Defining a Manufacturing Planning and Control Model

For a Lean Manufacturing Company

Jan Tamlander

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JAMK University of Applied Sciences

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Abstract

The research task was assigned by Marioff Corporation Oy. Recently, the company has been transforming from batch-flow production to lean manufacturing. The objective of the research was to define a suitable manufacturing planning and control (MPC) system for the future lean environment.

The study was conducted as a case study. Qualitative methods of interviewing and observing were used to find out the specific requirements and current problems of the MPC system in the case company. Lean literature was studied to map out the requirements for the MPC system in the lean environment. Additionally, a product data analysis – including ABC analysis – was done to assign product groups into appropriate manufacturing environments (MTS, ATO, MTO, ETO).

The results of the interviews and observations indicated that the case company had suffered from inaccurate customer delivery dates, insufficient inventory levels, improper replenishment of inventories, insufficient material in Kanban, frequent expediting requests, absence of consistent use of forecasts etc. Lean literature on the other hand concluded that the MPC system must contribute to value-adding, increase flow, enable pull, increase transparency and support continuous improvement.

Finally, the MPC model was drafted based on the requirements of lean manufacturing and the case company. The model also addresses several of the problems discovered during the research.

Keywords/tags (subjects)

Production planning, inventory management, materials management, lean, pull, push

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Tiivistelmä

Tutkimuksen toimeksiantajana toimi Marioff Corporation Oy. Tutkimushetkellä yritys on muuttamassa toimitustapaansa erätuotannosta lean-tuotannoksi. Tutkimuksen tavoitteena on tuottaa yritykselle tuotannonohjausmalli, joka soveltuu tulevaan lean-ympäristöön.

Tutkimus suoritettiin tapaustutkimuksena. Laadullisia keinoja kuten haastatteluita sekä havainnointia käytettiin kartoittamaan kohdeyrityksen nykyisiä ongelmia sekä tulevia vaatimuksia liittyen tuotannonohjaukseen. Lean-kirjallisuutta tutkittiin tulevan lean-ympäristön tuotannonohjauksen erityisvaateiden löytämiseksi. Lisäksi tehtiin tuoteanalyysi, joka sisälsi ABC-analyysin. Analyysillä luokiteltiin eri tuoteryhmät varasto-ohjauksen tai tilausohjauksen piiriin.

Haastatteluiden ja havannoinnin tuloksena huomattiin, että yrityksellä oli ollut vaikeuksia tarkkojen toimituspäivämäärien lupaamisessa, riittävien varastojen ylläpidossa, riittävien Kanban-tasojen ylläpidossa, toistuvien aikaistuspyyntöjen käsittelyssä, ennusteiden suunnitelmallisessa käytössä jne. Lean-kirjallisuudesta puolestaan määriteltiin, että tuotannonohjausmallin on oltava kykenevä tukemaan arvon tuottoa, lisäämään virtausta, mahdollistamaan imuohjaus, oltava läpinäkyvä sekä mahdollistaa jatkuva parantaminen.

Tutkimuksen päätteeksi kyettiin uusi tuotannonohjausmalli määrittelemään perustuen lean-tuotannon sekä kohdeyrityksen asettamiin vaateisiin. Mallilla myös otetaan kantaa tutkimuksessa löydettyihin ongelmiin.

Avainsanat (asiasanat)

Tuotannonohjaus, varastonhallinta, materiaalihallinta, lean, imuohjaus, työntöohjaus

Muut tiedot

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Terminology

ATO	Assemble-to-Order
ATP	Available-to-Promise
CONWIP	Continuous Work-in-Process
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
ETO	Engineer-to-Order
FG	Finished Goods
MPC	Manufacturing Planning and Control
MRP	Material Requirements Planning
MTO	Make-to-Order
MTS	Make-to-Stock
OPP	Order Penetration Point
S&OP	Sales and Operations Planning
WIP	Work-in-Process

1 Introduction

The purpose of this case study is to define a new improved manufacturing planning and control model for Marioff Corporation Oy. The demand for the new revamped model arose during the ongoing transformation from the current batch production / make-to-stock environment to a lean manufacturing environment.

This report first explains the research methods after which the related theories are introduced. Then the current state is described based on the interviews conducted with the production and inventory managers and the results of the production data analysis are presented. Finally, the new manufacturing control and planning model is defined based on the theories, interviews and the product data analysis. Discussion is presented in chapter 9.

1.1 Objective

The objective of the case study is to find out the requirements and to develop a manufacturing planning and control model that fits the future lean environment. More accurately, the conclusion of this thesis suggests how the different manufacturing environments should be managed in regard of

- forecasting,
- scheduling,
- inventory levels and
- material flow.

Also a suggestion of which product groups belong to which manufacturing environment in order to guarantee sufficient product availability, is presented.

1.2 Case: Marioff Corporation Oy

Marioff is a project-based company in the fire security sector focusing on high mist water pressure systems. The company manufactures, installs and services systems and related components such as pump-units, sprinklers, tubing and valves and provides maintenance and modernisation of such systems. Applications vary from land applications such as buildings, to marine applications, for instance offshore vessels and cruise lines.

The systems are preferably delivered project by project containing all needed parts. A single application or customer can include multiple projects. The business environment demands highly accurate on-time deliveries since the products are often needed in a precise time window. For example, the system can often be only installed or serviced during a certain construction phase of a building or a scheduled vessel maintenance. On the other hand, this also brings uncertainty in the delivery schedules as customers' projects can be delayed, advanced or even cancelled. Thus, Marioff's operations are often subject to rescheduling.

The business area of the case company requires that the new manufacturing planning and control model must work in a lean manufacturing environment, manage a broad customizable product portfolio and ensure on-time deliveries in a fast-changing environment.

2 Research Methods

This bachelor's thesis is a case study. A case study is a mixture of both qualitative and quantitative research with an emphasis on the qualitative side. (Kananen 2013, 23) In case studies, the research subjects are often complex and require multiple research methods to construct a thorough understanding of the subject. (Kananen 2013, 9) Thus, the use of both qualitative and quantitative methods can be justified.

There are also other mixed type research strategies than the case study. However, a case study only brings a solution whereas an action research and a development research include the application of the solution. (Kananen 2013, 15) The goal of this study is to only generate a solution and leave the application out. Hence, this study is neither; an action research or a development research.

2.1 Limiting the Subject

The initial subject was to define an operations planning model. This included all operations regarding the products and components of both purchasing and manufacturing. After the breadth of the subject became clearer while constructing the theory base, some limitations were needed to be done in order to bring more depth to the research:

1. The purchased products were excluded from the scope.
2. Only production related planning operations were included.
3. Planning operations were further limited to those of which adequately data could be gathered.

Therefore, the final subject concerned manufacturing planning and control operations which could adequately be researched with the available time resources and selected research methods.

2.2 Research Problem

In general, a scientific research revolves around the research problem and the derived research questions. The research problem is the research subject formulated into a problem which's solution is sought by carrying out the research. To make the problem more manageable, it is often split into a series of research questions – smaller problems that can be answered step by step during the research. (Hirsjärvi, Remes & Sajavaara 2007, 121-125)

Like other scientific research types, the case study also starts with specifying the research problem and questions within the research subject. (Kananen 2013, 60-61) The problem this case study seeks to solve is: *how the manufacturing should be planned and controlled in the future lean environment in the case company?* This can be further set to multiple questions:

1. Are there specific requirements for manufacturing planning and control in a lean manufacturing environment?
2. What are the specific requirements for manufacturing planning and control regarding the case company itself?
3. What kind of manufacturing planning and control model can be applied to the case company?

When all research questions are answered, the research problem is solved and as a result, a suitable manufacturing planning and control system can be proposed.

2.3 Data Collection and Analysis Methods

In a case study, the research questions are answered by collecting data from multiple sources due to the complex nature of the problem. The multi-source method can also be used to verify the results if the different sources give similar results. (Kananen 2013, 77-79) The selected research methods are both qualitative and quantitative and are presented in regard of the research questions (see chapter 2.2):

1. Most likely the answer to the first research question lies in the literature regarding lean manufacturing. Therefore, in order to answer the first question, a literature review will be done.

2. The second question is case-specific and unique to the company and sector. Therefore, instead, of a literature review, different methods must be used. The answer for the second question is sought to be answered through interviews and observation. In addition, to the qualitative methods, a quantitative method of product data analysis is used.
3. Finally, the last question is answered by abductive reasoning between the theoretical and actual company specific data.

TABLE 1 compiles the selected data gathering methods including their strengths and weaknesses.

