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Understanding the Requirements of Forecast in Demand Driven Material Requirements Planning

Master’s Thesis in the Master Programmes
Supply Chain Management and
Quality and Operations Management

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Abstract

In a world with high variations and uncertainties, the traditional material requirement planning is no longer sufficient. This planning system relies on fixed schedules and do not consider deviations. Therefore, a new demand driven material requirement planning (DDMRP) methodology has been introduced. This method enables companies to control variability using buffer levels to achieve high service level and low inventory costs. That said, companies are currently facing numbers of internal and external challenges when using this new method. The challenges are divided into four areas; external supply chain transparency, internal forecast methods, demand and production planning as well as setup of the DDMRP system. Hence, the purpose of this study is to investigate what is required externally from the supply chain and internally in the organization in order to use the DDMRP method for generating orders towards production and suppliers. Further, the study also aims to investigate the potential ways to incorporate forecast in sizing the DDMRP buffers.

One company that has met these challenges is AeroCo, which is currently in an implementation phase of DDMRP. Semi-structured interviews with 23 company representatives from various department, along with historical demand, production and delivery data, have been the foundation of the data collection. The qualitative data was gathered and analyzed using influences from a systematic approach presented by Gioia, Corley, and Hamilton. The quantitative data was compiled in excel and compared to find the best forecast method. Moreover, the literature review was used to obtain a better understanding of supply chain transparency, different forecast methods, overall demand and production planning, as well as the DDMRP method. Altogether, the theoretical framework combined with the empirical findings led to conclusions concerning the research questions.

Firstly, it can be concluded that DDMRP goes hand in hand with reaching full supply chain integration and the implementation of collaborative planning, forecasting, and replenishment. Secondly, it has been shown that relying only on the qualitative or quantitative forecast is not sufficient. For this reason, an integration method with both qualitative and quantitative approaches should be included. Thirdly, regarding the internal demand and product planning processes, it can be noted that the sales and operations planning process does not have to go through major changes in order to use the DDMRP method. However, the master production scheduling process will need to be further adjusted. Lastly, when incorporating the forecast into DDMRP, quality errors do not need to be incorporated since it is handled by a variability factor. Instead, the forecast used for DDMRP should reflect the general forecast but include a demand adjustment factor in order to take vacations and other capacity constraints into consideration.

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Gothenburg, June 10th 2019

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1. Introduction

In this chapter, the background of the problem, the aim of the study, the research questions and the limitations, are covered.

1.1. Background

A forecast assists management in its efforts to cope with the uncertainty of the future (Jonsson & Mattsson, 2009). However, a forecast will in principle never show the actual future demand, since it will, by definition, always include some level of forecast error (ibid.). Researchers and practitioners have for a long time studied the effects of such errors, and companies invest heavily in forecast systems (Fildes & Kingman, 2011). However, these errors are still present and cause problems in the supply chain, such as increased inventory costs and reduced service levels (ibid.).

In the description of the factors explaining the causes of forecast error, conducted by Jonsson & Mattsson (2009), many of them are seen to be due to the lack of communication between end-customers, the Original Equipment Manufacturers (OEMs) and their suppliers. These are, for example, misleading forecast data, such as occasional large ordering batches of customer orders which reduces the accuracy of linear demand statistics. Another example is unrealistic, i.e., too optimistic, expectations of customer demand. Arguably, such factors may be possible to reduce by increasing supply chain transparency (ibid.). A well-known phenomenon in supply chains is the bullwhip effect describing the increased variation in demand observed upstream the supply chain (Chen, Drezner, Ryan & Simchi-Levi, 2000). This effect can be explained by, for example, non-aligned planning actions and improper communication between customers and suppliers, not sharing the time when a retail transaction is performed at the end-customers (Jonsson & Mattsson, 2009). One of the most common solutions to reduce the bullwhip effect is to centralize demand information. Such centralization increases transparency by providing each actor with complete demand information along the supply chain (Chen et al., 2000). While most of the management literature assumes the accessibility to the information required at each level of decision making, limited attention has been paid to how lack of information and communication in the supply chain can affect the ability to achieve high forecast accuracy (Syntetos, Babai, Boylan & Kolassa, 2016). Therefore, the lack of information is also an essential issue to further investigate, since different forms of collaboration, including sharing of demand information between actors in the supply chain, provides a potential gain in the forecast accuracy (ibid.).

Another factor causing forecast errors is the choice of forecast methods, which is also proposed as a solution to minimize those (Fildes & Kingman, 2011). Forecast methods can be divided into qualitative forecast methods, building on subjective assessments by personnel with good knowledge of the market and its development, and quantitative forecast methods, based on calculations of historical demand (Jonsson & Mattsson, 2009). However, to achieve a good forecast, combining both qualitative and quantitative methods is often needed (ibid).

It is essential to recall that forecasts are often used as input to many different processes in an organization, such as the sales and operations planning process, the master production scheduling process and the material planning process (Jonsson & Mattsson, 2009). This process is also where the forecast is transformed into the production plan to guide the internal production and create orders towards suppliers. These processes all together will later be referred to as demand and production planning.

Demand Driven Material Requirement Planning (DDMRP) is a production planning method introduced by Ptak & Smith (2008) that promises to move away from the use of short-term forecasts. It instead relies on actual demand or consumption in creating a demand driven organization. This principle concentrates on the compression of lead time to market demands, taking the focus from previous inventory estimation in the Material Requirement Planning (MRP) and converts it into a demand driven focus (ibid.). It is accomplished by preparation, scheduling, and execution based on material consumption. Therefore, to become a demand driven organization means to undergo a shift in the organization, from the focus of supply and cost based operating systems, to a focus of actual demand and flow-based systems (ibid.). Moreover, the traditional MRP approach is not taking the unpredictability of demands into account, leading to a bimodal distribution as seen in Figure 1 where the x-axis shows the number of Stock Keeping Units (STU) i.e., the number of goods in stock. In a bimodal inventory distribution, the inventory level fluctuates from either too little (marked as red in the figure) or too much (marked as light blue). This inventory distribution causes high inventory cost and low service level (ibid.). However, the DDMRP method promises to solve this problem by formally protecting and promoting the progress of information and materials (Ptak & Smith, 2018).

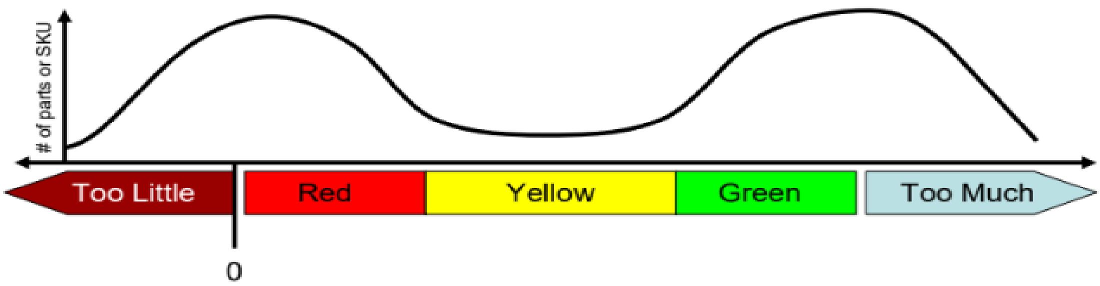

Figure 1. Bimodal distribution of inventory (Ptak & Smith, 2018).

In DDMRP, boundary levels for the available stock are used to plan and control production (Ptak & Smith, 2018). In order to react to customer demand variations quickly, but at the same time avoid high capital cost, it is essential for these buffers to be appropriately sized. In doing so, a forecast may play a large role in estimating the average daily usage (ADU), which is the foundation for calculating buffer levels in DDMRP (ibid.).

Many studies have been done regarding how DDMRP creates more efficient material planning (Lee & Jang, 2013, 2014; Ihme, 2015; Shofa and Widyarto, 2017, Miclo, 2016). However, only a few studies investigated the requirement of the supply chain transparency, the forecast process and the internal demand and production planning processes connected to the use of DDMRP. In order to investigate these areas, the research model in Figure 2 was created. It aims to explain the process of interpreting the information in the supply chain and out of this information create a forecast. This forecast will then be used to guide the internal production and to generate orders towards the suppliers.

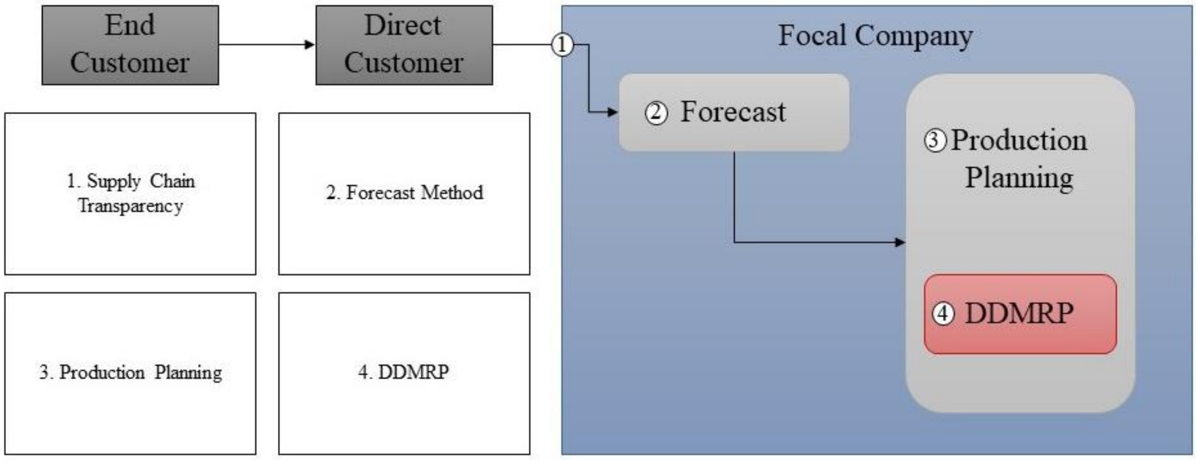

Figure 2. Research model.

1.2. Aim

The purpose of this study is to understand what is required externally from the supply chain and internally in the organization in order to use the DDMRP method for generating orders towards production and suppliers. Further, the study aims to investigate the potential ways to incorporate forecast in sizing the DDMRP buffers.

1.3. Research Questions

Given the research model presented in Figure 2, the first step is to receive and interpret the information available in the supply chain. Thus, in order for this process to work, the right information needs to be available. Accordingly, the first research question is formulated as follows:

1. *What is required from the supply chain transparency in order to use the DDMRP method?*

The second step of the research model is the step where the information is used to forecast the future demand. Since DDMRP aims to reduce the need of short term forecast and instead rely on actual demand, the requirements of the forecast will differ compared to the traditional way. Thus, the second research question is formulated as follows:

2. *How should a forecast be conducted in line with the DDMRP method?*

The third step in the research model is the internal demand and production planning processes in the organization. Also, in this matter, DDMRP will affect the requirements of these processes. For this reason, the third research question is formulated as follows:

3. *How should the demand and production planning processes be conducted in line with the DDMRP method?*

Lastly, the fourth step of the research model is the DDMRP method itself. Given the constraints from the communication in the supply chain and the other processes dealing with forecast within the company, there will still be different options for what to use as the forecast for ADU in the DDMRP system. In order to investigate these alternatives, the fourth research question is formulated as follows:

4. *What should be used as forecast in the DDMRP method in order to size the buffers?*

1.4. Scope

Regarding the scope of the thesis a first consideration is the number of steps in the supply chain to be investigated. All actors in the supply chain contribute to transforming the information about customer demand by communicating it to the next actor. Thus, increased transparency of an actor will cause effects far down in the supply chain. However, this study will focus only on the transparency of the actor placed just before the focus company, i.e., the focus company's direct customer.

Furthermore, the study aims at investigating the *changes* in requirements of forecast connected to DDMRP, rather than in detail investigating the general need of a forecast. It means that the study will not give an in-depth description of the use of forecast in such areas as finance or capacity planning but will instead focus on the changing need of forecast in demand and production planning. The study also does not investigate the economic effect of increased stock levels and delivery shortages caused by forecast errors resulting from the different methods. Instead, the study aims to find a way to get as close as possible to the ADU, regardless of the financial impact.

In terms of the components of DDMRP, this study is only focused on the buffer profile and levels, as well as dynamic adjustments since these are the stages where forecasting can play a role in the DDMRP method. The other parts of the method regarding where to position the buffers as well as the operational planning and execution of orders are not considered in this study. A final limitation of this study is that the research investigates the future state, after the implementation of DDMRP. Thus, the requirements during the implementation are not examined in this research.

1.5. Thesis Outline

This thesis consists of eight main chapters where the introduction, containing the background, aim, research questions and scope, is the first and present chapter. The second chapter presents the method used to answer the research questions. The third chapter contains the literature findings generated by the literature search upon the four main topics of the thesis; supply chain transparency, forecast methods, demand and production planning as well as the DDMRP method. The fourth chapter is a description of the company structure at the focal company AeroCo. The fifth chapter presents the empirical findings structured into the four main topics connected to the research questions. However, the answers to the research questions are given in the sixth chapter discussing the empirical findings in connection to the theoretical findings. This chapter also contains a discussion about implications for future research. The seventh chapter gives more practical recommendations to the case company based on their current situation. Finally, the eight chapter finishes the thesis with stating the conclusions.

2. Methodology

In this chapter, the overall research design, the case company description, as well as the data collection and analysis methods are covered. In addition, the final section discusses research quality with consideration to validity and reliability.

2.1. Research Design

The design process chosen for this research is a case study. It is chosen since the case study investigates the novel area of forecast requirements in DDMRP, where few earlier studies exist. As described by Bryman & Bell (2011), a case study attempts to perform a broader and more comprehensive understanding of the problem. Case studies are also a useful design strategy to increase knowledge of the progress within a unique set of environments (ibid.). Furthermore, a case study is suitable for theory building and phenomenon-based research and is ideal for novel research areas or areas where existing theory is incomplete (Eisenhardt, 1989). This study also aims to broaden the understanding of the problem within this unique environment of an organization using DDMRP, which further strengthen the rationality of choosing a case study as the research design.

Single case studies are often used to gain a deeper understanding of the exploring subject and high-quality theory (Gerring, 2004). Focusing on a single case enables the researchers to dig deeper into this case and more comprehensively understand it, rather than having to divide the focus into several cases (ibid.). Furthermore, there are only a limited number of companies which are currently in the implementation phase of DDMRP. Thus, due to the uniqueness of this project and because of the necessity to gain a deeper and more comprehensive understanding of the case, a single case study was chosen.

When deciding upon method approach, the present knowledge within the field needs to be considered (Wallén, 1996). In order to add new knowledge to a research field, an explorative study is often used (Malterud, 2009) It is also a method suitable to sort out relevant variables and concepts to examine what should be considered as part of the problem (Wallén, 1996). In the case of an explorative study, and especially when there is a lack of existing theory, it is often also suitable to use an inductive approach i.e. generating theory out of observations rather than confirming a hypothesis (ibid.). Since this study was carried out in an informative way to bring about knowledge of a topic where few earlier studies exist, the study was carried out inductively. Moreover, Bryman and Bell (2011) describe how research methods can be divided into two main categories; qualitative and quantitative studies. Usually, when the study is of an explorative kind, a qualitative approach is preferable (Malterud, 2009), since a qualitative study aims at explaining and interpreting concepts and connections in the research area (Wallén, 1996). In contrast, a quantitative method uses numbers and statistical analyses to answer the research question (Holme, Solvang & Nilsson, 1997). However, a combination is often used to complement each other (ibid.). This study aims at explaining and interpreting concepts and connections, which is why the major part of the study was done in a qualitative manner. Although, the research area itself is based on numerical calculations such as quantitative forecast methods and buffer level calculations. Thus, in order to answer some parts of the research questions, adding a quantitative part to the study was relevant as well. The research method is presented in Figure 3 and each step is further described in the following sub-chapters.

