sage.
SPEARMAN, M. L. & HOPP, W. J. J. I., CHICAGO, IL 1996. Factory Physics: Foundations of Manufacturing Management. 439.
SPEARMAN, M. L., WOODRUFF, D. L. & HOPP, W. J. J. T. I. J. O. P. R. 1990. CONWIP: a pull alternative to kanban. 28**,** 879-894.
SPIRA, J. S. 1993. Mass customization through training at Lutron Electronics. *Planning Review,* 21**,** 23-24.
STEVENSON, W. J. 2014. *Operations Management*, McGraw-Hill Education.
STEVENSON*, M., HENDRY, L. C. & KINGSMAN, B. G. 2005. A review of production planning and control: the applicability of key concepts to the make-to-order industry. *International journal of production research,* 43**,** 869-898.
STUMP, B. & BADURDEEN, F. J. J. O. I. M. 2012. Integrating lean and other strategies for mass customization manufacturing: a case study. 23**,** 109-124.
SUGIMORI, Y., KUSUNOKI, K., CHO, F. & UCHIKAWA, S. J. T. I. J. O. P. R. 1977. Toyota production system and kanban system materialization of just-in-time and respect-for-human system. 15**,** 553-564.

SURI, R. 1998. *Quick response manufacturing: a companywide approach to reducing lead times*, CRC Press.
THOMAS, R. M. 2003. *Blending qualitative and quantitative research methods in theses and dissertations*, Corwin Press.
THURER, M., STEVENSON, M. & PROTZMAN, C. 2016. *Card-Based Control Systems for a Lean Work Design: The Fundamentals of Kanban, ConWIP, POLCA, and COBACABANA*, CRC Press.
THÜRER, M., FERNANDES, N. O., CARMO-SILVA, S. & STEVENSON, M. J. J. O. M. S. 2018a. Lot splitting under load-limiting order release in high-variety shops: An assessment by simulation. 48**,** 63-72.
THÜRER, M., FERNANDES, N. O., STEVENSON, M., QU, T. & LI, C. D. J. I. J. O. P. R. 2018b. Centralised vs. decentralised control decision in card-based control systems: comparing kanban systems and COBACABANA. 1-16.
THÜRER, M., FERNANDES, N. O., STEVENSON, M. & QU, T. J. I. J. O. P. R. 2017a. On the backlog-sequencing decision for extending the applicability of ConWIP to high-variety contexts: an assessment by simulation. 55**,** 4695-4711.
THÜRER, M., LAND, M. J., STEVENSON, M. & FREDENDALL, L. D. J. I. J. O. P. E. 2016a. Card-based delivery date promising in high-variety manufacturing with order release control. 172**,** 19-30.
THÜRER, M., LAND, M. J. & STEVENSON, M. J. I. J. O. P. E. 2014. Card-based workload control for job shops: Improving COBACABANA. 147**,** 180-188.
THÜRER, M., STEVENSON, M., LAND, M. J. & FREDENDALL, L. D. J. I. J. O. P. R. 2018c. On the combined effect of due date setting, order release, and output control: an assessment by simulation. 1-15.
THÜRER, M., STEVENSON, M. & PROTZMAN, C. W. 2015. COBACABANA (Control of Balance by Card Based Navigation): An alternative to kanban in the pure flow shop? *International Journal of Production Economics,* 166**,** 143-151.
THÜRER, M., STEVENSON, M., PROTZMAN, C. W. J. P. P. & CONTROL 2016b. Card-based production control: a review of the control mechanisms underpinning Kanban, ConWIP, POLCA and COBACABANA systems. 27**,** 1143-1157.
THÜRER, M., STEVENSON, M., SILVA, C., LAND, M. J., FREDENDALL, L. D. J. P. & MANAGEMENT, O. 2012. Workload Control and Order Release: A Lean Solution for Make-to-Order Companies. 21**,** 939-953.
THÜRER, M., STEVENSON, M., SILVA, C. & QU, T. J. I. J. O. P. E. 2017b. Drum-buffer-rope and workload control in High-variety flow and job shops with bottlenecks: An assessment by simulation. 188**,** 116-127.
WHITE, R. E., PEARSON, J. N. & WILSON, J. R. J. M. S. 1999. JIT manufacturing: a survey of implementations in small and large US manufacturers. 45**,** 1-15.
WHITE, R. E. & PRYBUTOK, V. J. O. 2001. The relationship between JIT practices and type of production system. 29**,** 113-124.
YIN, R. 1984. case study research. Beverly Hills. ca: Sage.
YIN, R. 1994. Case study research: Design and methods. Sage Publications, Thousand Oaks, CA.
YIN, R. K. 1981. The case study as a serious research strategy. *Knowledge,* 3**,** 97-114.
YIN, R. K. 2003. Case study research: Design and methods (Vol. 5).
YIN, R. K. 2017. *Case study research and applications: Design and methods*, Sage publications.
ZAINAL, Z. 2007. Case study as a research method. *Jurnal Kemanusiaan,* 5.
ZÄPFEL, G. & MISSBAUER, H. J. E. J. O. O. R. 1993. New concepts for production planning and control. 67**,** 297-320.
ØRNGREEN, R. & LEVINSEN, K. 2017. Workshops as a Research Methodology. *Electronic Journal of E-learning,* 15**,** 70-81.