TABLE 1. The strengths and weaknesses of data sources (Kananen 2013, 80)

Data source	Strengths	Weaknesses
Documents, literature	Invariable, facts, comprehensive	Selectivity, infuence of the reporter, availability, confidentality
Interviews	Targetable, deeper understanding	Improper questions, improper answers, conformance
Partaking observation	Genuine conditions	Time consuming, interference of the researcher, selectivity,

2.3.1 Literature / Document Review

Before conducting the research, a comprehensive review of past researches regarding the subject should be done i.e. what is known of the researched phenomenon? These researches can be later used also as a base of reasoning. Field specific literature also provides the researcher with metrics, tools, concepts and data collection and analysing methods. (Kananen 2013, 81-82)

Written material may consist of minutes of meetings, memos, reports, biographies, articles and documents. Whenever a document or article is decided to include in the research material, the following questions must be asked (Kananen 2013, 82):

- Who created the material?
- When was it created?
- What information does it contain?
- Why was it created?

Availability of written materials (especially materials that include info of organisations) may be hard to reach due to confidential issues. (Kananen 2013, 82)
Also in this case study, there are limitations to accessibility of the material as later described in this chapter. The written material used in this case study consists of:

- Subjective books
- Methodological books
- Scientific articles
- Company reports

2.3.2 Interviews

Interviews are among the most frequently used methods of collecting qualitative data. However, they can also be used to collect quantitative data. Interviews are closer to discussion than enquiry. (Eskola & Suoranta 1998) Interviews can be divided into three categories based on their structure (Hirsjärvi et. al. 2013, 202-204):

1. Structured interviews have same questions for everyone and a fixed sets of answers.
2. Thematic interview is an open-discussion within pre-selected themes.
3. Open-interviews / in-depth interviews have no fixed framework

Eskola & Suoranta (1998) describe also a fourth type that falls between structured and thematic interviews:

4. Semi-structured interviews have same questions for everyone but the interviewees can answer them by their own words

Interviews can be either held within groups, pairs or individually depending on the resources and time. Individual interviews give the most accurate answers. (Kananen 2013, 88) This thesis uses individual semi-structured interviews combined with structured parts for data collection.

2.3.3 Observation

Observation is useful if other methods such as interviews or surveys cannot provide the information needed or the information cannot be trusted. Tacit knowledge is a good example of information that is hard to obtain via other methods. (Kananen 2013, 88)

Observation can be categorized in three categories (Kananen 2013, 88)

1. In direct observation the observer is present and recognized but takes no part in the researched phenomenon
2. In covert observation, the observer remains unnoticed
3. In participative observation, the researcher takes part in the phenomenon

In this thesis, the observation is done as a working colleague which means that the observation was not always acknowledged by others. In addition, order scheduling (a core part of this research) was one of the main parts of the job. This means that the observation done falls into all three categories.

2.3.4 Product Data Analysis

The analysis methods used in this case study are not recognized as classical quantitative research methods. Three methods were used to analyse the product data:

1. Grouping products by similarity

2. ABC-analysis
3. Assigning weights to criteria

ABC-analysis is an inventory management method which classifies the stock-keeping-units (SKU) by their sales volume. Typically, around 20% of the SKUs account for 80% of the revenue. (Benton 2014)

Heikkilä (2008, 133) advices to always keep the original data when categorizing data. This is because whenever, the data is aggregated, some data is lost. This proved to be difficult because the data had to be very aggregated when taken outside Marioff's premises.

3 Manufacturing Environments and Order Penetration Point

Benton (2014, 10) explains that to understand the significance of manufacturing planning and control (MPC), it is crucial to recognize the differences between the four manufacturing environments. Therefore, it is logical to present them before manufacturing planning itself. The different environments are:

- Make-to-stock (MTS)
- Assemble-to-order (ATO)
- Make-to-order (MTO)
- Engineer-to-order (ETO)

These production environments are separated by the order penetration point (OPP) which defines the point after which the material is assigned to a sales order. The OPP affects production, planning and other operations of the company and can greatly affect the lead time experienced by the customer. (Tilauksen kohdennuspiste (OPP) 2016)

The placement of the OPP must be carefully justified as all operations after the OPP contribute to the total customer lead time while all operations before the OPP will have to rely on forecasts instead of the actual sales data. However, in the latter case it is easier to level and control production peaks. (Tilauksen kohdennuspiste (OPP) 2016) The demand dependence of operations is presented in FIGURE 1 where dark blue indicates demand independent operations and light blue indicates the demand depended operations i.e. lead time experienced by the customer.

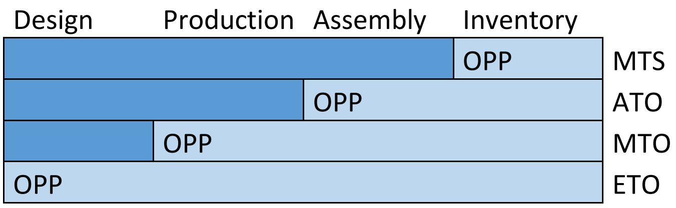

FIGURE 1. Order penetration point (after Tilauksen kohdennuspiste (OPP) 2016)

Lead time requirements of the customers tend to drive the OPP towards the customer whereas product variability and demand uncertainty drive it away from customer. The more product variables, less likely it is economically sustainable to keep every variable in stock. Therefore, often large and steady volume products are kept in stock whereas products with a lot of variance are either assembled- or made-to-order. Thus, companies have often multiple OPPs depending on the product characteristics. (Tilauksen kohdennuspiste (OPP) 2016)

The production environment also gives influence on how much an individual customer can affect the product design. In MTS-environment the customer is left only with the decision to buy or not to buy whereas in ETO-environment, the customer can influence the product design itself. (Chapman 2006, 3)

3.1 Make-to-Stock

In a make-to-stock (MTS) environment, the sales orders are placed in the finished goods inventory. The inventory is either replenished based on forecasts or by replenishment orders triggered e.g. by re-order points. MTS is a typical choice when:

- production through-put times significantly exceed required lead times,
- the demand is high and predictable and
- product variability is low. (Varasto-ohjautuva tuotanto (MTS) 2016)

It is also notable that the customer cannot request any modifications to MTS-products. (Chapman 2006, 3)

MTS strategy brings inventory risks however. Forecasts might not be accurate which leaves products to be unsold and working capital can be high depending on the inventory levels. Thus, accurate forecasts and good inventory management is the key for success in this environment. (Varasto-ohjautuva tuotanto (MTS) 2016)

3.2 Assemble-to-Order

In assemble-to-order (ATO) environment, the sales orders are placed in the final assembly. The products are then assembled from various sub-assemblies and components after which they are tested, packed and delivered. The final products are often designed to be modular i.e. the final products consist of combinations of different interchangeable parts. These parts (a.k.a. modules) are typically produced to stock based on forecasts or replenishment orders. (Tilauksesta kokoonpano (ATO) 2016)

At best, the ATO strategy enables high product variability due to the numerous final assembly options combined with relatively short lead times. (Tilauksesta kokoonpano (ATO) 2016). Recently, Marioff has modularised one of their main products to shorten the lead time and simplify the related order-to-delivery processes.

3.3 Make-to-Order & Engineer-to-Order

In make-to-order strategy (MTO), the sales order initiates the production. The inventories consist purely of raw materials and sales order specific work-in-process (WIP) inventories. This approach is common when:

- production quantities are low,
- product variability is high,
- product is not or cannot be modularised or
- keeping product variants or modules in stock is not economically or physically feasible. (Tilauksesta valmistus (MTO) 2016)

The engineer-to-order (ETO) strategy differs from MTO in a way that the customer order is placed at the initial design of the product - thus, offering most customisability for the customer. The product can be designed specifically after individual customers using special materials and unique designs. The downside of the ETO is the long lead time as everything from design, purchasing, production, assembly, testing and packing is included in the customer lead time. (Tilauksesta suunnittelu (ETO) 2016)

At a project level, Marioff’s manufacturing environment could be identified as ETO. The systems are tailored per application even though the system components are more or less standard. Therefore, the initial sale-to-delivery process is lengthy.

4 Manufacturing Planning and Control

In order to define the requirements for the manufacturing planning and control model, it is necessary to define what it is. Benton (2014, 2) states that the primary objective of manufacturing planning and control function:

> *...is to ensure that the desired products are manufactured at the right time, in the right quantities, and meeting quality specifications in the most cost-effective manner.*

According to Benton (2014, 2), a manufacturing planning and control system seeks to integrate the following activities:

1. Determining demand
2. Translating demand into production plans
3. Developing material flow plans
4. Capacity management
5. Delivery Scheduling

Therefore, the MPC function harbours many different activities including forecasting, aggregate planning, master production scheduling, inventory management, material requirements planning, capacity management and more. As stated in chapter 2.1, this research will not include all MPC activities.