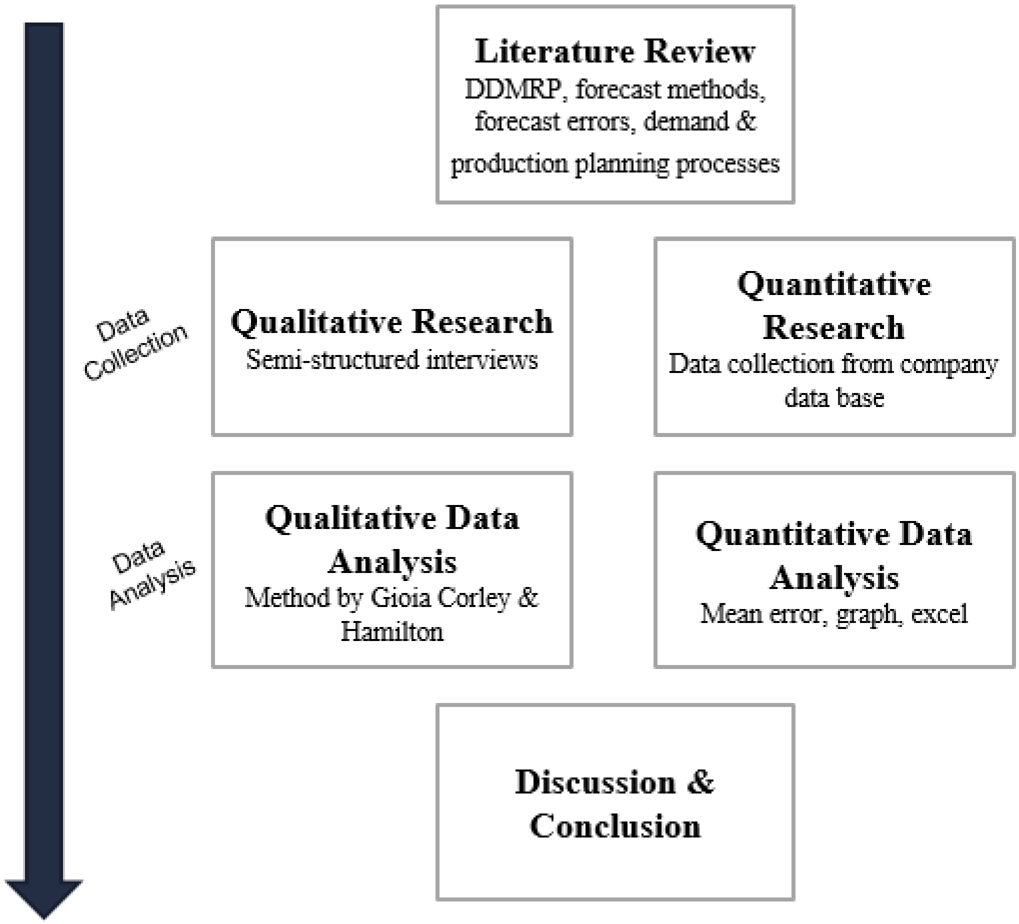

Figure 3. The research method of the study.

2.2. Case Description

AerospaceCo, as part of a company group, is a global engineering company with approximately 17,000 employees in around 50 manufacturing locations in 15 countries around the world. The division AerospaceCo Engines (henceforth denoted AeroCo) is located in the west of Sweden as a second-tier supplier on the aircraft engines market and supplies to three major engine manufacturers denoted the OEM’s. Currently, AeroCo strives to increase the understanding of the OEMs’ demand by focusing on the forecasting process. The confusion in communication with OEMs and the subsequent errors in forecasting has led to delayed deliveries and high inventory levels. Therefore, AeroCo is now attempting to implement a new production planning method, which is the DDMRP system.

2.3. Data collection

According to Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2015), there are two different types of data; primary and secondary data. Primary data is defined as data that comes directly from the source, for example, through interviews and observations. Secondary data is rather a set of compiled information that does not come directly from the source, such as literature or company reports and data (ibid.). In order to answer the research questions and thus fulfill the purpose of the research, a combination of both types of data collections was used in the study. When aiming to add a historical perspective to the data, a secondary data collection is often preferred (ibid.). Also, secondary data is less time consuming and requires less effort compared to the primary data. On the other hand, primary data is necessary when it comes to studies within novel research areas to increase the degree of accuracy. It is also essential when the study requires an analysis of the current situation of the company (ibid.). This study aims to both understand the current situation of the company in the novel area of DDMRP implementation and at the same time draw conclusions out of historical data such as demand variation and forecast accuracy. Thus, both primary data (collected through the qualitative data collection i.e., the interviews) and secondary data (collected from the quantitative data collection i.e., company reports and databases) was used for this study.

2.3.1. Qualitative Data Collection

Yin (2017) states that the majority of case studies has interviews as a part of the data collection method and that interviews give the possibility of understanding concepts that otherwise are not readily noticeable. Hence, this study contained interviews in order to understand the concept of forecast. In addition, qualitative data such as DDMRP-literature used by AeroCo reports written by the company about its current forecast process and demand variation was collected in order to build a foundation of the understanding of the concepts.

The design of interviews can be divided into two main approaches, namely, structured and unstructured (Yin, 2017). The difference between the two approaches is that the structured approach follows a strict guide of closed questions with predetermined answers, while unstructured interviews contain a set of open-ended questions. The unstructured interviews give the interviewer the opportunity to change the questions depending on the answer of the interviewee (ibid.). Hauge (1998) introduces a third approach, which is the semi-structured interviews containing a combination of both open and closed questions. Considering that semi-structured interviews provide a more agile way of managing a dialogue, which makes the means of gathering data more accessible, this approach was used in the present work. Accordingly, in Appendix I, the interview template can be seen.

As for the selection of interviewees, a three-step process proposed by Steiber (2012) was used. At the start, interviewees were selected by using recommendations from the supervisors at AeroCo. Further, the interviewees' suggestions of other interviewees were taken into account. The interviewees are presented in Table 1. To avoid miscommunication and minimize uncertainties, two rounds of interviews were performed. The first round of interviews was done early on in the data collection phase to create basic understanding, while the second round was done to follow-up any misunderstanding or uncertainties that appeared during the first round.

Table 1: Number of interviewees and their division at AeroCo.

Company Function		**Number of Interviewees at the Division**
Top Management	Global Management	2
Project Group	DDMRP project in the US	1
Sales and Marketing	Program	4
	Commercial	2
Finance	Finance	2
Supply Chain	Supply Chain	1
Operations	Operations	1
	Operations Excellence	4
	Value Stream Alfa	2
	Value Stream Beta	4
Total	Total	**23**

2.3.2. Quantitative Data Collection

For the quantitative part of the study, historical demand data (the OEMs' MRP data and historical deliveries) and forecast data (demand plan and production plan) were retrieved from AeroCo's database. In addition to this, data about the stock levels at one OEM and products in transit was given from an employee at AeroCo who had been collecting this data from e-mail correspondence with the OEM. All this data was further compared and analyzed in Excel as described in section 2.4.2. Quantitative Data Analysis. Finally, also the forecast accuracy follow-ups made by the company was collected.

2.3.3. Literature Study

In order to create a basic understanding of a topic, a literature study is usually applicable (Ericsson and Weidersheim-Paul, 2008). The literature study was started early on in the project to create a fundamental understanding of the different areas of the study, such as DDMRP and forecasts. Relevant literature from earlier studied courses was reviewed to get a basic understanding of the subject. It was complemented with academic literature searches in the Google Scholar and Chalmers Library Search databases to deepen the knowledge about the problem background. The articles were ranked by the number of citations in order to only use references that are well established. Additionally, literature used as references in relevant articles were reviewed in accordance with the snowballing sampling method described by Bryman & Bell (2011). The topics searched in this phase were mainly about forecast methods, DDMRP, and customer transparency. Keywords used when searching included for example, *forecast DDMRP*, *forecast error* and *forecast information access customer*.

2.4. Data analysis

The data analysis was further divided into a qualitative part and a quantitative part. The methods used for each of these parts will be described in the following subsections.

2.4.1. Qualitative Data Analysis

When analyzing interview material, open answers can be broken down into different categories (Andersson, 1985). Sometimes, open answers give direct information that can be connected to these categories when, at other times, the responses from different interviewees must be compared with each other in a more in-depth analysis. To analyze qualitative data, a possible method is Grounded Theory, a method based on coding the answers in order to more easily compare them to each other (Bryman and Bell, 2011). The method used for this study is presented by Gioia, Corley, and Hamilton (2013), which is based on Grounded Theory.

In the method presented by Gioia et al. (2013), the 1st-order analysis is conducted on a high level by comparing interviews in order to identify a long list of categories adding information to the research field. The similarities among the 1st-order were then categorized and clustered into more significant concepts to get a more manageable amount to analyze. The 2nd-order analysis tries to connect different categories to known theory in order to find the aggregate dimension that can help answer the research questions of the thesis. Having the concepts, categories and aggregate dimensions defined, Appendix II was created. Lastly, the findings were discussed and compared to literature.

2.4.2. Quantitative Data Analysis

In the quantitative data analysis, various numerical analysis has been done. First, in order to calculate the actual demand at the OEMs, the data given about the stock at the OEMs and products in transit was used to calculate the weekly demand. For those weeks where data was missing, an average weekly demand was calculated for a longer period, based on the available information. Quantitative forecast methods such as linear regression, moving average and exponential smoothing was applied to the data to predict the demand for the upcoming week. The prediction was then aggregated to a monthly demand in order to be compared with the demand plans and the OEM's MRP data. In those cases where one week belongs to more than one month, each weekday was considered to represent one-fifth of the full week's demand. Also, the weekly demand was aggregated to a monthly demand to be used as the observed values in the comparison. The comparison was made using Mean Squared Error (MSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) which are some of the most common measures for forecast error. The measures are calculated out of the observed value (E) and the predicted value (ε) as shown in the formulas:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(E_i - \varepsilon)^2, \quad MAE = \frac{1}{n}\sum_{i=1}^{n}|E_i - \varepsilon|, \quad MAE = \frac{1}{n}\sum_{i=1}^{n}\frac{|E_i - \varepsilon|}{E_i}$$

To further assess patterns in behavior when conducting forecasts, the demand plans and OEM's MRP data was plotted in a graph. This data was plotted both individually and together with deliveries and the calculated demand to show changes and deviations over time. Finally, to analyze the validity of the forecast accuracy follow-ups made by AeroCo, the definition of actual demand used in these follow-ups were compared to the demand calculated out of the OEMs stock.

2.5. Research quality

Two important aspects to elaborate on when assessing the research quality is the validity and the reliability of the study (Easterby-Smith et al. 2015). When it comes to validity in qualitative research, the study needs to include a variety of perspectives to give a good representation of the reality (ibid.). The study in question was based on interviews with a variety of employees from different departments, hierarchical levels and different backgrounds. Thus, the study was assumed to contribute with the variety of perspectives needed in order to give a valid description of the organization and its behavior. Regarding the quantitative study, the analysis was conducted at products only within the focus company of the case study. Thus, the study had no aspiration to reach statistical validity for other products in other companies or industries. However, a large amount of data was used for the products studied and the results can, therefore, be considered relatively representative of these products. Although, for a great part of the quantitative study, actual demand was calculated and used in the analysis. This calculation was based on data available for only one of the products at AeroCo, and consequently, only one product could be used for these analyses. However, this product represents a significant part of the company's total demand volumes. Furthermore, there is always a possibility of single author bias (Gioia et al. 2013). Therefore, having two different authors conducting the study strengthens the validity in the analysis of the study.

Reliability symbolizes the consistency of a measure, whether other observers will reach similar observations (Easterby-Smith et al. 2015). In other words, other researchers must be capable of performing the same analysis under the same circumstances and generate an equivalent outcome as the present study. Therefore, it is crucial for the researchers to display the steps of how the data collection phase was conducted (ibid). Since the method chapter clearly shows the steps of the study, for both the quantitative and qualitative parts, the reliability was assumed to be high. Furthermore, Gioia et al. (2013) stress the importance of using a systematic approach, which is why the data analysis approach presented by these authors was used in the qualitative data analysis to gain trust and obtain reliability. Consequently, this part of the study is also seen as sufficiently reliable.

Lastly, the generalizability of the research regards whether the captured result indicates the reality and the representativeness of the case compared to other cases (Easterby-Smith et al. 2015). According to Easterby-Smith et al., (2015), one way to handle generalizability is to implement the same criteria as for validity. This criterion can thus be argued to be fulfilled due to a large number of interviews conducted and the large number of perspectives incorporated.

3. Theoretical framework

In this chapter, the theoretical findings regarding supply chain transparency, forecast methods, demand and production planning processes and demand driven material requirement planning are described. In addition, the final section summarizes the findings in a conceptual framework.

3.1. Supply Chain Transparency

The first sub-chapter mainly discusses a model presented by (Holweg, Disney, Holmström & Småros, 2005) in order to analyze the supply chain transparency and collaboration. This theory is later used in section 6.1. to analyze the supply chain of the focal company and the requirements of transparency in order to use the DDMRP method. Supply chain collaboration has since the 1990's been encouraged by both consultants and academia (ibid.). Even though it comes in many different forms, it has one common goal of increasing the visibility in the supply chain to create a transparent and visible demand pattern that pace the entire supply chain. From studying this collaboration, Holweg et al. (2005) have identified four different supply chain configurations (see Figure 4). This classification builds upon the two most common ways of collaboration used in practice; inventory replenishment and forecasting.

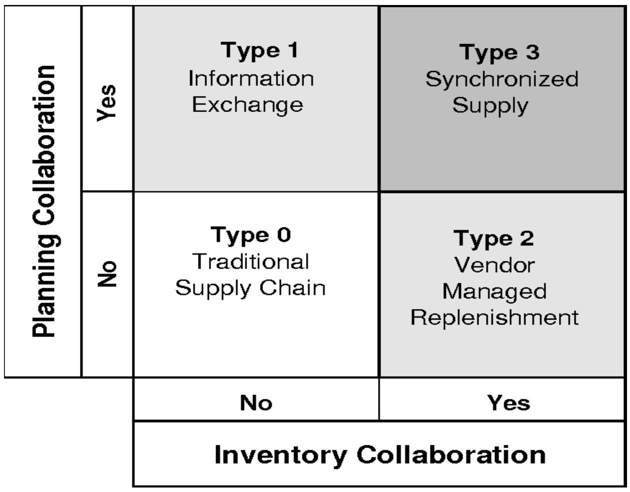

Figure 4. Four types of supply chain configurations (Holweg et al., 2005).

3.1.1. Traditional Supply Chain

The Type 0 Supply Chain is defined as the traditional supply chain, where each actor plans production and replenishes stock without consideration to other actors up- or downstream the supply chain (Holweg et al., 2005). This is the way in which most supply chains still operate, without formal collaboration. The only information available for the supplier is the purchase order placed by the direct customer. By only relying on purchase orders, without any visibility of the actual demand, the human mind is tempted to order some extra as safety towards shortage. Another common problem in this type of supply chain is the bullwhip effect (ibid.). The bullwhip effect is a known phenomenon in supply chain theory that describes how demand variation increases further up in the supply chain, i.e., the second-tier supplier has higher demand variability than the first-tier supplier, which has a higher variation than the OEM and so on (Chen et al., 2000).