Appendices

Appendix 1: VSM

Production family	Products	Ready for production	Prioritising orders	Printing production papers	Fabric cutting	Rolling 1	Welding Pockets	Rolling 2	Welding Zippers	Welding Reinforcement	Rolling 3	Welding Spline	Rolling 4	Packing (plastic)	Packing (container)	Packing Parts	Cutting profiles	Print and attach barcodes	Assembly	Packaging	Pick and regsiter fabrid kolli	Transport to packing	Pack and scan to Pallet	Close Pallet and move to transportation hall	Final transportation
1	ZS2	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZSXL	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZS100P	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	ZS80P	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
	SR-Screen	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	SLimeLine90	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	MS60	x	x	x	x	x	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x
	ZS100SQ	x	x	x	x	x	x	x	x		x		x			x	x	x	x	x	x	x	x	x	x
2	Screenduk	x	x	x	x	x	x	x		x	x		x	x				x				x	x	x	x
	Screenduk Zip	x	x	x	x	x	x	x	x		x		x	x				x				x	x	x	x
	Vental Screen	x	x	x	x	x	x	x	x	x	x	x	x		x									x	x
	Processing time	0	1 m	1 m	4 - 6 m	0,5 m	3 m	1 m	3 - 4 m	5 m	0,5 m	1 - 2 m	0,5 m	1 m	0,5 m	1 m	7 m	1 m	15 - 20 m	1 m	2 m	1 m	2 m	0,5 m	1 d
	Waiting time	5 m - 2 w	0,5 m	5 m - 1 w	1 m	1 m - 3 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	1 m - 1 h	0	0	1 h - 2 w	1 m - 1 w	1 m	1 m - 1 d	0	0	1 m - 1 h	1 m - 1 w	10 m - 1 h	1 h - 1 w	0

Figure 32 Value Stream Map (Large)

Appendix 2: Workshop 2

Workshop 2 (19.03.2019) was a follow-up of workshop 1 in cooperation with HD Sol and MFM, with the goal to build on workshop 1, and gain further insight and understanding to HD Sol's operations.

Table 16 depicts a four-way split of HD Sols value-chain, divided into (1) Purchasing and Procurement, (2) Production, (3) Transportation, and (4) Installation. The table represents an estimated lead time for each value chain link.

Based on the information in the table there is evidence that there is most need for improvements in purchasing and procurement, and installation, or at least most to gain. Storage and warehouse management is also a challenge for HD sol. This will not be part of the thesis but is merely stated as opportunities for HD Sol to improve upon. The project will focus on production, as it is part of the faculty of machining and production management (MTP).

Table 16 The value chain in parts

Purchasing and Procurement	Production	Transportation	Installation
3-6 weeks	1 day	1 day	1-3 weeks

The fact that purchasing, procurement and installation stress the production departments, effectively forcing it to be more efficient, could point to a need for a more stable and reliable production environment. With the goal to maximize the utilization of transportation, i.e. filling the trailers with as much goods as possible without over- or underproduction…

Findings are results of workshops in cooperation with MFM and HD Sol.

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