4.1 Demand and Forecasting

Product demand affects all supply chain functions including inventory coordination, manufacturing and scheduling; the core elements of this research. Without accurate demand management and forecasts, the supply chain cannot work efficiently. (Benton, 2014, 18) However, forecasts are used differently in different manufacturing environments as set out in chapter 3.

Forecasts have three interrelated qualities to them. Accuracy reflects how a forecast corresponds to the real conditions, simplicity describes how easily the forecast can be computed while flexibility expresses how adaptable the forecast is to changing conditions. High accuracy usually means more complex and less flexible forecast and vice versa. (Benton 2014, 19)

Benton (2014, 20-21) explains the forecasting process to be the following:

1. Determine the forecast purpose; for example, sales and operations planning and master scheduling have different requirements regarding the precision of the fore-casting. Where S&OP is forecasted with aggregate quantitative methods, master scheduling bases on qualitative or time series models. (Chapman 2006, 76)
2. Establish the forecast interval; S&OP and the Master Schedule have different time horizons
3. Select a forecasting technique:
    a. Qualitative forecasting; market surveys, panel consensus, life cycle analogy and informed judgement (Chapman 2006, 19-20)
    b. Quantitative forecasting; input-output, econometric, simulation, regression and time series models (Chapman 2006, 23-24)
4. Collect and analyse data
5. Initialize the forecast
6. Generate the forecast
7. Continuously monitor the forecast quality

As can be seen from FIGURE 2, the forecast is constructed by inputting historical data in a mathematical model. The forecast is then tested on actual data and the error is calculated. The error acts as an input to improve the model or switch input data. The error can also be used in safety stock calculations (Benton 2014, 19-20)

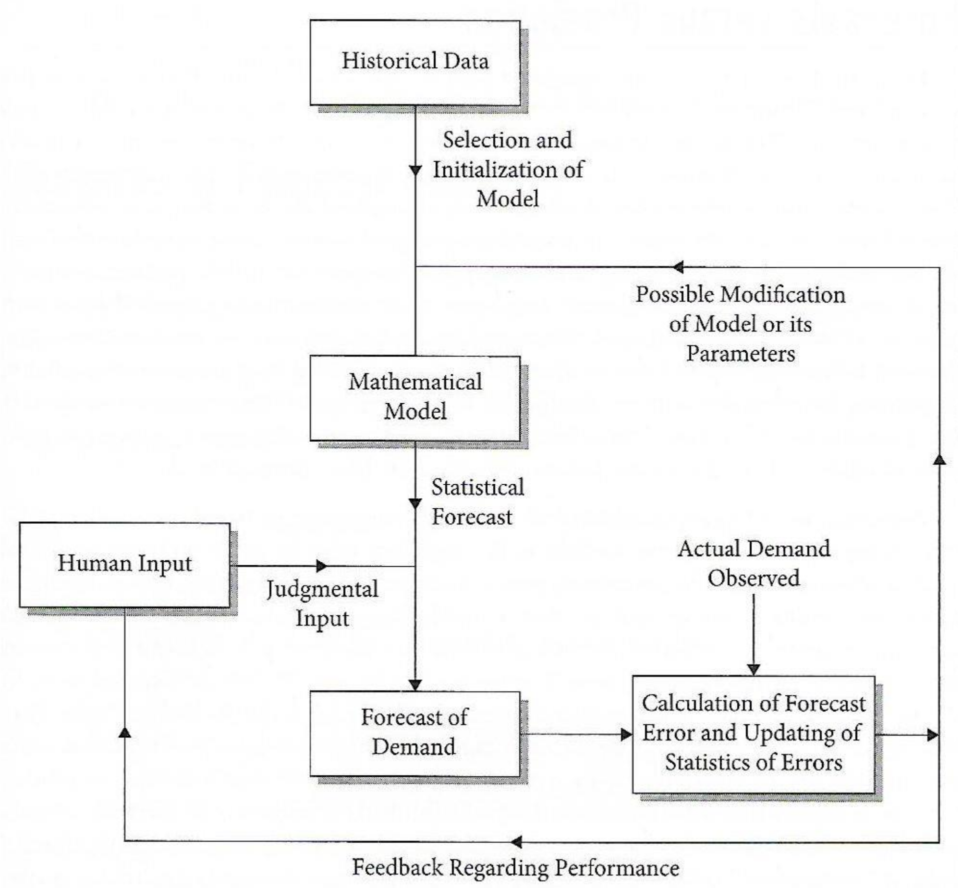

FIGURE 2. Forecasting Framework

4.2 Sales and Operations Planning

Although this case study does not concern the sales and operations planning, it is still introduced here briefly due to the importance of it in the production planning and control.

Sales and operations planning (S&OP) is used to plan how much, when and what kind of resources will be needed to meet the customer demand. The S&OP is the link between the business plan and sales and operations. The S&OP serves as input and sets constraints for various company activities such as (Chapman 2006, 46, 76):

1. Inventory levels
2. Cash flow
3. HR

4. Capital needs
5. Production Outputs
6. Capacity Planning
7. Sales and marketing activities

The S&OP is often called aggregate planning. The forecasts and product data is aggregated into families or groups and the time frame ranges between weeks and months. The data is aggregated to the point where no vital information is lost. The aggregation is due to the simplicity and reliability of grouped data. (Chapman 2006, 46-47)

In MTS environment the S&OP planning is done based on the inventory levels whereas in MTO, the planning is based on the order backlog. For example:

- MTS: Target inventory of 15 days; there is always 15 days of inventory.
- MTO: Target backlog of three weeks; the maximum amount of orders in the order book will not take more than three weeks to produce. (Chapman 2006, 49)

The S&OP can attempt to meet all demand, minimise inventory investment or minimise the impact on workforce. The S&OP strategies can be divided into three categories (Chapman 2006, 52)

- Level strategy; maintains steady production rate and uses inventories to even out the changing demand (FIGURE 3)
- Chase strategy; adjusts the production to match the demand by temporary workers for instance (FIGURE 4)
- Hybrid strategy; A mixture of these (FIGURE 5)

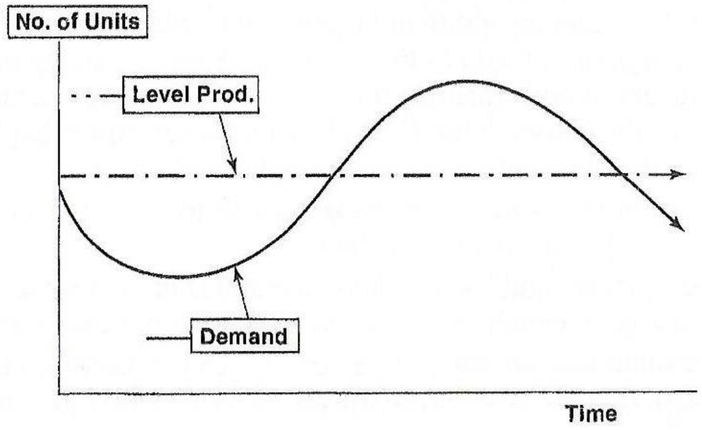

FIGURE 3. S&OP level strategy (Chapman 2006, 54)

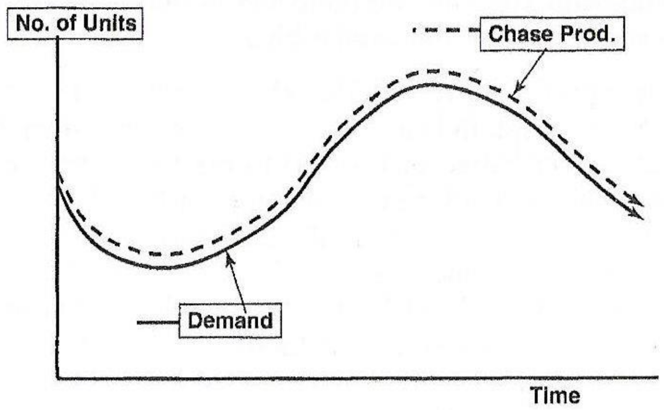

FIGURE 4. S&OP chase strategy (Chapman 2006, 54)

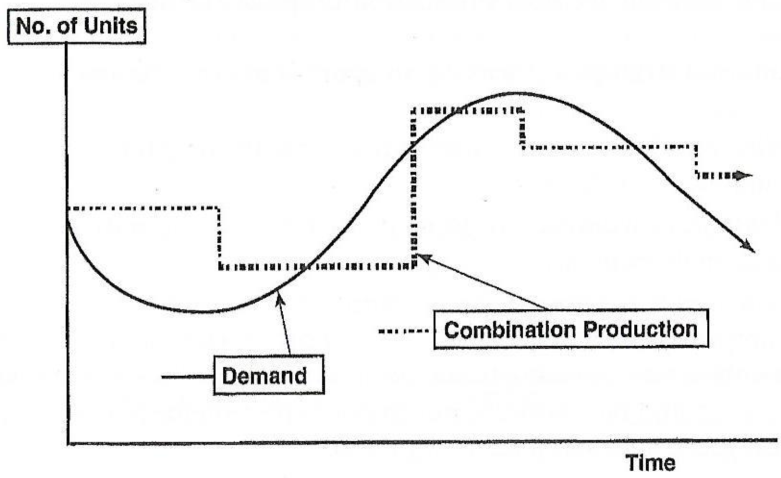

FIGURE 5. S&OP hybrid strategy (Chapman 2006, 55)