A main reason for the bullwhip effect is rationing and shortage gaming, which is a psychological phenomenon caused by poor communication (Jonsson & Mattsson, 2009). This phenomenon appears when suppliers are unable to meet the delivery times, which causes the customer to safeguard against this by ordering larger quantities than needed and/or placing orders earlier, which then appears to be actual demand for the supplier. Later, when the supplier has managed to increase their capacity and deliver according to the new demand, the order quantities decrease to a lower level than initially, since the customer is high on inventory due to the larger order quantities not being matched by a real increase in demand. This leads to the supplier perceiving a decrease in demand which does not match a real demand change either. Thus, the supplier will first perceive an increase and then a decrease in demand, none of them which is an actual change in demand, only because of the lack of communication and relevant information (ibid.).

Another major reasons for the bullwhip effect to appear is non-aligned planning and control activities between actors in the supply chain (Jonsson & Mattsson, 2009). This means having an MRP system that, in the case of a demand change, not only forwards the increase in demand itself but also recalculates the needed buffer levels. It thereby increases the demand towards the supplier even more than the actual change in demand from the end-customer. This is an even bigger problem in supply chains with a low degree of information exchange, less frequent communication and non-aligned material planning (ibid.).

3.1.2. Information Exchange in the Supply Chain

Chen et al. (2000) show that the frequently proposed solution to centralize demand information, i.e. giving all the actors in the supply chain direct access to end-customer demand, can reduce but not eliminate the bullwhip effect in a supply chain. Information exchange is also the Type 1 Supply Chain identified by (Holweg et al., 2005). The actors still order independently but exchange demand information and action plans in order to align their forecasts for capacity and long-term planning.

The centralization of demand information is also comparable to another one of the main reasons for the bullwhip effect to appear, proposed by Jonsson & Mattsson (2009), of not sharing point-of-sales (POS) data. Sharing POS data is one example of making more accurate demand information available in the supply chain, since the actors do not have to act solely on the orders placed by their immediate customers. By sharing POS data, a standard deviation forecast error reduction between 8% and 19% have been observed in a study by Syntetos et al. (2016), which has a linear relationship with inventory costs. Even without achieving full visibility in the supply chain, having end-customer sales taken into consideration in addition to direct customer orders, is an improvement (Holweg et al., 2005). It removes uncertainty and delays in translating the demand signal.

In taking the information sharing one step further, the collaborative forecast is a cornerstone for both Collaborative Planning, Forecasting and Replenishment (CPFR) as well as Vendor Managed Inventory (VMI) (Holweg et al., 2005). However, the implementation of these concepts into the industry has made slow progress due to a lack of understanding and difficulty in integrating external collaboration with internal control (Syntetos et al., 2016). It is also common that the customer does not have a forecast and planning process in place that can provide the supplier with information on the level of detail required and at the right moment in time (Holweg et al., 2005).

3.1.3. Vendor Managed Replenishment in the Supply Chain

Having a vendor managed inventory, which is the Type 2 Supply Chain defined by Holweg et al. (2005), means that the task of generating replenishment orders is given to the supplier. By having full visibility of the stock at the customer's site, the supplier takes full responsibility for maintaining this inventory. The supplier then has the task of generating replenishment orders based on the same information that the customer previously used to make the purchase orders. Holweg et al. (2005) state that in this way, the inventory needed to retain customer service level can be reduced.

The term consignment stock is used to denote products that are stored at the customer site but are still owned by the supplier (Holweg et al., 2005). The customer is not obliged to pay for them until they are removed from the consignment stock, and unused stock is commonly returned to the supplier. Important to note is that this method can also be used in Type 0 supply chain and is not the same as a VMI-system. The change in ownership does not necessarily change the process of replenishment. Furthermore, it is common for companies only to implement VMI and thus settle with collaborating only through the replenishment and not extending the collaboration to the production planning. This means that there will still be two decisions points in the supply chain. Something that can lead to misalignment in decisions and that the bullwhip effect remains even with VMI (ibid.).

3.1.4. Synchronized Supply Chain

To get the full benefit from the collaboration, a Type 3 Supply Chain is required (Holweg et al., 2005). This means eliminating one of the decision points and merging the replenishment decision with the production and material planning of the supplier. The supplier is in charge of the customer's inventory replenishment on the operational level and uses this visibility to plan its own operations. In doing so, a reduction of the bullwhip effect can be achieved. The critical step to take is to incorporate the customer demand information into the supplier's production and material control. It is common that companies collaborate on a higher level, but that the collaboration on a production planning level is often overlooked. It is necessary not only to exchange information but also to modify the replenishment and production planning decision process (ibid.).

To achieve full collaboration and synchronization in the supply chain, the concept of collaborative planning, forecasting, and replenishment (CPFR) has emerged. It aims at creating collaborative relationships between actors in the supply chain by the use of standard processes and structured exchange of information in order to achieve more cost-effective material flows and less tied-up capital (Jonsson & Mattsson, 2009). The concept builds on five principles (ibid.). The first principle is about collaboration in the form of partnership relations and mutual trust built on common goals and activity plans. The second principle concerns the use of common and agreed upon forecasts which all actors use as a base for their planning and activities. In order to do so, the customer shares its historical sales statistics and information about planned future campaigns affecting the demand throughout the supply chain. The forecast produced by the customer is also sent to the suppliers and compared with their forecasts in order to discuss differences and adjust the forecasts to correspond to each other. This is done to ensure that the actors use one common forecast throughout the entire supply chain (ibid.). The third principle is about exploiting the core competencies in the supply chain irrespective of which company they belong to. Which means that the actor most suitable to perform the activity will do so, no matter who owns the resources. The fourth principle is about using a common performance measurement system based on end-customer demand to create a shared focus for all the actors in the supply chain (ibid.). The fifth and final principle is about sharing the risks and utilities arising in the supply chain (ibid.). It means that all actors will collaborate in mitigating risks and be able to benefit from any progress made in the supply chain. It will motivate behaviors that facilitate and benefits other actors in the supply chain.

3.1.5. When to Aim for a Synchronized Supply Chain

Finally, Holweg et al. (2005) discuss which industries that can benefit the most from reaching the Type 3 Supply Chain of full synchronization. In many cases where there are a large number of different customers, it is not worth it economically to move away from the traditional Type 0 Supply Chain, since the effort of making the implementation increases with the number of nodes between customers and suppliers. However, for other companies, it is often a worthwhile target since it reduces both excess inventories and reduces the bullwhip effect. Holweg et al. (2005) also highlight that the characteristics of both demand and products should themselves be considered. For products with short shelf life, such as fresh food, the possibility to work with product buffers is limited. Instead, for products where high capacity utilization and low inventory levels are essential, greater benefits are possible to create. Furthermore, seasonal products such as lawn mowers, require seasonal forecasts and safety buffers, which mitigates the benefits of supply chain synchronization (ibid.). Instead, non-fashion driven products with stable demand create more significant possibilities for success.

3.2. Forecast Methods

The second sub-chapter present some main forecast methods and their advantages and disadvantages. These methods can be divided into qualitative forecasting methods and quantitative forecasting methods (Jonsson & Mattsson, 2009). The main difference is that qualitative forecasting methods rely on estimations and expert evaluations, while quantitative forecasting requires hard data and calculations. Although, in practice, most industries tend to use a combination of both methods to increase the accuracy of the forecasts (ibid.). Table 2 shows a breakdown of the main advantages and disadvantages of some common quantitative and qualitative forecast methods. Further, these methods will be deeply discussed in the subchapters 3.2.1. and 3.2.2. The quantitative methods are used in section 5.2 to assess the potential forecast accuracy using these methods. Further the theory in this sub-chapter was used in section 6.2. to analyze what forecast methods should be used to achieve as high forecast accuracy as possible in the case of AeroCo. In section 6.3. the suitability of this method to be the base for the average daily usage in the DDMRP method was analyzed.

Table 2: Advantages and disadvantages of various forecast methods.

Method Type		Advantages	Disadvantages
Quantitative Forecast Methods	**Moving Average**	Simple and easy to implement.	Time lag when it comes to systematic trends in the historical data.
	Exponential Smoothing	Weighting demand values.	Time lag when it comes to systematic trends and random variations in demand.
	Simple Linear Regression	Easy to implement and learn.	Sensitive to anomalies in the data.
	Multiple Linear Regression	Considers multiple independent variable.	Sensitive to anomalies in the data.
Qualitative Forecast Methods	**Sales Management approach**	Efficiency in decision making and allows a joint evaluation and agreement.	Ideal thinking and manager high authority that affect the decision making.
	Grassroots Approach	High quality of the forecast since relevant people are in the center of the analysis.	Time-consuming and requires additional data processing.

3.2.1. Quantitative Forecast Methods

Quantitative forecasting methods are based on statistical techniques to predict the future (Sanders & Ritzman, 2004). These methods analyzes the time series of sales and various historical data. This method has the advantage of being entirely objective, consistent, and capable of processing a large amount of data, considering the relationship between numerous variables (ibid.). However, the quantitative method highly relies on the foundation of historical data and any unexpected market variation is not incorporated in the model, which will affect the forecasting quality significantly.

In order to obtain a good demand forecast, the forecast has to be done based on the right forecast data (Jonsson & Mattsson, 2009). However, it is rather difficult to obtain actual demand for the reason that measured demand has some errors when it comes to capacity loss and time lag compares to the actual demand. Also, historical data often do not represent the actual current demand because of many indirect factors such as stock shortage, loss of sales or delays sales (ibid.). Differences between desired, promised and real delivery dates can also arise. Therefore it is crucial to choose the right forecast data depending on the current company situation. If the company has sales with long delivery lead time, then it is more appropriate to choose delivery statistics or invoicing statistics (ibid.). If the company has accelerated invoicing procedures i.e., shorter delivery lead time, then it is preferable to choose invoiced statistics of the reason that the invoiced volumes will almost directly correspond to delivered volumes. However, if the company has a slower invoicing procedure, and the time between delivery and invoicing are longer than the previous situation, it is more beneficial to use delivery statistics (ibid.).

Quantitative forecasting methods can be classified into an extrinsic or an intrinsic forecast method (Jonsson & Mattsson, 2009). Extrinsic methods are characterized by making a model out of relationship between the variables to be forecasted and some explanatory variables which the forecast variable is dependent on. On the other hand, intrinsic forecasting methods analyzes only the variable data to be forecasted (ibid.). One example of an intrinsic quantitative forecasting method is the method moving average. This method analyzes the average value of demand during recent periods. For each period in time, this is calculated based on a set number of periods, and when a forecast is made for a new period, the oldest period's demand value is replaced by the latest period's demand value. Depending on the context the number of periods considered can be significantly different from time to time (ibid.). A limitation with moving average is systematic trends in the historical data, the moving average will always have a time lag since older demand data will also be taken into consideration depending on the number and length of periods used to calculate the average (ibid.).

Another intrinsic quantitative forecast method is the exponential smoothing (Jonsson & Mattsson, 2009). This method considers the weighting of the most recent demand, having a higher weight compared to older demand. In order to achieve this valuation, the individual demand values are multiplied by a weight. The following formula shows the most common way to calculate this forecast, where F(t+1) means forecast value for the upcoming period t+1, F(t) is the forecast of the current period t, and A(t) is the actual demand during this period. Lastly, α is the smoothing factor arbitrarily chosen between zero and one (ibid.).

$$F(t+1) = \alpha * A(t) + (1 - \alpha) * F(t)$$

Then, for example, if choosing an alpha equals 0.1, the most recent demand value will be given a 10 percent weight, while the oldest demand value will be given a 90 percent weight. However, a limitation with this method is that it can still not react to ups and downs associated with random variations (ibid.).

Linear regression is also a commonly used forecasting method. This method can be both extrinsic and intrinsic depending on which data are used for the calculations. There are two main types of linear regression methodologies (Yan & Su 2009). The first is the simple linear regression. This method analyzes the linear relationship between two factors, one dependent variable, and one independent variable, and adjust a linear function according to this relationship (ibid.). One example of the simple linear regression can be the relationship between the number of sales and time. The advantage of simple linear regression is that the method easy to implement and learn. However, a drawback is that this method is that the method is susceptible to anomalies in the data since simple linear regression assumes that the relationship between the two factors is constantly linear. The second regression method is the multiple linear regression. This methodology has one dependent variable and several independent variables (ibid). For instance, it can be the number of sales as a function of time, season, weather and any other variable explaining the changes in number of sales. However, similar to simple linear regression, the method is still sensitive to anomalies in the data (ibid).

When looking at the demand as a times series, it is possible to find various hidden demand patterns (Jonsson & Mattsson, 2009). These demand pattern could be trends, where the demand is either increasing or decreasing for several consecutive periods, and seasonal variations, when demand changes during specific periods of time (ibid.). These factors are both essential to take into consideration when analyzing the forecasting data in order to prepare the organization for future demand changes.

3.2.2. Qualitative Forecast Methods

The use of qualitative techniques is most feasible when the product is recently introduced to the market or going to be phased out (Jonsson & Mattsson, 2009). The method also has an advantage when the number of products to forecast is small, when the forecast horizon is long, and when there are requirements for the forecast for long-term planning (ibid.). It is as well preferable if the number of forecasting periods is small, for example, an annual forecasting period instead of a weekly demand (ibid.).

The objective of qualitative methods is to break down information in a logical, unbiased and systematic way. There are two general approaches when using the qualitative methods; the sales management approach and the grassroots approach (Jonsson & Mattsson, 2009). The sales management approach mainly collects the top management team and then drive a discussion to determine the forecast of future businesses. There are two potential alternative team setups (ibid.). The first team setup includes a top management meeting to produce a forecast. This setup is particularly advantageous when forecasting for the long-term business development process. The second team setup comprises only the managers within the marketing and sales department. This variant is more beneficial for short-term forecasting of expected future sales and delivery volumes. The advantage of this management approach is its efficiency in decision making for the forecast and the fact that it allows a joint evaluation and agreement on the forecast in an efficient way (ibid.). However, its weaknesses are that if one manager has high authority, it might affect the result of the forecast significantly since it will mainly reflect his or her opinion. Moreover, there might also be a chance that the forecast tends to reflect ideal thinking rather than a realistic evaluation.

The grassroots approach is a more individual analysis method, where every individual that has contact with the market makes their judgement and provide their proposal for the forecast (Jonsson & Mattsson, 2009). Thereafter, these individual forecasts are gathered, processed and summarized to a joint forecast for the whole company. One advantage of this approach is that the most relevant persons that have contact with the forecast are in the center of the analysis (ibid.). The forecast will also then hold a higher quality of future judgments. However, one drawback is that it requires more time and demands additional data processing compares to the sales management approach (ibid.).

3.2.3. Qualitative and Quantitative Method Integration

Even though the forecasting methods can be divided into qualitative and quantitative types, researchers have found that in practice, it is often necessary to work with a combination of the two (Barrow & Kourentzes). Qualitative forecasting has the advantage to be up to date with information about changes in the various circumstances that can influence the forecasts (Jonsson & Mattsson, 2009). However, the intrinsic biases in qualitative forecasting can build significant forecast errors, and these errors can have a severe effect on forecasting quality. Meanwhile, quantitative methods are mainly created from historical data, which are often more stable and consistent (ibid.). Although, quantitative methods do not react to changes as well as the qualitative methods, which affects the credibility of the forecast. Therefore, it is necessary to combine the advantages of both qualitative and quantitative forecasting approaches. However, the way to integrate these methods is also essential. According to Sanders and Ritzman (2004), it is crucial that the integration of the methods are independently generated, has a low correlation of forecast errors and is unbiased. Table 3 shows the four different integration methodologies and their advantages and disadvantages.