4.3 Master Scheduling

Whereas the sales and operations plan is aggregated, the master schedule concerns individual products. The master schedule is used to promise customer orders and to translate customer orders into the production schedule. (Chapman 2006, 72)

According to Chapman (2006, 72), the purpose of the master schedule is to:

- Break down the aggregated plans of S&OP into focused information on specific products
- Serve as an input for specific capacity and resource plans
- Serve as a medium to translate customer orders into timed production orders
- Serve as a tool to manage inventory levels

The planning horizon used in master scheduling is shorter than in S&OP. The horizon must extend only as far as the cumulative lead time specified in the bill of materials (BOM) of a certain product. Additionally, the planning horizon includes a planning time fence and a demand time fence as shown in FIGURE 6. The planning time fence is generally longer than the maximum lead time of the product whereas the demand time fence the forecasts are ignored and little or none (in which case the period is frozen) changes are made to the master schedule. Between these two time fences, the orders may be changed to a certain extent depending on e.g. lead time of purchasable items. Orders outside the planning time fence can be freely changed. (Chapman 2006 72-76)

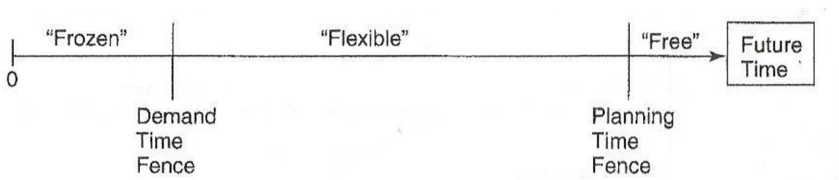

FIGURE 6. Degree of Fluidity in Scheduling (Chapman 2006, 76)

Master schedule uses forecasts and actual customer orders as an input and is thus managed differently depending on the production environment (Chapman 2006, 76-78):

- The master schedule acts as an inventory replenishment schedule in a MTS environment. Order confirmation does not often have to be done via the master schedule as the orders are delivered straight from the finished goods (FG) inventory.
- In an ATO environment the different sub-assemblies are forecasted and scheduled instead of the final goods. This is due to the enormous amount of possible end combinations. The delivery lead time is thus the final assembly lead time assuming that the selected options are in stock.
- The high variability of the demand of design and quantity in a MTO environment makes it impossible to schedule any production before-hand. Instead, aggregated plans (S&OP) may be used for capacity scheduling and raw material needs.

Benton (2014, 104) states that most companies should have a master scheduler; a person that connects marketing, distribution, engineering, manufacturing and planning. The key tasks of such person include:

- Confirm delivery dates for customer orders
- Evaluate the impact of possible delay reports from purchasing and production
- Revise the master schedule when material or capacity constraints are infringed
- Communicate the conflicts of demand and capacity to marketing and manufacturing

Marioff has recently formed a production planning team in order to centralise the planning functions. This team can be seen as the master scheduler mentioned by Benton.

4.4 Inventory Management

Benton (2014, 112) explains that inventory management decisions play a substantial role in the function of manufacturing planning and control by answering the questions:

1. What to store?

2. How much to invest?
3. How much service to offer (protection against stockouts)?

The inventory management decisions are closely dependent on the company's manufacturing strategy and the OPP. It should be noted that in a MTS environment, inventory management has a key role in customer service due to the direct impact in product availability. (Benton 2014, 112)

Defining an inventory replenishment strategy consists of determining how the inventory levels should be reviewed, how much should be ordered and when should the replenishment order be placed. (Sehgal 2008)

4.4.1 Review Period

The review periods of the inventory levels can be divided into two categories: continuous review and periodical review. In the continuous review model, the inventory levels are continuously monitored. As soon as the inventory level drops below a certain level (re-order point for example) a replenishment order is made. The continuous review requires a sophisticated IT system monitoring the exact inventory levels. (Sehgal 2008) Unlike real-time inventory review systems, enterprise resource planning (ERP) systems often calculate the inventory levels according to finished work orders and consumption.

Periodic review means that the inventory levels are checked with pre-determined intervals. If the levels are below the re-order point, are replenishment orders sent. The periodic review is viable when the process is manual, large scale of products are checked or when the orders can only be sent on a specific day. (Sehgal 2008)

4.4.2 Order Quantity

The order quantities can be fixed or dynamic depending on the selected method. (Sehgal 2008) The fixed re-order quantities can be calculated through various economic lot-sizing techniques. The economic order quantity can be calculated with various deterministic – when all input data is known, stochastic – input data includes probability a density function and fuzzy models – uncertain information about the input parameters. The most traditional is the Wilson's EOQ model (Andriolo, Battini, Grubbström, Persona, Sgarbossa 2014, 3 & 22):

$$Q = \sqrt{\frac{2KD}{h}}$$

Where,
Q = order quantity
D = annual demand in units
K = cost of ordering
h = inventory holding cost per unit

Another way of determining the order quantity is to set a base stock level. With periodic review, the replenishment quantity equals the set maximum level subtracted with the stock level at the time of review. When combined with continuous review, the base stock level model becomes very similar to the Kanban system: whenever the inventory level drops below the maximum, a replenishment order (pull signal) is sent. (Verma 2006, 3)

4.4.3 Safety Stock

Safety stocks are implemented to guard against changes in demand and lead times to prevent stockouts. Safety stocks are calculated separately from the base inventory. (Benton 2014, 123) There many ways to calculate the safety stocks. Here is presented one example of the various safety stock models. Talluri, Cetin and Gardner

(2004, 62) propose a matrix model which accounts for volatilities in both supply and demand:

		Lead-Time: Constant	Lead-Time: Variable
Demand	Constant	No Safety Stock	$R_L = RL$ $\sigma_L = \sqrt{R^2 s_L^2}$ $SS = F_s^{-1}(CSL)\sigma_L$
	Variable	$R_L = RL$ $\sigma_L = \sqrt{\sigma_R^2 L}$ $SS = F_s^{-1}(CSL)\sigma_L$	$R_L = RL$ $\sigma_L = \sqrt{\sigma_R^2 L + R^2 s_L^2}$ $SS = F_s^{-1}(CSL)\sigma_L$

FIGURE 7. Safety stock matrix. (Talluri et. al. 2004)

Where the variables are,

R = average demand per period

L = average replenishment lead time

s_L = standard deviation of lead time

SS = safety stock

CSL = cycle service level

F_S^{-1} = inverse normal

5 Lean

The revised manufacturing planning and control model will be operating in a lean manufacturing environment. A key for its success is to define lean and its key principles and make sure that the manufacturing planning and control model applies to these principles.

Every author tends to have a different grasp of what lean is. Probably the simplest definition is given by Antti Piirainen (2011) during his Lean-tietoisku lecture where he states:

> *Lean is about creating flow. It is an aid for growth; the way we can achieve more with less.*

Flow is the amount of units (=products or services) the company sells over a certain period of time. In business terms, flow can be thought of as revenue since every sold product or service brings revenue. (Piirainen 2011)

Waste on the other hand is everything that obstructs or does not increase flow. The waste has been originally categorized in seven categories in order to help identifying them. These categories are:

- Defect – defect products or services
- Over-Production – producing products or services that have no real demand
- Transportation – unnecessary transportation
- Waiting – the time between value-adding processes
- Inventory – inventory ties up money and resources. Inventory also hides other wastes.
- Motion – e.g. unnecessary moving by the workers in production.
- Over-Processing – e.g. over quality (Piirainen 2011)

In addition, Liker (2004, 28) mentions an eight waste:

- Latent Skills – unused skills of employees

Waste is always a consequence or a symptom of something. This is why it is more important to remove the root cause than the symptom. (Piirainen 2011)

Womack and Jones (2003) describe the five principles of lean which are then explained further in the following chapters:

1. Identify value
2. Identify the value stream
3. Create flow
4. Implement Pull
5. Hone to Perfection

5.1 Value

Identifying the value can be started with asking what the customer wants. What does the customer value or what does the customer pay for in a product? (Womack & Jones 2003, 16-19)

The next step is to identify the value stream. In another words mapping out all the steps that add or do not add value to the product. The non-value-adding steps can be divided in steps that:

- do not add value but cannot be discarded with the current technology available or
- do not add value and can be discarded immediately

The value stream is threefold: from concept to availability, from sale to delivery scheduling, from raw material to product. However, the value stream does not necessarily stop or begin at company's boundaries but streams through the company continuing through the next company. A true lean enterprise is a business that creates and maintains a cross-company value chain. (Womack & Jones 2003, 19-21)

Manufacturing and planning play important roles in value-adding. A well fitted MPC system with the manufacturing environment enables better execution of operations that add value (Newman & Shidharan 1995) In another words, if the manufacturing is planned properly, the planning function supports value-adding.

5.2 Flow

Traditional resource-efficient companies focus on the efficient use of resources. However, when creating flow, the main point is to focus on the flow-unit (customer or product) and the throughput time. When the focus is shifted from the resources to the flow-unit, often it can be noticed how much waiting there is between the value adding processes. For example, products and tasks are often processed in batches. While very resource-efficient, the throughput time of a single product suffers greatly from sitting around in batches. (Womack & Jones, 2003 23-24)

The first step in creating the flow is to concentrate on the product through the whole value-stream. The second step is to ignore the traditional departmental and functional boundaries to ensure the connected flow from process to process. The third step is to re-engineer the tasks and processes to prevent waste. The goal is to have the product continuously processed without waiting. (Womack & Jones 2003, 23-24)

5.3 Pull

First visible effect of creating flow, is the substantial drop in the lead times in concept to launch, order to delivery and raw material to customer processes. This makes it possible to discard the sales forecast and plan on the actual demand of the customers. In another words, enabling the pull system (Womack & Jones 2003, 24-25) Sheldon (2008, 24) however states that companies have often components with long lead times that require at least some level of proactivity before customer orders can be delivered. This is not different from Marioff. Marioff also has components which supply lead times greatly outcome the sales lead times.

Traditionally in a push environment, a team called expediters manually prioritise work orders whenever a critical delay or change in demand has been noticed. In a lean enterprise, there is no need for expediting because there are no production stoppages. The products are built to order with short lead times and the production capabilities are clear and precise. Takt time is used to synchronize the rate of sale to the rate of production. (Womack & Jones 2003, 55-56)

5.4 Perfection

There are two ways to perfection: the incremental path, *Kaizen* and the radical path, *Kaikaku.* The Kaizen events are frequent events that attempt to correct specific activities in the value stream. Kaikaku however, is the total re-engineering of the entire cross-company value stream. Both are needed for the pursue for perfection. (Womack & Jones 2003, 90-94)

In order to aim for perfection, the picture of perfection must be envisioned. However, this cannot be done until the four previous lean principles have been implemented. While picturing perfection, it is notable to not only compete against competitors but also the perfection itself. After the perfection has been defined, management will decide two or three clear steps to achieve the perfection. (Womack and Jones 2003, 94-95)

The paradox here is the fact that nothing is perfect. Therefore, it is not humanly possible to envision or achieve perfectly perfect perfection. The point is to continuously set new objectives, plan on how to reach them and after reaching them, make a set of new objectives. I.e. endlessly and continuously improve until perfection is reached. (Womack and Jones 2003, 95)

5.5 Transparency

Womack and Jones emphasize on transparency throughout their book. One of the key elements in successfully creating a lean enterprise, is to make everything visible. Everyone along the value stream should be able to see the value, the value stream, the flow, the pull and the perfection. “Transparency in everything is a key principle”. (Womack and Jones, 2003)

6 Push and Pull

Because pull is such a core concept of lean manufacturing, it is useful to define what is pull and its counterpart: push. Benton (2014, 202-203) states that in a push manufacturing system, the production is based on forecasted demand whereas a pull system bases on the actual customer demand. Similarly, Chapman (2006, 205) distinguishes the push system to base production on planned production order releases whereas pull system reacts to the customer demand without preplanning. Therefore, push is proactive and pull reactive.

Hopp & Spearman (2008, 356-358) come to a less broad conclusion of the multiple definitions of pull and push: “A pull system establishes a priori limit on the work in process, while a push system does not”. The distinction is further established by stating that a push system releases the work orders by a schedule that is based on actual demand and forecasts while a pull system allows the work order release depending on the system status (e.g. triggered by the inventory level). In other words, as seen in FIGURE 8, the work order releases are controlled externally in a push system opposed to the internal control in a pull system. A system where the production is triggered by both, external and internal triggers, for example, MRP combined with Kanban, is called a hybrid system.

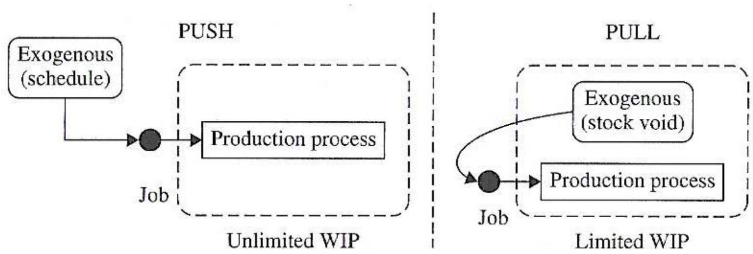

FIGURE 8. Release of work in push and pull systems (Hopp & Spearman 2008, 357)

Many of the lean production companies have not implemented a pure pull system. Chapman (2006) deciphers that because of the low inventory levels in lean production, securing the needed resources is extremely important. Therefore, many companies have master scheduling and S&OP running side by side with pull systems.

The following sub-chapters will describe some of the common push and pull production systems.

6.1 Batch-Flow and MRP

In a batch-flow system, same products of different customer orders are batched together to save in setup costs and increase resource utilisation. This leads to large level of WIP in the system due to ensuring that the workstations have always material. (Miltenburg 2005, 340)

The production lead times consist mostly of waiting free production capacity due to several orders being processed at the same time. Due to this, confirmed order delivery dates go long and are often unreliable. Whenever, an order is in a risk of delay, personnel will try to expedite the process regarding the order. The expediting is not always successful however. (Miltenburg 2005, 340-341)

If a company is unsatisfied to the production outputs of batch-flow production, it may choose to adopt a line flow production model or a just-in-time production model. (Miltenburg 2005, 339) Marioff can be currently identified as a batch-flow manufacturer. However, the company has chosen to adopt the just-in-time production a.k.a. lean manufacturing model.

6.2 Just-in-Time, CONWIP & Kanban

In JIT production, each area produces to response of pull-signals. MRP sets the capacity plan and master production schedule. (Miltenburg 2005, 405) The amount of work in the system is limited by the pull material control methods described below.

The constant work-in-process model (CONWIP) is probably the simplest pull-based material control models. The CONWIP simply limits the amount WIP allowed in the system. Whenever the WIP is full, no work orders are allowed to be released until a WIP work order finishes. The CONWIP system passes the pull signal straight from the end of the production chain to the start. (Hopp & Spearman 2008, 362-363)

The Kanban system works in a similar fashion as the CONWIP but limits the WIP at every work station. The system has two types of cards, one for material and one for the production authorisation. If the work station has received a production card, a downstream work station or inventory or a customer needs the materials provided by the work station in question. After a production card is taken, the work station operator checks whether the materials needed for the production are present. Once the materials are removed from a specific bin or a vessel, the operator places a “move” card to send a pull signal for the used materials. (Hopp & Spearman 2008, 168-169)

7 Research & Results

The research was conducted between November 2015 and April 2016. The company data gathering was focused between November 2015 and January 2016. The following chapters describe the data collection methods used and present the results of these methods.

7.1 Interviews with Planners

In January 2016, a semi-structured interview was held individually with the production planners of machining, light assembly, heavy assembly, kitting and warehousing resulting in total of four interviewees. Each planner was interviewed once, interviews were held individually and each interviewee had the same questions. Before the interview, the interviewees were sent the themes of the questions so that they could prepare for the session. After the interviews, the answers were transcribed and sent to the planners to be confirmed. If any corrections had requested, the answers were corrected and sent back for confirmation. Once the answers were confirmed, the gathered information could be used in the research.

The results of the interviews are thematically aggregated below.

7.1.1 Planning Horizon

In the case company, the MRP gives each production unit a visibility of three months ahead. More precisely, the MRP does not generate planned orders past three months. Regardless of the MRP, the production can be planned even further when requested. For example, light assembly had opened work orders for certain products until mid-summer at the time when the interview was held in January.

It was also found that the master schedule is made as accurately as possible once the demand and capacity are known. No short-term, mid-term or long-term plans are distinguished in production.

The planning horizon in the warehouse operations however, is only five workdays. This is due to the high possibility of changes in the customer demand. This coincides with the observations made while working at the company. Additionally, the mid-term planning was partly done by the customer service team by not allowing orders to be scheduled on days or weeks with heavy load and rescheduling current orders if needed.