The first integration methodology means to use qualitative reasoning to adjust already existing quantitatively generated forecast based on specific information about the trend or seasonal variation (Sanders and Ritzman, 2004). This way, the latest knowledge about the changing environment and product will be taken into consideration. The advantages of this methodology are the timing since this method allows the latest information to be communicated into the forecast. Another benefit is that this method creates a high sense of ownership since the forecaster is the primary adjustment person of the forecast. However, the disadvantage is that this method is only applicable when there is specific information about the changing environment (ibid.).

The second integration methodology implies the use of quantitative approaches as a correction method to the qualitative approaches to reduce bias (Sanders and Ritzman, 2004). This method is applicable when there is limited quantitative information or in situations where the corrected judgment can consequently be merged with the quantitative forecast. Although, this method creates a low sense of ownership, especially if two different persons make the quantitative and qualitative forecast. Since the qualitative person might feel that they have been corrected (ibid.).

The third integration methodology combines two individually produced forecasts (Sanders and Ritzman, 2004). The combination can be conducted objectively with a simple average or subjectively. The advantage of this method is that it diminishes bias, erroneous assumption and model errors. However, the objectivity of the method also creates a low sense of ownership and is only applicable when the forecaster and user are not the same person (ibid.).

The fourth integration methodology uses qualitative reasoning in the selection and development of the quantitative forecast (Sanders and Ritzman, 2004). Qualitative methods are applied to choose variables, designate the model formation and establish parameters. This method has shown to be the least subject to an adverse effect from judgmental biases and is considered highly useful for forecasting (ibid.). The limitation of the method is that it entails significant technical knowledge and perception of quantitative systems.

Table 3: Advantages and disadvantages of different integration methodologies

	Advantages	Disadvantages
Method I. Judgmental adjustment of quantitative forecasts	Timing, information novelty and high sense of ownership.	Only applicable when information regarding changing environment is available.
Method II. Quantitative correction of judgmental forecasts	Useful when there is limited historical data.	Low sense of ownership.
Method III. Combining judgmental and quantitative forecasts	Diminishes bias, erroneous assumption and model errors.	Low sense of ownership. Forecaster and user cannot be the same person.
Method IV. Judgment as input to model building	Least subject to an adverse effect from judgmental biases.	Entails significant technical knowledge and perception of quantitative systems.

In general, there is no best individual forecasting method and neither is there a best forecasting integration method. The method selection is always dependent on the situation and the amount of information available (Fildes & Kingman, 2011).

3.3. Demand and Production Planning

This sub-chapter presents the demand and production planning processes normally taking place in companies using traditional MRP. Figure 5 shows a summary of these processes. In section 6.3 a comparison is made with the demand and production planning processes at AeroCo as well as the demand and production planning described in the DDMRP method, the Demand Driven Adaptive Enterprise model in order to analyze what changes are needed for these processes to handle the DDMRP model.

Figure 5: Forecasting within several of demand and planning phases.

Whenever a product or service must be delivered in shorter lead time than they can be produced or acquired, a forecast will be necessary to generate (Jonsson & Mattsson, 2009). The production cannot be done only upon request but must be initiated before receiving an order. However, it is not necessary to forecast every individual product in the organization. Researchers often divide the demand into two main aspects; dependent demand and independent demand (Jonsson & Mattsson, 2009). Dependent demand refers to the demand for a product being directly dependent on the demand for another product. This is primarily the use of raw material and sub-finished products that are used as components in the end product. A calculation deriving the demand for the end product to the demand of the dependent product is often useful. Independent demand is the demand for a product that is not directly related to the demand of other items, for example, spare parts or end products (ibid.). These items require more traditional forecast methods like the ones described in section 3.2 Forecast Methods.

A demand forecast is often divided and practiced in several different levels of the organization. First, at the longest planning horizon, sales and operations planning (S&OP), the forecast is used at the beginning of the process and is often conducted in a product group level (ibid.). The marketing department at the organization performs a forecast for the demand of the future planning period. It is essential that the forecast is not influenced by the wishful thinking of the potential future sales or an attempt to achieve a full capacity production. The forecast should instead only contain sales capacities obliged by the market (ibid.). This form of forecast is often denoted in financial basis and is conducted in a longer time period in the future, usually one to two years depending on the time required to alter the company's capacity (ibid.). The aim of S&OP planning is to optimize the company's efficiency and competitiveness by obtaining a balance between capacity and demand. S&OP is an iterative process that both sizes the capacity of required resources in order to fulfil the demand and at the same time produces a production plan that suits the internal and external capacity (ibid.).

Secondly, the forecast is also important when it comes to master production scheduling (MPS). In the MPS process, the number of products planned to be manufactured and delivered is communicated for up to a six months time horizon. This plan is frequently updated, e.g. every week and strives to attain a balance among supply and demand (ibid.). As for S&OP, the forecast of future sales is the central driver for MPS. However, the major difference between S&OP and MPS is the length of the horizon, aggregation level of products and the frequency of the forecast. In order for the production and suppliers to meet the requested customer demand, a more frequent forecast at a shorter period and at individual product level is thus needed. Other important difference is that the MPS can also take placed customer orders into consideration when forecasting the future, which is often not possible in the S&OP process (ibid.).

Thirdly, like MPS, material planning strives to balance the supply and demand of materials (Jonsson & Mattsson, 2009). However, material planning handles only the replenishment of ingoing material and does not focus on the internal production as in S&OP and MPS. This planning phase is based on a short time forecast period and with a continuous communication with suppliers regarding the future situation, in order to maintain the right capacity in the organization (ibid.).

In a broader perspective, a forecast is also used in the financial budget aspects (ibid.). Organizations use forecasts to gain a deeper understanding of their future financial situation. The difference between the budget forecast compared to the other kind of planning forecast is that the budget forecast is fixed during the year meanwhile other forecasts mirror the fluctuations in demand to the degree that sales and manufacturing can be modified (ibid.).

3.4. Demand Driven Material Requirement Planning

The fourth sub-chapter presents the five stages of the DDMRP method to give a basic understanding of the methodology. It also presents the Demand Driven Adaptive Enterprise (DDAE) model which is the demand and production model presented in the DDMRP methodology. The DDAE model is in chapter 6.3 compared to the traditional demand and production planning processes to analyze what changes that is needed to be done for a company moving from the traditional MRP to DDMRP.

Today, most businesses use MRP to plan and execute production (Miclo, 2016). However, due to increasing variability and complexity in today's business, MRP has had almost no development since the 1970s. In addition, it has been concluded by Kortabarria et al. (2018) that MRP is not the best system in a volatile and variable world. In addition, by being based on forecasts of the end product demand, it causes additional uncertainty. A growing production planning method is lean manufacturing. However, lean has been shown unsuitable for the unstable environment and hard to apply to the entire supply chain (Miclo, 2016). The system in its aspiration of working without buffers, thus becomes sensitive to variation in demand (Kortabarria et al., 2018). An upcoming alternative to these methods is the DDMRP method, which has two main promises; reducing flow variability and detecting demand variations (Miclo, 2016). The theory behind DDMRP is that many of the currently used methods give the bimodal inventory distribution, as was shown in Figure 1, with either too high or too low inventory. However, DDMRP promises to solve this problem by remodeling the stock and center the distribution on a sufficient amount of inventory.

DDMRP as a method has been inspired by both MRP and lean manufacturing, but also six sigma, theory of constraints and Distribution Resource Planning (DRP) (Ptak & Smith, 2008). In addition to this, the DDMRP method also adds some new innovative content. The idea is to have decoupling points with buffers that can be dynamically adjusted protecting the flow, which is pulled by demand-driven planning. It also includes daily visual and collaborative management for both planning and executing (Miclo, 2016).

3.4.1. The Five Stages of DDMRP

DDMRP implementation has five stages, divided into three steps, as shown in Figure 6 (Ptak and Smith, 2008). The first step is positioning, which contains the strategic decoupling stage. The next step is about protection, where the operations are protected with buffers. This step includes buffer profiles and levels as well as dynamic adjustments. The last step is pull, where a pull flow is built out of the two steps; demand driven planning as well as visible and collaborative execution.

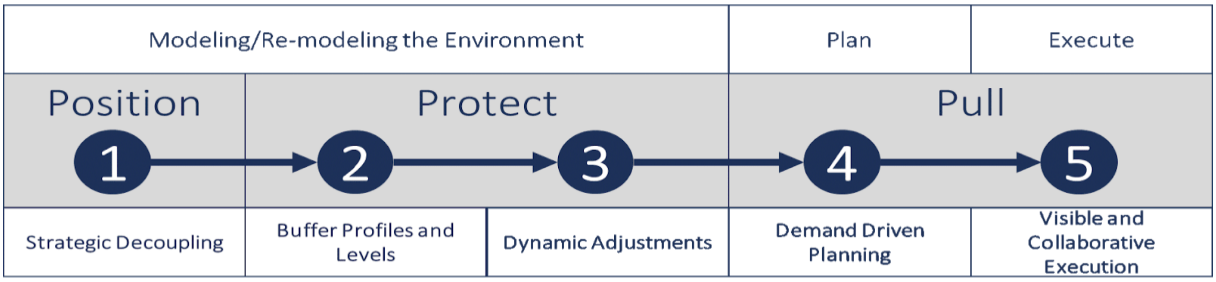

Figure 6. The five stages of DDMRP divided into three steps (Ptak & Smith, 2008).

3.4.1.1. Positioning

In DDMRP, the first question to ask is where and not how much to store (Miclo, 2016). This question is answered in the first stage. In DDMRP only strategic parts have to be buffered, and these buffers are placed to optimize the total return on investment (Ptak & Smith, 2008). This is done by defining the Decoupling Lead Time (DLT), the longest unprotected lead time in a Bill of Material (BOM), i.e. the longest lead time without buffers.

3.4.1.2. Protecting

In the protecting step, the question about how much to store is answered. First, the buffer profiles and levels are defined. DDMRP uses three different kinds of buffer zones; red, yellow and green (Ptak & Smith, 2008). In the buffers, the yellow zone represents the in-process orders and correspond to the Work In Progress (WIP) held at each time (Miclo, 2016). The red zone is the safety stock protecting against variations both in the production or supply delivery and in demand. Finally, the green zone represents the order stock and is supposed to correspond to the number of products to be ordered (ibid.). The three zones are defined as follows (Ptak & Smith, 2008):

$$Yellow\ Zone = ADU * DLT$$

$$Red\ Zone = Red\ Zone\ Base + Red\ Zone\ Safety$$

$$Red\ Zone\ Base = Yellow\ Zone * LTF$$
$$Red\ Zone\ Safety = Red\ Zone\ Base * VF$$

$$Green\ Zone = Max\ [Yellow\ Zone * LTF, MOQ, ADU * OCT]$$

Order Cycle Time (OCT) and Minimum Order Quantity (MOQ), the smallest quantity for which it is allowed to place an order can both be used in calculating the green zone (Ptak & Smith, 2008). The Lead Time Factor (LTF) is a percentage of ADU within the decoupled lead time where a longer lead time leads to a lower lead time factor. For long lead times, a percentage of 20-40% is used, for medium lead times, 41-60% is and for short lead times a 61-100%. However, it is important to note that the definition of what is long or short varies between different organizations. The Variability Factor (VF) contains both the supply and demand variability. For low variability, a percentage of 0-40% is used, for medium variability 41-60%, and for high variability 61-100% (ibid.).

Average Daily Usage (ADU) is the foundation of buffer calculations and significant changes to the ADU will result in significant changes in the buffer levels (Ptak & Smith, 2008). There are four main decisions to take about the ADU calculations. The first two is the consideration to the length of the period used and the frequency of update. The third consideration is about using past-looking historical average, forward-looking forecasted average or a mix of the two (ibid.). It is important to note that if choosing the forward-looking option, the forecast is incorporated in the DDMRP buffers and not in the DDMRP ordering mechanism that will still be driven by actual demand. The final consideration is ADU exceptions (ibid.). This concerns reacting to significant changes in the ADU by generating an alert if the ADU increases or decreases with more than a certain percentage within a certain time frame. If this change is a random event that will soon return to normal demand, then it should be excluded from the ADU. However, if the change is assumed to remain in the future, then the change should be included in the ADU.

For the dynamic adjustment, the buffers can be adjusted by constantly recalculated and updating the ADU (Ptak & Smith, 2008). It can also be done by including a Demand Adjustment Factor (DAF) manipulating the ADU within a specific period. This is done with the following equation (ibid.):

$$ADU' = ADU * DAF$$

A DAF can be used for several reasons but is often used to manipulate the ADU according to historic patterns or planned decisions (Ptak & Smith, 2008). It can also be used as a rapid buffer adjustment to react to an alert for significant changes in ADU. The reason behind the change should be discussed at a higher level in the organization, and then a possible decision of reacting to the change can be carried out with the help of the DAF. DAF is also used for planned product introductions and deletion or where there is a known trend in the sales volumes (Ptak & Smith, 2008). Finally, it can also be used to handle seasonality. When doing so, a consideration to capacity has to be made, since if the seasonality is so severe that it will exceed capacity, production has to be moved forward in time (ibid.).

3.4.1.3. Pull

In the pull step, the demand driven planning is carried with the help of the Net Flow Equation (NFE) calculated out of inventory levels (Ptak and Smith, 2008). In this calculation, three different inventory levels are used. The first is the on-hand inventory, the quantity of physically available inventory. The second one is the on-order inventory, the quantity of ordered but not yet received inventory. The final one is the Qualified Sales Order Demand (QSOD), the sum of sales ordered due today or earlier demand not yet delivered. The calculation of the NFE is done using the following equations (ibid.):

NFE = On-hand + On-order - QSOD

TOR = Top of Red Zone = Red Zone
TOY = Top of Yellow Zone = TOR + Yellow Zone
TOG = Top of Green Zone = TOY + Green Zone

For the demand driven planning, there are two possibilities. Either the NFE is larger or equal to TOY meaning that the inventory is sufficient and no order has to be placed (Ptak & Smith, 2008). The other scenario is when the NFE is lower than TOY. This results in a supply order of the quantity that differs between the NFE and the TOG. The visible and collaborative execution contains four different alerts (Ptak & Smith, 2008). They enable correct prioritization of orders based on on-hand buffer status rather than relying solely on the due date (Kortabarria et al., 2018).

3.4.2. Demand Driven Adaptive Enterprise

The Demand Driven Adaptive Enterprise (DDAE) model is a management model that spans over the operational, tactical and strategic ranges of an organization (Ptak & Smith, 2008). This model aims at adapting to the complex and volatile markets of today and thus enable companies to sense changes on the market by focusing on the protection and promotion of the flow of materials and relevant information. As could be seen in Figure 7, the model consists of three components; Demand Driven Operating Model (DDOM), Demand Driven Sales and Operations Planning (DDS&OP) and Adoptive Sales and Operations Planning (Adoptive S&OP) (ibid.). What is important to note with the Demand Driven Adaptive Enterprise model according to Ptak & Smith (2008), is that it does not start at one end and finish in the other, but rather is a bidirectional iterative process. In addition, there is market interaction in both ends of the process, where the DDOM takes the input of actual demand, and the Adaptive S&OP considers the innovative changes on the market (ibid.).

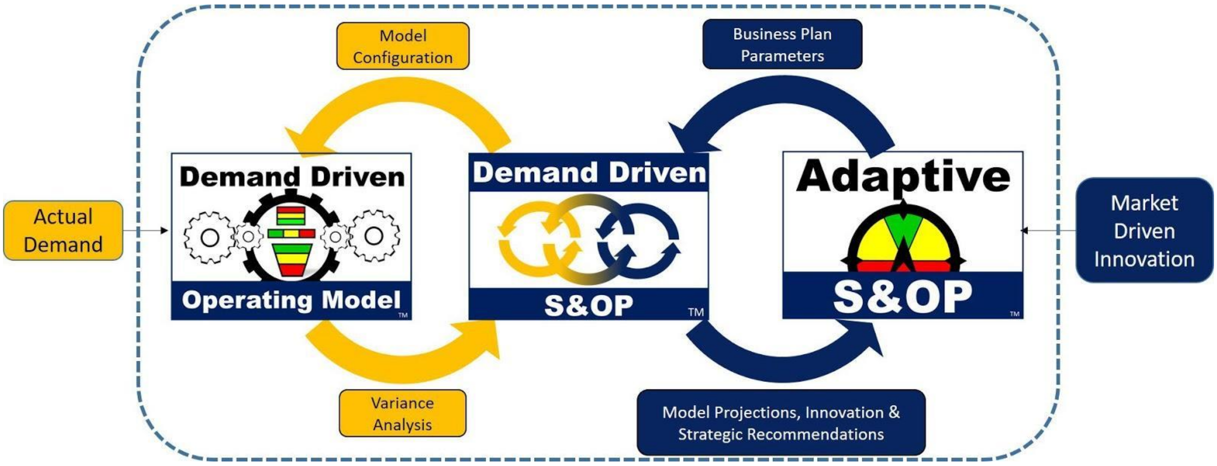

Figure 7. The Demand Driven Adaptive Enterprise model (Ptak & Smith, 2008).

The Demand Driven Operating Model is a flow-based operating model where the DDMRP method is the core component (Ptak & Smith, 2008). The DDMRP method is used to generate supply order signals to production, purchase and stock transfer. One unique feature of the DDOM is that it does not use a master production schedule which is replaced with the master setting input (ibid.) from the DDS&OP. There are three main settings; buffer profiles, part demand data, and part profile assignment. The buffer profiles consist of the part type (purchased, manufactured or distributed) as well as the lead time and variability factor. The part demand data is the average daily use (ADU) and any applicable demand adjustment factor (DAF). Finally, the part profile assignment is the assignment of replenishment to a particular buffer profile. Altogether, these are the input used to design the DDMRP buffers. Based on these buffer levels, the DDOM uses actual demand, rather than forecasts, to generate supply orders. According to Ptak & Smith (2008) the actual demand is better to use since this is the most relevant and undistorted demand signal. When the actual demand triggers a need for replenishment of an item in a buffer, the demand for the next part of the flow is directly derived from the actual demand, even though the demand is accumulated at the decoupled points.

The second process is Demand Driven Sales and Operations Planning, which is the traditionally missing link between the strategic S&OP process and the day-to-day operational activities (Ptak & Smith, 2008). Traditionally, an S&OP process has tried to provide the organization with a doable production plan that meets the financial requirements, with consideration to available market information. This has been done with the master production schedule, which on a detailed level specifies what has to be done and when. A specific demand plan, like the master production schedule, is required by the traditional MRP system to perform its calculation. Even though this plan does not take any variation into consideration. On the contrary, to create a more effective S&OP plan, it should contain an expected range from the pessimistic scenario to the optimistic scenario in order to contain the strategic direction as well as the tolerated deviation (ibid.). DDS&OP here creates a bidirectional tactical agreement where the perceived demand range and capacity requirements from the Adaptive S&OP are used to set the master setting input for the DDAE model. At the same time, the performance of the DDAE is followed up and projected to recommend strategic changes to the business plan done in the Adaptive S&OP (ibid.).

Finally, the Adaptive Sales and Operations Planning is the process to strategically plan the company's business (Ptak & Smith, 2008). A strategic business plan is used as input for the tactical DDS&OP. In return, the DDS&OP gives signals about the operating model's performance and suggests changes to the business plan. For example, when new potential markets or capital investments are needed (ibid). By differentiating between DDS&OP and Adaptive S&OP, the organization can work with two parallel processes that treat the tactical and strategic planning separately.

3.5. Conceptual Framework

Uncertainty, both internal and external, can affect the MRP system in various ways (Fildes & Kingman, 2011). The internal uncertainty, such as variations in manufacturing and purchasing lead times are often possible to control and manage by the company. The uncertainty in external demand, on the other hand, is outside the control of the company, and thus the Material Requirements Planning (MRP) can only be based on a forecast of demand. When referring to forecast errors, practitioners usually mean the difference between the actual and the forecasted value of demand (Fildes & Kingman, 2011). However, this error contains both the randomness in the demand generating process, the process which is communicating the demand from the customer towards its supplier, as well as the error derived from the used forecast method. This means that there are two different sources of uncertainty in the demand forecast process which both increase capital costs of high inventory levels and/or reduced service levels when the company is not able to properly assess future demand (ibid.).

The first source of uncertainty, the variation in the demand generating process, can only be reduced by changing the demand generating process itself. For example by changing the customers' order behavior or through collaborative forecasting. In section 3.1 Supply Chain Transparency, possibilities of how to reduce the variations in the demand generation process through increasing the collaboration in the supply chain was discussed. The main findings of this section is summarized in the first box of information in Figure 8, representing the interface between the focal company and its supply chain.

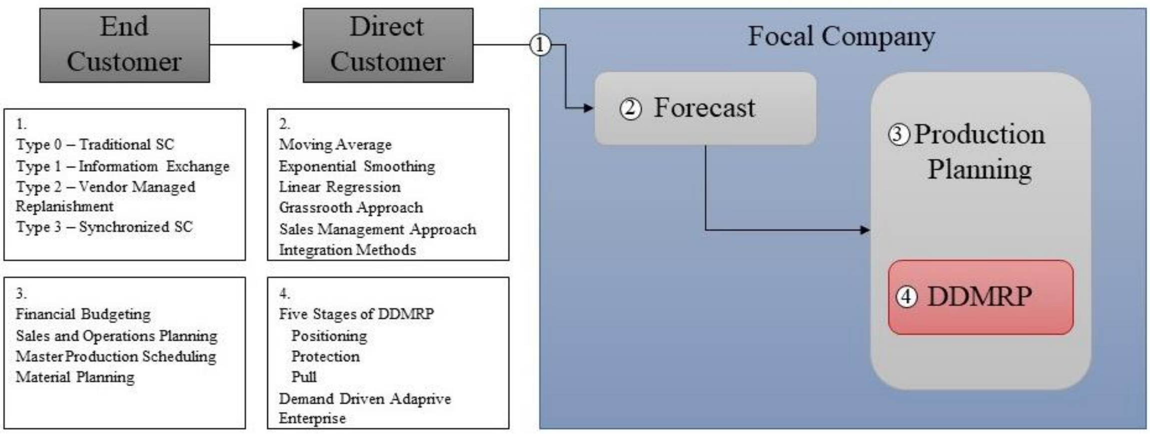

Figure 8. Research Model - Conceptual framework.

The second uncertainty, connected to the forecast errors, can be reduced by optimizing the forecast method, but will never be completely eliminated since demand-related uncertainty cannot be fully captured. However, there is no general best method for forecasting (ibid.). Instead, how suitable a forecast method is depends on the textual demand uncertainty. In addition, not sufficiently combining historical calculations with a manual assessment of the future can increase the forecast error (Jonsson & Mattsson, 2009). If relying too much on historical data, necessary changes on the market may be omitted. Therefore, the qualitative and quantitative forecast methods as well as integration methods was compared in chapter 3.2. Forecast Methods. The findings of this section are summarized in the second box of information in Figure 8.

An example of internal uncertainty connected to forecast errors is the risk of tensions and mistrust in the organization. Reasons for this are unrealistic expectations, low acceptance level and conflicting interest (Jonsson & Mattsson, 2009). Since the forecast is only an assessment of the future demand, and by definition never shows the actual future demand, this is also how it should be thought of by those who use it. Thus, when having too high expectations of forecast accuracy, there is a significant risk of disappointment. Further, if the personnel start to doubt the accuracy of the forecast and begin making their own forecasts, the division responsible for conducting the forecasts will be less motivated to produce a good forecast. This will then result in an even less accurate forecast and lower acceptance level of even fewer employees using the forecast.

In addition, there may be conflicting interests between different departments of the company (Jonsson & Mattsson, 2009). The sales department may have an interest in optimistic forecasts in order to ensure manufacturing capacity to secure production of the volumes assumed possible to sell. On the other hand, the production department may have an interest in pessimistic forecasts in order to reduce the risk of over-capacity and high idle time for expensive resources. To avoid this problem, it is crucial to have a well-functioning demand and production planning process in the company that is able to control and follow-up the forecast (ibid.). These processes was explained in the chapter 3.3. Demand and Production Planning, covering the traditional processes for demand and production planning and 3.4. Demand Driven Material Requirements Planning, covering DDMRP. The main findings of these sections are presented in the third and fourth box of information in Figure 8.

4. Company Structure at AeroCo

In order to understand the internal processes in which forecasts are being made and used, the current organizational structure of AeroCo is presented (see Figure 9). The organization is structured in such a way that there are different Integrated Program Teams (IPT). The teams are responsible for the different contractual customer agreements with the OEMs, also referred to as programs. Each team include representatives from all the different functions of the supply chain, engineering, finance, and commercial, which in the figure is symbolized with black borders. The teams consist of an IPT manager, a commercial manager, a finance manager, a purchasing industrial manager (PIM) and two managers from engineering. This includes one engineering manager responsible for manufacturing and one for design. The PIM is a rather new role at the company, invented one and a half year ago to take the general responsibility for finding a supplier base, internally in AeroCo or externally, in order to satisfy its programs demand.

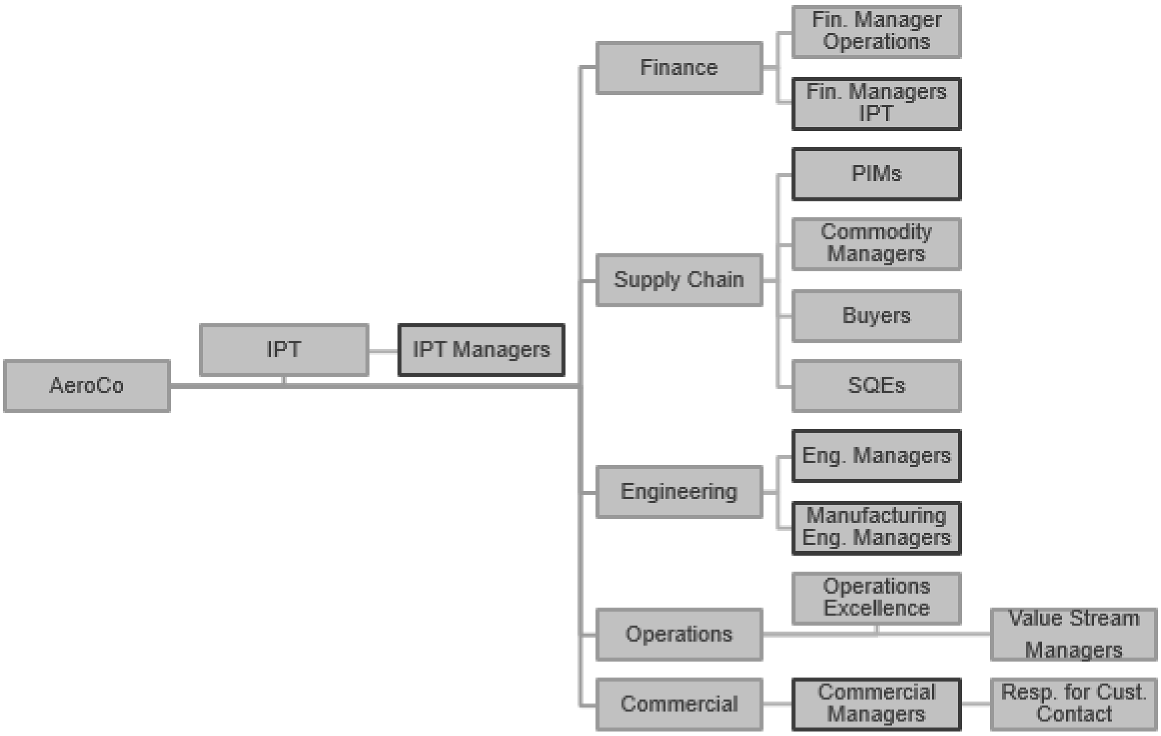

Figure 9. General Company Structure.

In the perspective of the PIM, the internal production is only one out of many suppliers, although the collaboration is closer with the internal operation than external suppliers. The IPT has the responsibility to create a demand plan which works as an order towards the internal operations division. Most of the materials ordered from external suppliers are connected to the internal production (as seen in Figure 10) and thus also follows the demand plan. However, for many spare parts, the products are shipped directly from the supplier to the OEMs with the confirmation from AeroCo. It then requires a different demand plan than the internal one and is thus directly communicated to the supplier.

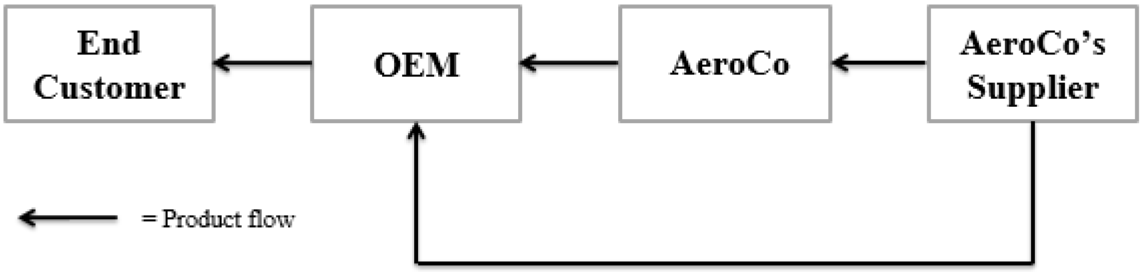

Figure 10. Product flow in the supply chain.

The IPT works both with strategic and operative questions on a horizon up to two years. One of the interviewees stated that he would appreciate if the work was focused only on longer time horizons (more than six months), which would be possible if all the suppliers would deliver as promised and AeroCo would be able to satisfy the OEMs. As it is now, much time is spent on solving problems at a shorter time horizon to secure deliveries to the OEM, in order to avoid interrupting their production.

At the supplier side of the company, there is a supplier team consisting of a purchaser, a supplier quality engineer (SQE) and a material planner who is operatively responsible for the supplier side. In the supplier team, the purchaser is responsible for the administrative and commercial parts, the material planner is responsible for the physical supply of materials, and the SQE is responsible for quality. The earlier mentioned PIMs are also part of the supplier side of the company as well as commodity managers, which both work more strategically with make or buy decisions. The PIM is responsible for the suppliers within his or her program while the commodity managers are responsible for creating a supplier base within his or her commodity. At this strategic level, the demand plan is used to forecast the requirements of the supplier base. It is stated by the PIM that it is important in the creation of a supplier base to not only use the expected volumes but also use the upper bound communicated from the commercial side of the IPT. This enables some safety in the event of maximum demand levels. In addition to this information, the PIM also looks at the yearly internal capacity as one parameter of the total supply chain capacity. According to the PIM, it is important in order to know if the operations department can meet the demand.

The operations side of the company is divided into five different value streams; each of them managed by a value stream manager. These value streams are responsible for different products and different steps of the production process. Responsibility of the product is given depending on which value stream that has available capacity, and similarities in production. The value streams are located in three different factories. For example, the product used in the pilot study of DDMRP at AeroCo starts within Value Stream Alfa in factory X, then it moves on to Value Stream Beta, first in factory A and then in factory C. Moreover, there is a support function named Operations Excellence. This division focuses on creating best practices, standard work and clear processes concerning lean and production logistics. It also drives improvement projects and follows up the performance of the production.