Production and inventory planners were often obliged to control the day-to-day operations as well. Due to this, some dissatisfaction has surfaced as the day-to-day operation control should be left with the supervisors. Namely, planners should be able to primarily focus on the planning function.

7.1.2 Demand Forecasts

The general note across the production units (except light assembly) on forecasts was that proper systematic demand forecasts are not available. The forecasts provided are mere anticipations of the future high demand given informally via e-mails and meetings as opposed to ERP generated calculated forecasts. Interestingly, not all planners had not even needed forecasts as they have already such good visibility in the future combined with long delivery lead times of some products. Light assembly differs from the rest by adding that in addition to the informal forecasts, the demand data of the last 12 months is used.

In cases, the demand predictions are addressed by making capacity reservations. The capacity can be reserved as long as other orders do not need the capacity. Some cynicism towards the demand prediction has built up as there has been numerous times when the anticipated demand never actualized resulting in unused capacity.

In the warehouse operations, the anticipations of demand are considered difficult to take into account due to the short visibility of capacity. The uncertainty in the presence of the workforce combined with fixed tasks greatly impact the capacity planning.

7.1.3 Capacity Transparency

One of the main problems encountered, was the lack of transparency in capacity information. The capacity information is well-known within the production unit, but currently there is no systematic way of sharing the information with sales for instance. This is a great issue in the way of synchronizing the rate of sale with the rate of production (as presented in chapter 5.3). The current unsystematic ways of capacity sharing consist of:

- General daily meetings; short-term exceptions and other daily news.
- Weekly meetings; medium-term capacity, demand planning and analysing of delayed order lines.
- Emails and other discussions concerning capacity and demand planning. For example, a new order entry often requires collaboration with the production planners as the standard lead times given by the ERP are not satisfied with.

The problem with the lack of capacity visibility is that the project managers and coordinators who enter orders into to the system, cannot see the capacity directly but have to rely on the rudimentary standard lead time provided by the ATP calculation. This calculation is often not satisfied with which frequently leads to expediting requests.

7.1.4 Delivery Lead Times

The very consistent opinion across the production units was that the customers are not satisfied with the current lead times. Despite the fact, that the lead times of certain products are very short, there are frequent orders that require ever faster deliveries. This has raised a suspicion, whether closing the sale takes too long leaving the operations only a limited time to complete the delivery. Additionally, the customers should be able to plan their purchases.

Minimum customer lead time of one week is generally considered to be sufficient for MTO and ATO products across the production units and warehouse. Spare parts could be delivered faster.

7.1.5 Prioritisation and Expediting

The dissatisfaction toward standard lead times given by the ERP can be seen in frequent expediting requests. The expediting requests are generally anticipated by leaving some slack within the production schedule. However, no slack is left in the warehouse operations for express deliveries.

Processing the expediting requests are often perceived as laborious – especially during times of high demand when the constant requests cause the master schedule to be re-planned multiple times per day. This rescheduling extends upstream causing re-planning in other production units and purchasing as well.

Rescheduling the master plan is considered tedious also because of the lack of clear priority information across the work orders. Work orders have to be examined individually if they have a direct customer need or if they are only for inventory replenishment. Typically, the inventory replenishment orders are postponed in order to expedite customer orders. Other priorities include key customers' orders, orders without allowed backorders (in case of unexpected stockouts) and orders that if delayed, impose sanctions. In general, if the reason for hurrying is important, the delivery is done even in the expense of other orders.

Some consider that e-mailing expediting orders is problematic. Sometimes they remain unnoticed which can cause double work in case when:

1. Order entry in ERP
2. Not satisfied with the standard lead time
3. Requesting expediting via e-mail
4. The e-mail remains unnoticed

5. MRP creates a planned work order during the night
6. Production planner accepts or reschedules the planned order thus opening a work order
7. MRP creates another set of planned orders based on the previous decision.
8. Upstream production planners and purchasing open work and purchase orders.
9. Second expediting request done via e-mail or phone.
10. The planners and purchasers have to reschedule the recently created orders → double work

Another notion on the laboriousness of the expediting requests, is that the availability of the parts have to be manually re-checked every time. Some way to simulate the impact of the expediting on the inventory levels would be warmly welcomed.

7.1.6 Inventories

MTS products are often demanded with very short lead times but the inventory levels cannot cover all demand however. Thus, whenever a stockout happens, production is rushed to supply the demand. However, there was some criticism across the production units if the inventory levels even need to match the highest demand spikes. Additionally, prioritization of direct customer orders is seen problematic because the inventory levels are not replenished accordingly. The problem is that are the levels too low or are they not replenished accordingly?

Regarding some products, the safety stocks and WIP inventories surpass the needs. Once the processes are re-engineered to be lean, the WIP inventory levels are expected to drop. Especially the light assembly products have short throughput times which do not justify the current excess inventories.

All finished goods inventories of heavy assembly products will be removed in the near future. This is justified by concluding that the throughput times of these products will be reduced tremendously as a result of the lean transformation in addition to the physical and economical characteristics of the products.

7.1.7 Production / Material Control Methods

Currently all production is managed with the MRP regardless of the production environment (MTS-MTO). The MRP creates planned orders whenever a (future) stock level of a product or component fall below zero (MTO) or the defined safety stock level (MTS & ATO)).

In addition to the MRP, there is a Kanban system in place for certain products. The Kanban has received some criticism though; it is seen very inflexible to the changes in demand. The fixed number of Kanban cards cannot account for larger orders due to the insufficient amount of material in the system. The material within the Kanban is not kept in record. Therefore, the real time amount of material is not shown in the ERP which has resulted in manual checks of the material inside the Kanban. This is done mainly to find out the need for additional work orders in order to address the increase in demand. Also, some level of prioritization is sought after the Kanban replenishment due to the cases of machining supplying currently parts without current demand instead of parts that are needed hastily.

7.1.8 Other Notions

Limitless capacity is seen as a major issue throughout the functions. The ERP / MRP schedules orders within a standard lead time regardless of the quantity or relevant capacity utilization. This causes a lot of manual rescheduling and expediting.

Products could be categorized into availability classes and reviewed periodically to readjust the needed availability. Additionally, orders limits could be established for instance, orders of 100 pcs are supplied directly from stock as 10 000 pcs are made to order. Also, some inconsistency in the current product classes was perceived. Certain MTO-products had an exceptionally sufficient availability in the FG stock.

7.1.9 Emphasis on the Future Model

At the end of the interview, the planners were asked to rate things to be considered in the future model with a score within 0—5 range; five meaning the most important. The results can be seen in FIGURE 9.

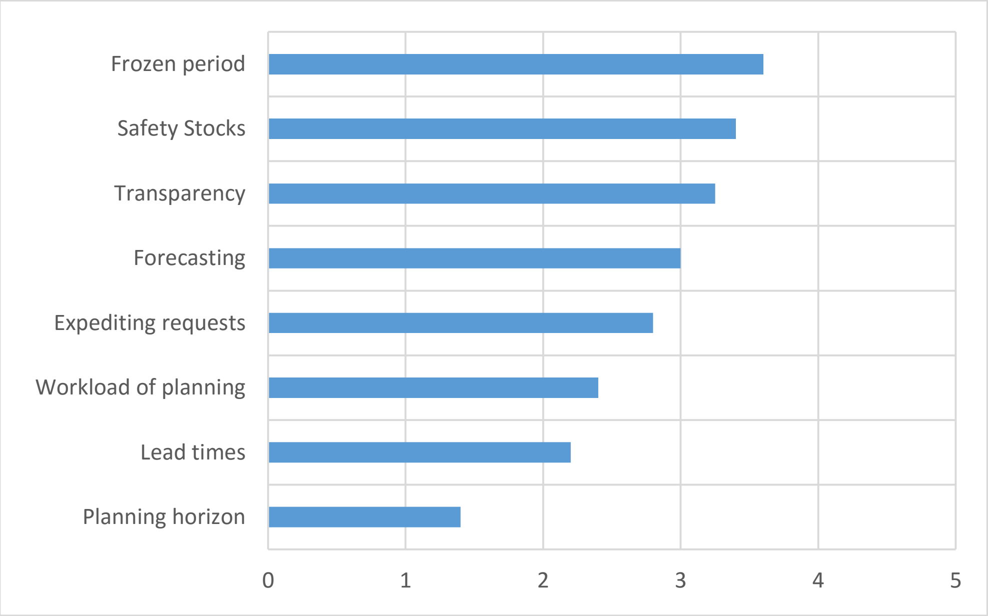

FIGURE 9. Subjective importance of different aspects of the future MPC.

Many commented on the demand time fence being frozen. However, not all planners wanted to completely freeze the period but to leave in some flexibility. For example, any changes within this period should always be discussed through with the planners.

The most important notice of safety stock levels was to assign their management to someone in particular. This way the levels would possibly be updated frequently without excessive bureaucracy.

An interesting note – possible resulting from interviewing only the production planners – is that the current planning horizon is not seen problematic. Nevertheless, there are no clear rules or set flexibility time fences (as presented in chapter 4.3) in place which could often be observed problematic because work orders are rescheduled freely throughout the planning horizon.

7.2 Product Data Analysis

In order to give recommendations on how different products should be managed and categorized, two sets of data were extracted from the ERP and analysed. The data consisted of sales history of quantity, price, manufacturing and delivery lead times, deviation of demand, average order lead time and confirmed on time delivery percentage. The products were then grouped into fourteen categories which were then analysed with the ABC-method and further divided into A, B and C classes. Finally, the data was aggregated to represent the whole class.

Once the data was aggregated according to the product type and ABC-class, the different manufacturing environments were weighted to favour products with certain characteristics as can be seen in TABLE 2. For example, products with high volume and steady demand are associated with MTS whereas products with long customer lead times can be made-to-order (see chapter 3). The weights were tested and fine-tuned with trial and error method by changing the weights and reviewing the proposed results until reasonable (not necessarily desired) results were given.

TABLE 2. Weighted characteristics per production environment.

	MTS/ATO	MTO/ETO
Consumed, pcs	90 %	10 %
Volume in €	70 %	30 %
Standard Cost	30 %	70 %
Product Variants	40 %	60 %
Demand Deviation	40 %	60 %
Order Lead Time	30 %	70 %
Physical Dimensions	80 %	20 %

To reduce the binomial nature of the manufacturing environment selection, a polarity column was added which describes the polarity of the results. For example, if the polarity is low (less than 20%), the decision between the environments is not very clear and vice versa if the polarity is great.

The results can be seen in

APPENDIX 2.

8 Conclusions

By answering the research questions and solving the problem, can the research be concluded. (Hirsjärvi et. al. 2007, 121-125) In this chapter, the questions are answered and finally the research problem solved.

8.1 Requirements of Lean

The first research question is: “Are there specific requirements for manufacturing planning and control in a lean manufacturing environment?”. As discussed in chapter 5, the lean manufacturing environment requires the production planning model to be able to support value-adding, increase flow, to enable pull, be transparent and support continuous improvement.

The MPC model can support value-adding in a way that it enables the value-adding operations to perform effectively. Consequently, this also increases flow when the value-units are processed in a quicker way. For example, reducing the batch sizes and increasing product mixes reduce the waiting times and thus throughput time of a value-unit.

The MPC has a tremendous effect on implementing the pull. The way that production is planned and material flown greatly determine whether the production is push or pull. For instead, when choosing to manufacture only based on the actual customer demand, the fundamental shift is already made towards the pull. This essentially eliminates over-production.

To increase transparency within the company, the MPC model can affect how capacity information is generated and shared. In a similar fashion can MPC decisions impact the demand side. Demand forecasts and capacity constraints could be openly and systematically communicated between the production and sales ends of the company to enable the synchronising of the rate of sale and rate of production as mentioned in chapter 5.3.

The MPC has a great role in supporting the continuous improvement of the lean philosophy. By gradually lowering inventories, reducing batch sizes and moving production from MTS towards MTO, can the MPC drive the company towards perfection by exposing the waste. After the processes have been made better, the inventory levels and batch sizes can again be reduced to expose more problems that need to be fixed.

8.2 Requirements of the Case Company

The second research question is: “What are the specific requirements for manufacturing planning and control regarding the case company itself?”. The interviews and observations conclude that the new MCP model must ensure the sufficient availability of products, provide accurate delivery dates, manage a broad product portfolio, bring inventory levels into control, preferably enable a frozen period, reduce expediting and clarify the forecasting process.

Ensuring sufficient availability can be done by re-evaluating the product groups and placing them into suitable manufacturing environments (MTS-ETO). Similarly, controlling the inventory levels has a tremendous effect on the product availability as unplanned stockouts cause the lead time to increase greatly.

Revising the master scheduling principles could increase the accuracy in customer delivery dates. For example, production scheduling with finite instead of infinite capacity can increase accuracy and at the same time, reduce expediting activity. Scheduling with finite capacity results in placing the order in a correct time frame right from the start. Thus, no expediting is required unless the customer decides to advance their purchase order.

8.3 The New Model

The third research question is: “what kind of manufacturing planning and control model can be applied to the case company?”. Now that the specific requirements of both the case company and lean manufacturing are known, can a future MPC model be proposed. The model proposed here goes by the name: “Continuous Replenishment Model with Forecast-Based Inventory Management” The model can be seen graphically in APPENDIX 1. Continuous Replenishment Model with Forecast-Based Inventory Management

The model enables pull by basing all production on real demand. As Hopp & Spearman (2004, 143) state, a MRP system with WIP limit is a pull system. Therefore, even though the model partly uses MRP to schedule orders, it is considered as a pull system. The inventories work only as a buffer and are carefully controlled to avoid excess stock.

8.3.1 The Manufacturing Environments

MTS products are made to finished goods inventory which base-stock level is controlled by forecasted demand. Whenever MTS products are sold, a replenishment order for the sold amount is created and scheduled (or pulled via Kanban if in place for the product line in question).

ATO products are assembled when a customer order is received. The assembly then consumes modules from the module inventories which base-stock levels are controlled by forecasted demand. Similarly, a replenishment order is created and scheduled (or pulled via Kanban) for the consumed modules.

MTO products are made from raw materials once a customer order is received. The raw material stock can also be controlled by forecasts depending on the future purchasing strategy of the company. ETO products remain a speciality.

Additionally, the product availability can be altered by introducing availability classes based on type and quantity. For example, when a vast amount of MTS products is ordered with a single delivery date causing a high swing in demand, the order could be directed to MTO instead of emptying inventory and sending the rest as a backorder.

The reassigned manufacturing environments per product groups can be seen in APPENDIX 2.

8.3.2 Forecasting

In this model, the forecasts are used to determine the maximum stock levels and safety stocks. Additionally, forecasts can be used to configure the WIP limits set by the Kanban system. This means that clear and systematic forecasting principles must be in place in order to keep the levels up to date.

The forecasting for the current products can be done based on a time series model which takes past consumption data into account. However, when introducing a new product, a time series model cannot be used because of the lack of historical demand data. In this case, a qualitative forecasting method is in place.

8.3.3 Scheduling

The key of successful scheduling is to implement finite capacity in the scheduling. This way the work orders are immediately scheduled to an available capacity slot. Thus, the current situation of the system giving a standard lead time (ATP-calculation) which is then asked to be expedited, will not happen. Additionally, the master schedules and capacity should be shared with the sales end to enable syncing the rate of sale with the rate of production.

In order to replenish the inventories in a timely manner, MTO orders cannot be prioritised over inventory replenishment orders. In another words, the inventories can be thought of as a real customer. After all, the replenishment orders are based on a real customer demand.

If there is not enough capacity to replenish the inventories, investment in capacity must be considered. Another question for addressing possible although reduced expediting requests is whether to increase the capacity e.g. by overtime or to postpone existing work orders. The balance between accurate delivery dates and the costs from the capacity increments must be thus carefully studied.

8.3.4 Inventory and Material Management

The finished goods and module inventories are immediately replenished by the consumed amount. Meaning, that when an order is placed on a finished goods stock, a replenishment order for the same amount is then issued to the production, thus authorizing the production as is typical for a pull system.

The base-stock-levels and Kanban quantities have to be updated periodically in order to react for the changing demand. The update periods can be connected with the ABC-class of the product. For example, A-products are updated quarterly, B-products every six months and C-products annually. This is crucial if the release of the updates cause sudden major changes in the workload of planning or production.

Safety stocks are updated in a similar fashion as the maximum inventory levels. A suitable way of calculating and updating the safety stocks must be implemented. This keeps the safety stock levels in accordance to the changing demand and wanted service level.

Production lines where Kanban is not yet in use, could benefit from implementing a temporary CONWIP pull system. This means that no work orders are allowed to release into the system before one is finished. The work stations however work independently pushing the material forward.

The current Kanban system could possibly be added with a priority system. For example, red tagging the cards that are needed to be produced as quickly as possible. There is a danger however that the majority of cards start to be tagged with red which defeats the purpose of the concept. It must be studied whether the appropriate Kanban levels and replenishment methods call for red tagging.

As currently, machining is a bottleneck in the production, the raw material inventory should be kept with sufficient material. According to the theory of constraints, the bottleneck should be kept going as much as possible as it determines the throughput time of the whole value chain. Therefore, a sufficient amount of machining raw materials must be ensured.