In each value stream, there is also a logistics manager responsible for material planners, production planners and individuals responsible for customer contact as seen in figure 11. The production planner is responsible for the logistics within the factory as well as for creating the production plan. The material planner is responsible for ingoing material, and regular call-offs of material from already established agreements. He or she has access to the demand plan but is not supposed to use this in the daily work, since there may be additional strategic decisions at operations that are not included in the demand plan. Instead, it is the production plan which is the base for ordering material, taking also purchase lead time and time buffer into consideration. The material planners arbitrarily choose these buffer levels based on a volume value analysis and earlier experience. For some products, the complexity in material planning is described in the interviews as being too high for the IT-system to handle. For example, in the case of using multiple sources where the different material number are used for different suppliers. To get around this problem, a material planner describes how she creates her own excel-sheets to manage the inventory levels.

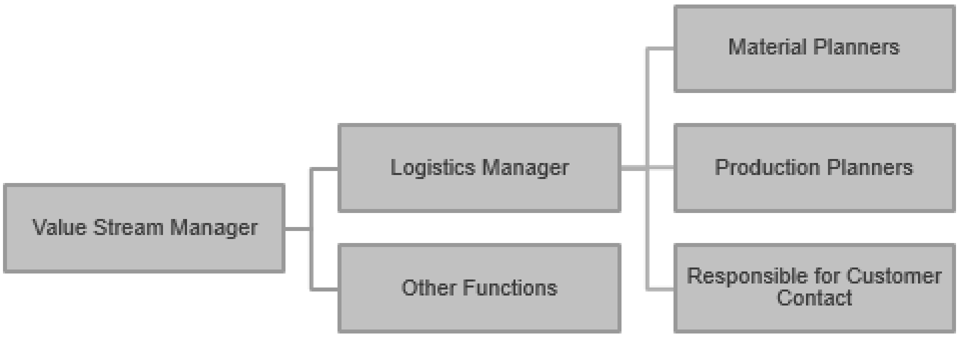

Figure 11. Value Stream Structure.

Regarding the commercial division, there are different ways to handle this in different value streams. Some time ago, the company tried to place people of the commercial function in the value streams, to be responsible for customer contact at the operational level. The intention was to increase the trust from the value stream towards the demand plan made by the commercial division. However, this change was reversed at most value streams because of the opinions communicated both by value streams and the responsibility for customer contact of not being very pleased with the change. Although, some interviewees argued that this change would have been good if one would have had the patience to wait for the initial problems to be sorted. For example, it was mentioned that it is easier to get information about the internal production and the status of ingoing material from suppliers if placed in the value stream. Also, even though not being as involved in the contractual and commercial parts of the customer contact, it is still possible to get the required information through weekly meetings and daily communication with the commercial function. However, this will not be as good as if working in the commercial department. It was also mentioned in the interviews that for some value streams, the high number of OEMs served by the value stream means that no single person could handle all the contacts. Instead, the commercial department already handling the communication about demand levels at a longer time horizon, are supposed to take over the contact also for a shorter time horizon, about, for example, material shortage and quality errors. However, this is currently handled by the production planners.

The finance function aims to describe the financial situation for the company in order to show senior management and the owners the future situation of the organization. In this way, the finance division is responsible for performing a financial forecast for the company. Because of the general structure of the company with the IPTs placing orders at the value streams, the financial structure is different for the revenues and the costs. The revenues are structured according to the IPTs, where the finance manager of each IPT is responsible for the program's revenues. The costs are structured based on which value stream it belongs to where one financial manager is responsible for all value streams. However, the IPT sets the expectations for the costs by creating the demand plan. The costs in the value streams can be translated to costs for the program by dividing them by each product separately.

5. Empirical Findings and Analysis

In this chapter, the findings from interviews, as well as the quantitative data analysis will be presented. The structure of the findings is based on the concepts found by using the method proposed by Gioia et al. (2013), described in the method section of this paper. The concepts, which can be found in Appendix II, were further structured according to the research model, as presented in Figure 12.

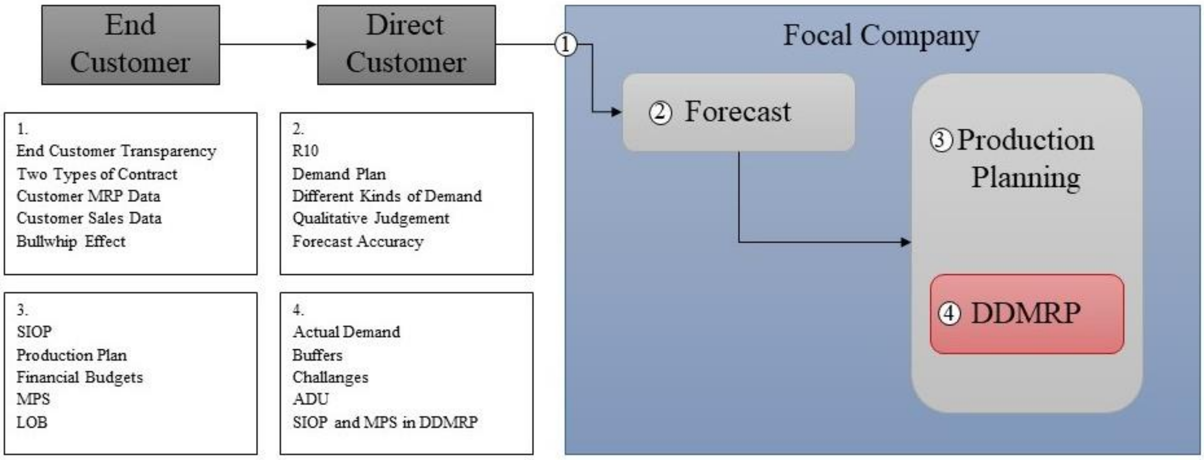

Figure 12. Research Model - Findings.

5.1. Supply Chain Transparency

The aerospace industry is a very stable and transparent market. A placed order at Airbus is currently required eight years before a plane can be delivered. Thus, the end-customer demand is known already eight years in advance. The information regarding the production and sales of the aircraft manufacturers is also made public as communication towards the stock market. There is information regarding which airplanes are in order, and based on history, it is possible to guess which engines will be chosen as well. Many interviewees believe that AeroCo should become better at listening to what the end-customers say. Both Airbus and Boeing delivered almost exactly what they had promised.

5.1.1. Communication with OEMs

The information process between the OEMs and AeroCo is different depending on the contract type. There are two major contract agreements; Risk and Revenue Sharing Partner (RRSP) agreements and Long-Term Agreement (LTA). One interviewee describes the differences in communication between the two contract types.

> *The information processes start when you have won a deal. Here, there are two different agreements; RRSP and LTA. With the RRSP agreement, you have more continuous communication and weekly plans. At LTA you only have a weekly schedule.* - Employee, Operations Excellence

RRSP agreements are the most common for AeroCo and imply that the company will not get paid until the entire engine is sold to the end-customers and AeroCo thus owns the product parts until then. The RRSP contracts apply throughout the entire engine lifetime, and AeroCo is obliged to deliver parts as long as the engines are demanded from the end-customers or needed as spare parts for the aftermarket. An interviewee argues that for this reason, long-term strategic planning is required with a RRSP deal, in order to always have the right capacity to deliver. Thus, AeroCo often holds a dialogue with the OEMs regarding their long-term strategy, and then compile a qualitative conclusion of their strategy. With the RRSP agreement, AeroCo also has access to more transparent and continuous information from the OEMs. Information about the OEMs' buffer stock and the amount of WIP are accessible upon request. However, it was stated in the interviews that some OEMs are less transparent and dynamic with their communication with AeroCo than others. On the other hand, with the LTA contract, there is no transparency obligation from the OEMs. Only a weekly schedule, for the short-term demand is available. With LTA, AeroCo is also able to renegotiate the agreement if there is a capacity shortage.

The communication between the OEMs and AeroCo is mainly held through two different channels, which was shown in figure 13 showing the information flow in the supply chain. The IPT is responsible for the long-term strategy communication with the OEMs. Meanwhile, the person responsible for customer contact placed either at the commercial division or in the value stream has more detailed weekly communication with OEMs. Within shorter time horizon, communication from AeroCo towards the OEMs is displayed through the LOB described earlier. However, it was mentioned during the interviews that, if there has been a significant delay in the production for an extended period, more managers will be involved in communication with the OEMs.

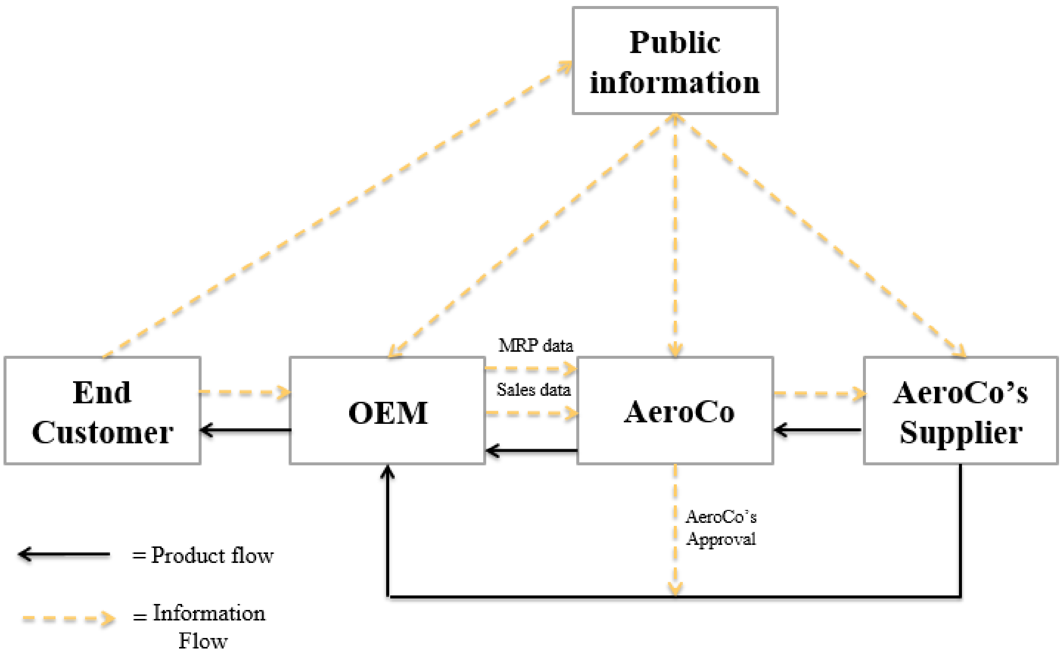

Figure 13, Information flow in the supply chain.

Concerning the long-term communication, the OEMs communicate their needs in different ways. When discussing one of the OEMs, denoted EngineCo, it was stated that as a partner in an RRSP agreement, AeroCo has access to both what EngineCo communicates as orders via a tool called ABC as well as the company's sales forecast. ABC has a horizon of up to five years and corresponds to EngineCo's MRP. However, not all demand is filled in for the whole five-year period. Within three years ABC contains most of the demand and is thus seen as reliable, according to the interviewee. AeroCo uses ABC for a period of at least one year. The sales forecast, on the other hand, includes confirmed and speculative orders from the end-customers towards EngineCo as well as stated volumes for the spare engines. In the long term, there are less confirmed and more speculative orders.

Seeing the OEMs' MRP data as highly reliable is one reason why AeroCo performs their forecasts as a qualitative judgement, mainly based on this data input. However, the demand plan volume is often lower than the ABC. The IPTs believe that this is because of that the OEMs tend to increase the volumes compared to their actual demand in order to be safe against shortage. However, when plotting the evolvement of OEMs MRP data over time (see Figure 14 where darker color means older versions of the OEMs MRP data), it can be seen that the data is not consistent, but varies over time.

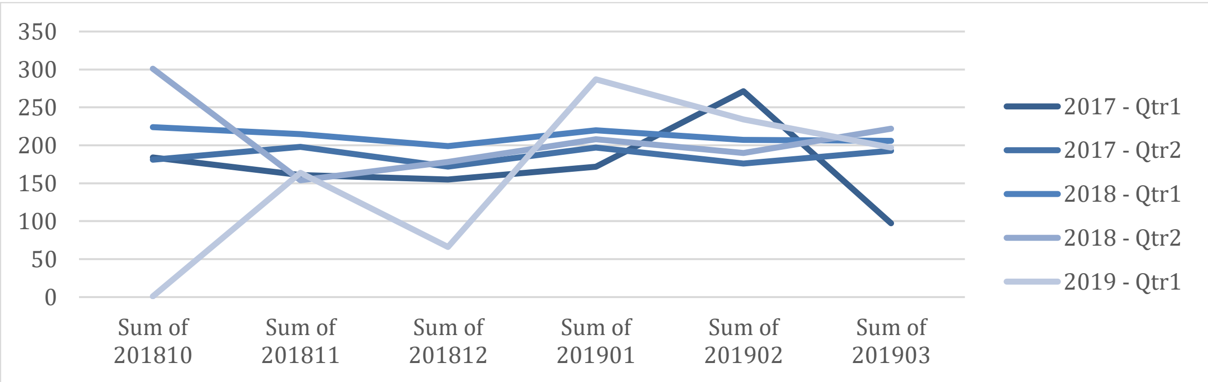

Figure 14. OEMs MRP data, evolvement over time. Qtr1 represents the data communicated early in January, while Qtr2 represents the data communicated in late June.

Furthermore, there are reasons mentioned in the interview for the ABC not being very accurate. ABC is described in the interviews to be frequently updated based on changes in the internal production at the OEMs, which does not always represent significant changes in end-customer demand. Thus, AeroCo has to discover which changes that represent a change in end-customer demand themselves. Also, it is described that towards the end of the year, the OEMs often realize that there are errors in their MRP systems, which may lead to several changes in their communication of demand. This is also described in the interviews to be the reason for the previous year's forecast to be included in the demand plan. This update of the demand plan is also described as essential since the backlog has to be placed at the current year in order to be incorporated in the current budget.

The IPTs also believe that there might have been some internal communication error within EngineCo regarding their current stock level when conducting the ABC. They also think that there are different people responsible at EngineCo for the ABC system and the material replenishment from AeroCo. This thought is based on that AeroCo can receive answers that differ from the ABC data when asking questions about the demand volumes. It is also described in the interviews how it is possible to receive additional information regarding the actual demand of the OEMs. This can, for example, happen if AeroCo has been late with deliveries towards OEMs MRP during a longer time period, or if AeroCo in their sales and operations planning process gets to the conclusion that there is not enough capacity to meet customer demand. This actual demand can also differ a lot from the customers MRP, but it is not at all certain that changes will be made in the MRP. However, one interviewee states that given how much material that is included in an engine, and how many other first-tier suppliers there are in addition to AeroCo, it would require a lot of time and resources from the OEMs to communicate personally with each one of the suppliers. Thus, as long as everything is working according to schedule, the OEMs do not spend any more time on communicating the actual demand more than sending out the MRP signals.

Moreover, it is described by the IPTs that whenever a supplier is far behind in the delivery, EngineCo compensates by ordering even more of that product. This is done since they do not trust the suppliers to deliver the full volumes that has been ordered. This action was also described in many interviews to take place between several actors in the supply chain. One interview describes this phenomenon as follows.

In addition, there is the issue of not trusting the suppliers to deliver what is promised, which leads to higher orders than the actual demand to compensate for that. That is a phenomenon present at both sides of AeroCo, both in communication with customers and suppliers. - Employee, Global Management

The interviewees describe that in the aerospace industry, there has always been mistrust between the OEMs, AeroCo and the suppliers. It was described how this leads to each actor in the supply chain setting higher order levels than their actual demand, which creates a bullwhip effect. The OEMs often set a higher volume because they expect to win a higher share of the deal of supplying a certain airplane model with engines. Moreover, in an interview with a material planner, it was stated that it is not always possible to trust the material replenishment signals in the IT system, and therefore the material planners tend to order for extra buffers towards AeroCo’s suppliers. In addition, the supplier uncertainty was described as a significant problem leading to that AeroCo has to order more than what is needed in order to be safe against shortage.

This phenomenon is also present between the different departments internally within AeroCo. It was described in many interviews how traditionally there has been a lack of trust internally where the commercial function tends to set higher demand plans towards the operations function compared to the actual demand. However, some departments state that this problem is not as significant anymore. Anyhow, it is described in the interviews that in the production, there is still a mistrust against the demand plans. This is based on the perception that the actual demanded volumes at the end of the year come in much lower than the demand plan made in beforehand. However, the interviewees say that they understand that this may be due to bad communication from the OEMs.

5.1.2. Communication with Suppliers

The communication toward the suppliers is described in the interviews to be done differently depending on the supplier. The supply chain department describes how it is essential to be able to provide a long term forecast to secure raw material as the industry is very complex in terms of product uniqueness and long lead times. For some material, the lead time starting from the raw material can be several years. Although the aerospace industry is quite stable in demand at a high level, whereas at the lower level many suppliers are fighting for the same share of production capacity, and the suppliers of raw material are limited. Therefore, there is pressure on all actors to secure the material required already before winning the deal. This pressure is described in one of the interviews.

There are many suppliers, but ultimately, there are few who produce raw materials. Therefore, there is stress from all actors to secure the material required since this is only available in a limited amount. - Employee, Supply Chain

Therefore, AeroCo has an agreement with the suppliers where they communicate the current demand plan and its structure every twelve or six months. Furthermore, if there are any significant changes during the sales and operations planning process, it will be communicated directly to the suppliers. It is described in the interviews that some suppliers require a more transparent demand plan from AeroCo in order to understand the actual demand from the end-customers. However, some suppliers already have enough information regarding the end-customer demand.

AeroCo has closer relationships with suppliers nearby, and these suppliers tend to be more flexible in what they can produce compared to large forging industries, which are less receptive to changes. There is also a contract with some of the suppliers that imply that no new orders can be placed within 200 days. At the supply chain department, it is argued that for the suppliers to be more responsive to changes, this usually has to be paid for with a higher unit price.

5.2. Creation of the Forecast

At AeroCo, forecasts are done at different horizons where the longer horizon is beyond three years and mainly aims at detecting trends in demand. This forecast is called R10 and is generated centrally at AeroCo Aerospace and not locally for Engine Systems. This forecast is used as input to the forecast made at shorter time horizon, the demand plan. However, the demand plan is at the same time taken into consideration in the creation of R10. Thus, these forecasts should align with each other. These two forecasts were described in one of the interviews.

The forecast process consists of two different flows. One short term, which is mainly based on the customer need, and one long term, where one look at the airplane producers' production to conduct a forecast. - Employee, Operations Excellence

For the shorter time horizon, this forecast is generated by the commercial part of the IPT and is presented as a demand plan towards the operations department. This demand plan is supposed to represent the best anticipation of customer need. Demand consists of several different kinds of demand. First, there is the demand derived from engines going directly into the airplane production, which is easier to forecast. Added to this is a certain percentage representing the production of spare engines. In addition, there are spare parts, which are more difficult to forecast. It is not as easy to know what engines will need reparation and the variation in demand is more extensive. However, the demand for spare parts is rarely incorporated in the demand plan since these products are often shipped directly from suppliers to OEMs.

In the interviews, it was described how there is no general tool used for doing forecasts at AeroCo. Instead, it is created manually out of information from the OEMs and earlier experiences. Closer in time, the commercial function looks a lot at what the OEMs' MRP data says, while further ahead, it is more judgment involved. If looking at how the forecasted volumes for the last six months have evolved (see Figure 15 where the darker lines are older versions of the demand plan), it can be seen that the forecasted volumes increase over time.

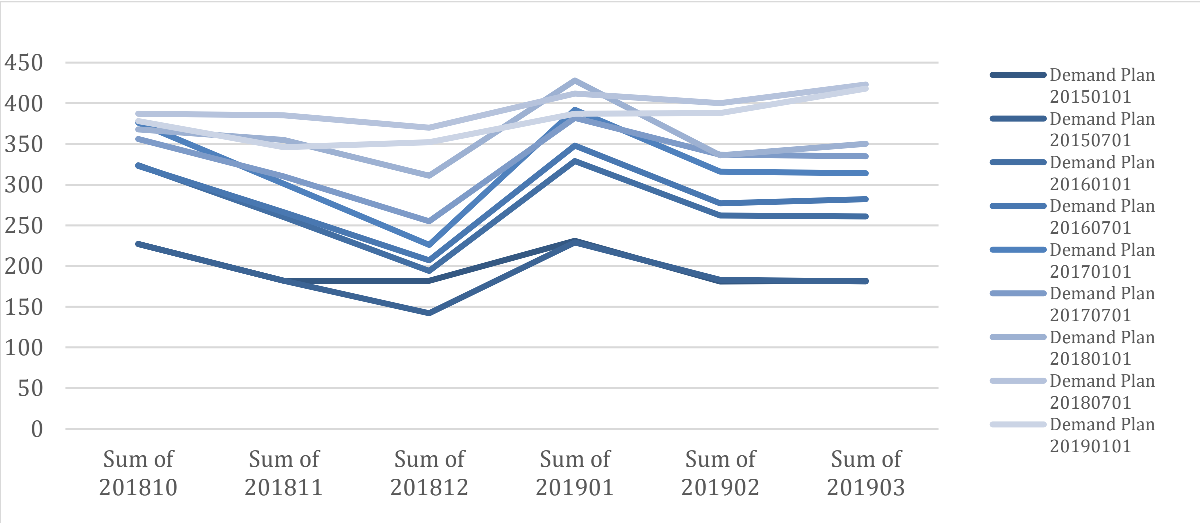

Figure 15. The demand plans evolvement over time.

This increase can be explained by general ramp up in the industry that may not have been fully predicted in the demand plans. However, it can also be because of the way in which the forecast is done. If looking at Figure 16 showing both the demand plan for the same period, but at an aggregated level, together with the OEMs MRP data for the same period (plotted in red), as well as the actual deliveries (plotted in yellow), an interesting effect explaining the increase in demand plan levels can be seen. The demand plans made before the OEMs start communicating their MRP data (plotted in green) differs from the later demand plans (plotted in blue). When the MRP data is communicated, the demand plan follows this communication rather than the judgement done in earlier demand plans. It can also be seen that the actually delivered volumes are in-between the earlier and later demand plans.

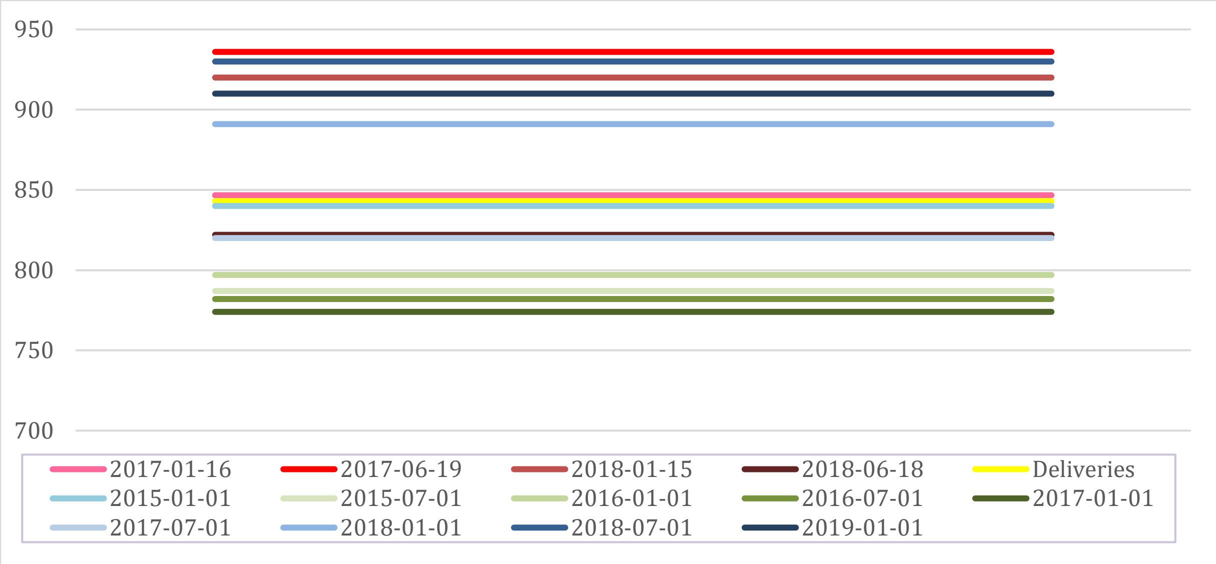

Figure 16. Demand plan, OEM customer data and deliveries.

In addition to the OEMs' MRP volumes, which is communicated directly to AeroCo, the company as part in a Risk and Revenue Sharing Program (RRSP) has access to the sales forecast of the OEMs. In the interviews, it was explained that these forecasts are also used as input information in creating the demand plan. This means that the demand plan created by AeroCo does not have to follow the MRP of the OEMs strictly. However, some opinions during the interviews were that the commercial side is not brave enough in reducing these volumes and trusts the OEMs MRP signal too much. There are also different reasons for why this method is used instead of quantitative forecasting tools, which were discussed in one of the interviews.

The reason for why the company has not looked more into statistical tools for demand forecasting is partly because one thinks that it (the demand forecast process) works well already today, but also that the possibility has not been investigated and thus one is not aware of the benefits that it might bring. There is also a question of whether one would have the courage to rely on the statistics if it shows lower demand than what is communicated by the customer. There is a lot going on in the industry that means that old data is no longer relevant. - Employee, Commercial

There are also different opinions on whether there is enough data to use for quantitative forecasts or not. At AeroCo, the definition of actual demand when measuring forecast accuracy is the delivered amount of product during a specific time period, plus the difference in ingoing and outgoing balance towards the OEMs' MRP data. This means that if the product has an ingoing balance of being two products behind the OEMs' MRP schedule and deliver five products during a week, meanwhile the current OEM's MRP plan has four products scheduled, it will lead to an actual demand of four. This since the outgoing balance will have changed from minus two to minus one given that no changes have been done to the OEMs' MRP data.

$$\begin{aligned} &AeroCo's\ def.of\ Actual\ Demand \\ &\qquad = Delivered\ quantity + Ingoing\ balance - Outgoing\ balance \end{aligned}$$

Thus, the actual demand will according to the definition by AeroCo depend a lot on the OEMs' MRP data and the question raised in the interviews is if this is accurate enough to base a quantitative forecast on. For one of the products, one responsible for customer contact has been saving the information about the OEMs ingoing stock of material to their production during the last six months and thus have been able to calculate the actual demand of products in the OEMs production. This can in Figure 17 be seen to differ compared to the demand measured using AeroCo's definition of actual demand for the fourth quarter of 2018 but is similar in the first quarter of 2019. Initially, when AeroCo started using their definition of actual demand, the program managers filled in the ingoing and outgoing balance manually, but this has been changed afterwards to be calculated automatically out of the OEMs MRP data. At this point, AeroCo did not have the information collected by the responsible of customer contact, and therefore came up with this definition. Also, today there is no systematic way where AeroCo receives this information from the OEMs even though many interviewees stated that the RRSP agreements allow AeroCo to have access to this. Thus, whether AeroCo has access to enough data to perform a quantitative forecast is debatable.

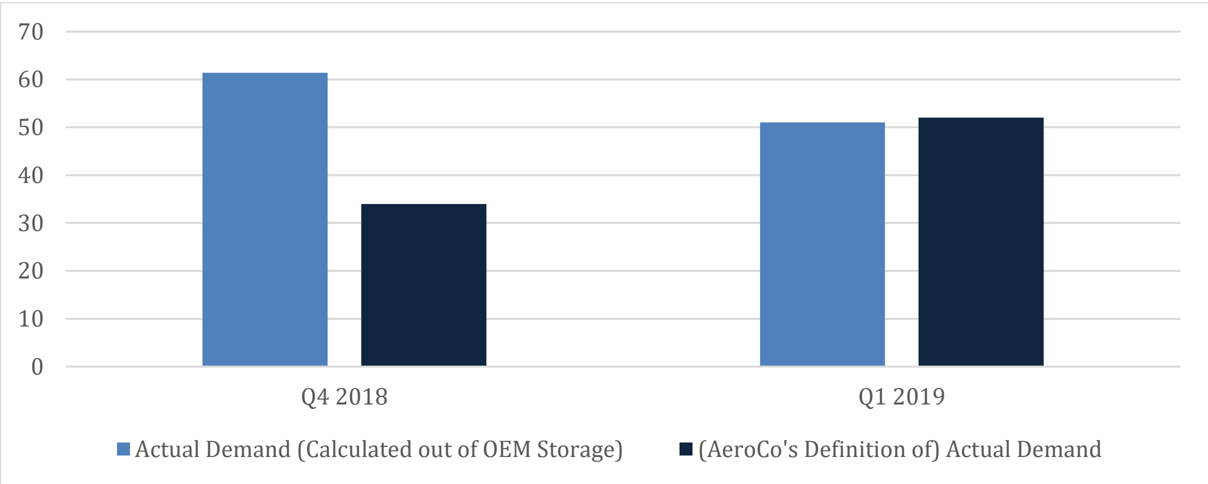

Figure 17. Different definitions of actual demand calculated as an average per quarter.

In the interviews, there were also different opinions on whether a quantitative forecast would help to increase the forecast accuracy or not. Comparing a moving average and an exponential smoothing based on the collected demand data from the OEMs production to the best performing demand plan and OEMs MRP data, it can be seen that the quantitative forecast methods perform much better (see Table 4). Also, it can be seen that having a fixed production tact (17 represents the established tact for this product, while 13 is the average of the collected demand data) perform worse than the demand plan. It can even be seen that the quantitative forecasts perform better than the demand plan created in January 2019 for the three months in 2018 (value in parenthesis). However, the demand plan still performs better than the OEMs MRP data.

Table 4: Forecast Error for different forecast methods.

Method	Moving Average (3)	Exp. Smooth. Alpha = 0.5	17 per week	13 per week	OEM MRP	Demand Plan
MSE	52.5	39.2	554.3	147.8	154.6	135.4 (74.6)
MAE	6.3	5.5	20.7	12.4	9.4	9.3 (8.4)
MAPE	14%	11%	46%	25%	21%	15% (16%)

A single linear regression of the data regarding OEMs ingoing stock of material to their production was also conducted. However, since the period of the data is quite short, no significant results could be obtained.

For the aftermarket, containing the spare parts, more statistical tools are used today at AeroCo. However, these do not consider historical demand but rather fleet size and probability of breakdown. These forecasts are also provided by the OEMs and are not generated by AeroCo themselves. The commercial function also emphasizes that even if more quantitative tools were introduced, it is still essential to use the knowledge about the demand to understand its changes and not only rely on history alone.