8.4 Notes on Implementation

The model presented in this research can be gradually implemented. As mentioned in chapter 5.4, there are two ways to implement the change. The kaikaku way is to first implement the key areas of the model such as forecasting methods, inventory control methods and new scheduling principles. After that can the model be gradually implemented to the full scale. Here are some notes on the gradual implementation and continuous improvement:

- Before the production processes support one-piece flow, a minimum quantity for the inventory replenishment orders can be set. This minimum quantity can then be gradually lowered, supporting the lean principle of continuous improvement.

- Same applies to the inventory levels themselves. Once the throughput times drop, so can the inventory levels constantly exposing more waste to address.
- Sheldon (2008, 24) describes that once the production lead times decrease due to continuous improvement efforts of lean, the order penetration points can gradually be shifted towards MTO or ETO.

9 Discussion

The research problem "*how the manufacturing should be planned and controlled in the future lean environment in the case company?"* has now been solved and a new framework for the manufacturing planning and control presented. In that regard, the research fulfilled the research need presented by Marioff. However, this research has raised a bundle of questions regarding the details of the presented concepts. Many of these concepts presented in this study withhold several broad research subjects. Every single of these subjects could be studied in a depth that fulfils the requirements for a bachelor's thesis. Therefore, at the end, I would have hoped to focus more on a single field e.g. inventory or material control in order to thoroughly gain understanding and research the specific concepts. Here are a few examples of the studies that could be conducted regarding this thesis.

- Implementing suitable safety stock calculations
- Determining the way to calculate the Kanban limits
- Researching and applying suitable forecasting methods
- Hands-on approach of master scheduling principles in a lean environment etc.

In addition to the breadth of the subject, the reliability of the research could have been made better by interviewing also personnel who are not production planners. For example, sales managers would have been very interesting to include in the research as some of the questions raised (see chapter 7.1.4) could have been answered by them. Additionally, the literature could have been more broadly studied.

All in all, this was the first research I have done and it gave me valuable experience on conducting a research. The next similar task will be much easier as the scientific methods and requirements have already been learned.

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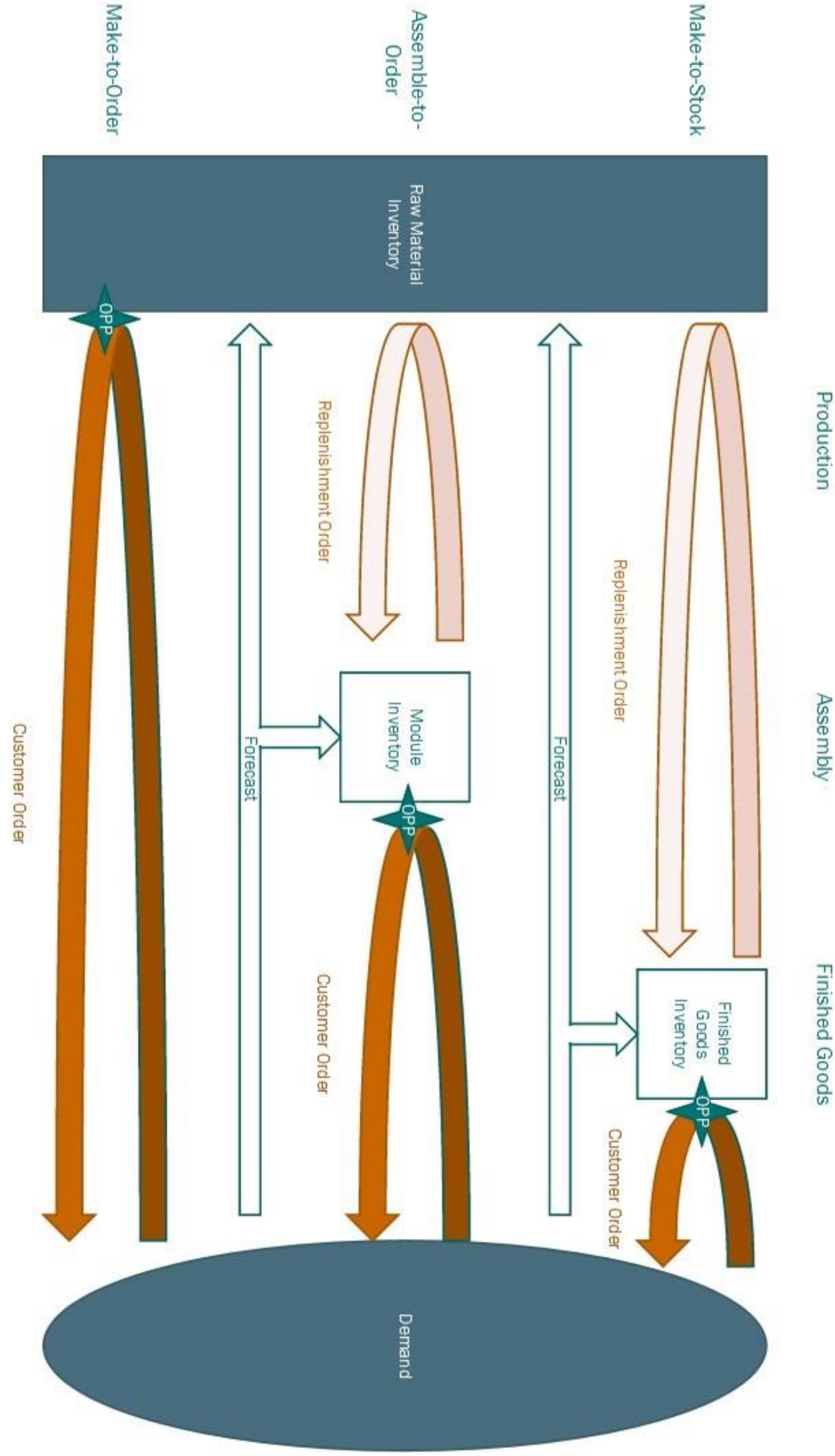
APPENDIX 1. Continuous Replenishment Model with Forecast-Based Inventory Management



APPENDIX 2. Manufacturing Environments per Production Category

Production Groups	MTS/ATO	MTO/ETO	Polarity
PRODUCT GROUP 1-A	83	124	33 %
PRODUCT GROUP 1-B	60	115,8	48 %
PRODUCT GROUP 1-C	72	150,8	52 %
PRODUCT GROUP 2-A	n/a	n/a	n/a
PRODUCT GROUP 3-A	93	161	42 %
PRODUCT GROUP 3-B	83,6	159,4	48 %
PRODUCT GROUP 3-C	88,4	174,6	49 %
PRODUCT GROUP 4-A	104,5	200,5	48 %
PRODUCT GROUP 4-B	180,1	285,9	37 %
PRODUCT GROUP 4-C	180,3	292,7	38 %
PRODUCT GROUP 5-A	55,7	109,3	49 %
PRODUCT GROUP 5-B	84,8	143,2	41 %
PRODUCT GROUP 5-C	98,9	168,1	41 %
PRODUCT GROUP 6-A	61,2	130,8	53 %
PRODUCT GROUP 6-B	49,2	101,8	52 %
PRODUCT GROUP 6-C	74,2	137,8	46 %
PRODUCT GROUP 7-A	42,4	97,6	57 %
PRODUCT GROUP 7-B	76,6	142,4	46 %
PRODUCT GROUP 7-C	192,1	269,9	29 %
PRODUCT GROUP 8-A	103,9	91,1	14 %
PRODUCT GROUP 8-B	53,8	62,2	14 %
PRODUCT GROUP 8-C	48,7	70,3	31 %
PRODUCT GROUP 9-A	66,2	53,8	23 %
PRODUCT GROUP 9-B	41,7	65,3	36 %
PRODUCT GROUP 9-C	52,7	89,3	41 %
PRODUCT GROUP 10-A	169,1	107,9	57 %
PRODUCT GROUP 10-B	36,7	47,3	22 %
PRODUCT GROUP 10-C	42,2	62,8	33 %
PRODUCT GROUP 11-A	124,1	56,9	118 %
PRODUCT GROUP 11-B	37,2	52,8	30 %
PRODUCT GROUP 11-C	50,9	84,1	39 %
PRODUCT GROUP 12-A	50,6	45,4	11 %
PRODUCT GROUP 12-B	60,5	53,5	13 %
PRODUCT GROUP 12-C	38,9	56,1	31 %
PRODUCT GROUP 13-A	42,4	55,6	24 %
PRODUCT GROUP 13-B	36	57	37 %
PRODUCT GROUP 13-C	42,5	72,5	41 %
PRODUCT GROUP 14-A	60,5	76,5	21 %
PRODUCT GROUP 14-B	54,3	68,7	21 %
PRODUCT GROUP 14-C	54,8	88,2	38 %