Considering forecast accuracy, some people think that the forecasts perform well, while others mean that it does not. The opinions also differ on whether the forecast has become better or worse during the last years and if it is generally too high or too low. The accuracy is also argued to differs for different OEMs, and to be less accurate if there is a dual-source agreement or if done for an immature engine program. The forecast accuracy may, according to the interviewees also differ for different time horizons as well, and can be accurate in the matter of total volumes but may not be as good at the single product level. The forecast accuracy is at AeroCo measured for three different time horizons; six, twelve and eighteen months (see Appendix III).

$$AeroCo's\ def.of\ Forecast\ Accuracy = 1 - \frac{|Forecasted\ value - AeroCo's\ def.of\ Actual\ Demand|}{max\ (Forecasted\ value, AeroCo's\ def.of\ Actual\ Demand)}$$

For the six months horizon, the accuracy has decreased from around 80% to around 65% as an average of all products during the last four years. For the twelve months horizon, the accuracy has gone from around 70-75% to around 65% during the same time period. For the 18 months period, the accuracy been quite stable somewhere around 55-75%. However, both trends and levels differ for different products and different OEMs.

A reason why the forecast may be inaccurate given in the interviews is that the supply chain lacks capacity. Even if the demand turns out to be as forecasted towards the engine producers, the actual demand for AeroCo's products may not be as high. This is due to other engine part suppliers not meeting the requested volumes, and thus fewer engines can be built, and the demand for AeroCo's parts will be pushed forward to a later period in time. Still, the OEMs always tends to order at a level assuming that all suppliers will meet the demand. Even though a minority of the suppliers cannot handle the demand, it is easier to keep a fixed level instead of pulling down the level for all the other suppliers. The focus of the OEMs will instead be to raise those suppliers who are unable to meet the demanded levels.

In order to increase the accuracy of the forecast, it was therefore suggested by the commercial function that a good idea might be to increase the communication with other engine part suppliers and to get a better insight into OEMs' inventory levels and WIP. It would increase the understanding of the logic behind the OEMs' MRP signals. Another suggestion is to further follow up and discuss the forecast accuracy, which is a recent initiative to be part of the sales and operations planning process.

What is stated in many interviews about forecast, is that an inaccurate forecast leads to problems and costs. One of the problems is low service level. It leads to extra work both in the information flow in identifying the reason for shortage, and in the material flow to speed up production in meeting customer demand. It also creates problems in prioritizing and capacity dimensioning. If a forecast predicts a too high volume, the company allocates unnecessary production capacity for this product, and thus some other product may be down-prioritized. There is also a risk that the suppliers will not trust AeroCo's communication of demand and thus use their own forecast. This might be a problem, for example, if AeroCo is ordering higher volumes in order to build up buffers as a strategic decision.

5.3. Creation of the Production Plan

The demand plan is primarily used as input in the company's sales and operations planning process called SIOP (sales, inventory and operations planning). The SIOP process is done eight times per year and considers a 6 to 36 months planning horizon since this is the time required to build up capacity. The assumption is that for everything that happens beyond 36 months, the company is able to respond. The lower bound is supposed to represent one lead time, but is somewhat questioned in the organization. It is proposed during the interviews to be changed to twelve or eighteen months in order to be able to better react to changes in demand since some of the lead times exceeds the six months horizon. For the shorter time horizon up to six months, the Master Production Scheduling (MPS) process is done on a weekly basis. The general SIOP process was described in one of the interviews.

In the SIOP process, the capacity is analyzed to create a production plan. At the final meeting of the SIOP process, the SIOP executive meeting, this plan is either accepted, if it manages to meet the demand plan, or actions are taken so that the demand plan can be reached. - Employee, Operations Excellence

The goal of the SIOP process is to dimension the capacity so that the demand plan volumes can be achieved. In most deals, AeroCo is a partner and is thus required to meet the demand and is not able to decide not to deliver. Therefore, the demand plan will always be set as the best anticipation of customer demand and will not be changed because of capacity shortages. Neither will the OEMs be told that their demand will not be fulfilled. Thus, the SIOP process needs to dimension the capacity according to the volumes requested by the OEMs. This dimension is described in one of the interviews.

If this (the SIOP process) is carried out in a good way, it means that the company will have a good fit in the short term. In the shorter term, no capacity changes can be done since there is too little time to be able to react. - Employee, Commercial

The first main activity of the SIOP process, shown as activity three Demand Review in Figure 18, is where the IPTs present changes in the demand plan compared to the last demand review. In one interview it is stated that the focus is supposed to be placed at the underlying assumptions leading up to the demand plan rather than the actual numbers, but that the numbers are often given more attention. The interviewee also states that there have been discussions about communicating a range rather than a fixed number in the demand plan, since this would have the possibility to include the uncertainty and thus be more accurate. But no final conclusion regarding this has been reached. Currently, the demand plan is based on a fixed number since this is what is provided by the IT-system. In addition, owners at the stock market generally request communication, including fixed numbers rather than ranges.

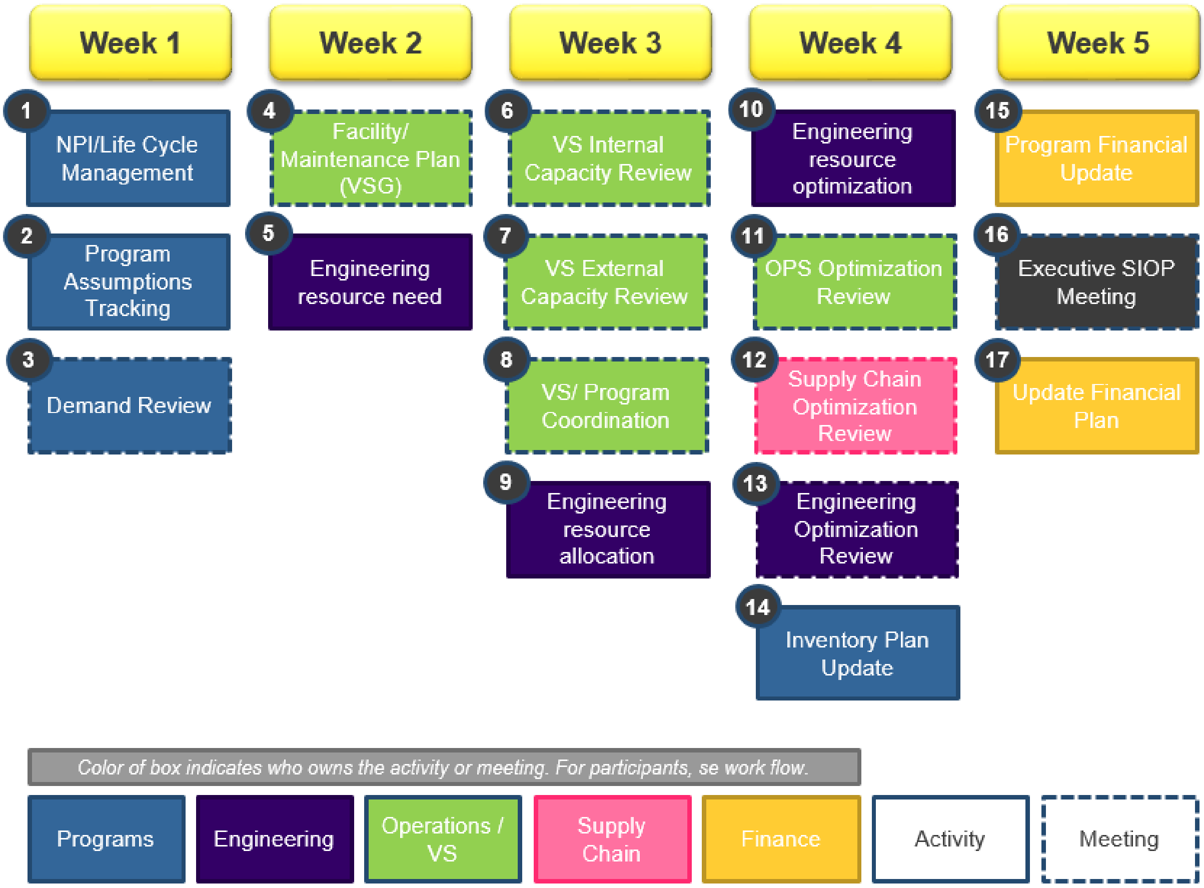

Figure 18. The SIOP Cycle described by AeroCo.

After the first meeting, there is one meeting where, among other things, the facility layout and maintenance plans are discussed. Also, several activities take place where discussions are held about the requirements of engineering resources. In the third week of the SIOP process, meetings are held within each value stream where a production plan is created and the internal and external capacity is assessed. The production plan is created by the production planner in each value stream based on production capacity and the material planners' perception of supplier capacity. The production plan shall meet the demand plan, but should also take vacations and quality errors into consideration. This plan is supposed to represent what the operations department promises towards their direct customer, the IPTs. Meanwhile, the demand plan is the IPT's plan of what should be delivered to the OEM.

The production plans are then presented at the Operations Optimizations Review, where all the value streams come together. At this meeting, decisions are taken whether the demand plan can be met or if there is a need to build up storage or increase capacity. Similarly, the Supply Chain Optimization Review is held with all the PIMs, the purchase managers, the SQEs, and the material planners. This meeting assesses which are the most significant risks and compares them to the other programs. Based on these meetings, the IPTs should update the inventory plan with changes in inventory levels. However, it is questioned in the interviews if this is really done as a part of the SIOP process today.

The finance activity taking place during the SIOP process mostly concerns translating the changes communicated in the earlier steps into financial numbers. This translation is done in order to be able to take decisions during the Executive SIOP Meeting. However, during certain SIOP-cycles, the decisions taken during the process lead to updates in the financial forecast. One of the interviewees states that the updates are done in connection to the SIOP cycle since it is important for the financial forecast not to be a separate activity, but closely connected to the other forecasts generated in the company.

Traditionally during spring, a financial forecast is done at the ten-year horizon. However, this has been discussed to instead cover only three or five years due to changes in ownership of the company. The long-term financial forecasts are generated based on the decisions taken in the second SIOP cycle of the year. During the fall, a financial forecast for the upcoming year is conducted based on the data from the fifth SIOP cycle, where each division calculates its costs. Also, a financial forecast for the whole lifetime of each program is done every year. The financial forecasts for revenues are based on the information in R10, which at a shorter time horizon should align with the demand plan. For costs, the financial forecasts are based on the capacity calculations. These are calculations done for each value streams out of the production plans where the requirements of personnel, machines, and material are translated into financial numbers. In addition to the long term forecast and the yearly forecasts, a financial forecast is made each week covering the current month. In this forecast, R10 is no longer used. Instead， both revenues and costs are calculated strictly out of the production capability communicated by the value streams. That is, what is going to be delivered for the upcoming time period.

At the final meeting, the Executive SIOP Meeting, each division presents its needs in order to meet the demand plan volumes. During the meeting, all the decisions about turning down customer orders, outsource production or increase capacity is taken. After the meeting, the demand plan for the period is fixed and cannot be changed until the next SIOP iteration.

5.3.1. Master Production Scheduling

In the MPS process, the production plan is made in weekly buckets for a set cumulative lead time. This cumulative lead time currently covers the upcoming six months, but it is in the interviews proposed to be longer since some of the products have longer lead times. The MPS process takes place at different levels of the company, as described in one of the interviews.

> *This process (the MPS process) takes place at different levels of the company, both in the value streams but also at higher levels. At the MPS executive level, the operations manager reports every week to the production site manager.* - Employee, Operations

Within the MPS horizon, the capacity is hard to change, and the decision is more about prioritizing. If the SIOP process is working well, the MPS process should be possible to go through rather easily. However, this is not always the case in the organization today.

Involved in the MPS process in the value streams are the value stream manager, the logistics manager, the production planner, the material planner, the material quality engineering (MQE) manager responsible for quality errors, and any individual responsible for customer contact. In some value streams, also the workshop managers, responsible for the production resources, are present. At this meeting, changes in customer demand, quality errors, material shortage and any other issue affecting the production plan is brought up. The aim of the meeting is to decide about actions to take in order to avoid rescheduling the production plan, or if actions are not sufficient, to decide to change the production plan. The production plan is what should be used to schedule the production. However, one interviewee questions if this is really done in practice since the production plan in many cases is a "dream scenario". This was further explained by another interviewee.

Sometimes, deviations occur when material is missing, a machine breaks down or an employee become sick. This should be incorporated in the production plan, but maybe a too low percentage is used for the machines' uptime (80%). If one cannot follow the production plan, changes are done in the line of balance (LOB) document at short term, and if there is no possibility to catch up with the schedule within two months, a change in production plan is required. However, I have understood that this update is mainly done in connection to the SIOP process. - Employee, Operations Excellence

Instead, a prioritization is done for the OEMs' demand within the upcoming week, which is communicated through the line of balance (LOB). The LOB is a tool used to follow up how the value streams perform according to the production plan, and if the production plan deviates from the demand plan. It also shows what is shipped to the OEMs each week and thus what the balance is towards the customer demand.

It is stated in many interviews that the LOB should not be used to plan the production but only as a communication tool towards the OEM. Despite this, it is also described in the interviews that the LOB is sometimes used to schedule the production according to the OEMs' communication about short term needs. One interviewee also argues that it is hard to know if re-planning the production plan is the best way to visualize the backlog. If the backlog is too big, it can be demotivating. On the other hand, re-planning means eliminating the backlog, which in turn implies that it is no longer visualized that production is behind schedule.

The LOB is also used for communicating with the OEMs at shorter time horizon. For this, the LOB consists of two parts of delivery data. The first part is the delivery plan for the upcoming week. This part is also the part communicated toward the OEMs. A comparison between the OEMs' MRP and LOB is conducted every week, and AeroCo also provides a plan of how to reach the demand requested in the future. The other part is the current stock level at AeroCo, which is communicated internally within the company. Further on, OEMs have no insight regarding AeroCo's production plan. However, if the production is able to meet the OEMs' MRP volumes, it is not a necessity to communicate the LOB to them since this is primarily used when production is unable to follow the plan.

5.4. AeroCo's Expectations of DDMRP

When discussing DDMRPs aim to plan production based on actual demand, a logistics manager stated that the OEMs do not understand themselves what their actual demand is. He means that the actual demand does not correspond to the demand communicated by the OEMs' MRP signal. Something that was also seen in Table 4, where the forecast error of the OEMs MRP data is high. One interviewee describes the logic behind this.

The demand plan should show what the customer needs, while ABC instead shows what the customer wants. Therefore, when the demand plan deviates from the ABC, it shows that the customer does not know what they need. - Employee, Program

The question about when the payment occurs is complex but also relevant for the DDMRP method. It has been described in the interviews that the revenue is being budgetary accounted for when the product is delivered to the OEMs. However, the cash flow does not occur until the engine is attached to the plane at the end-customer. According to one interviewee, this means that there are no incentives for the OEMs to keep track of their demand to reduce their safety stock. Instead, the interviewee means that there is a need for AeroCo to do so. However, this is not done properly today where the data is collected only by one responsible for customer contact and for one single product. One way proposed in the interviews could be to use the OEMs' inventory level as a control signal for DDMRP. This is described as more accessible in RRSP contracts since it has more transparency obligations compared to LTAs. Thus, one interviewee stated that the information required for implementing DDMRP is contractually available, such as the buffer levels and the WIP. Further on, another interviewee argued that AeroCo is already using parts of the DDMRP methodology in their tool for visualization of buffer levels.

There are opinions within the organization meaning that DDMRP is a tool to take care of the internal variations and not external. In addition, out of budgetary reasons, there will still be incentives to continue delivering the products to the OEMs according to their MRP plan, even if the buffer levels are full and the money transfer will not be done until later. A value stream manager stresses that DDMRP should use tolerance for how the pace should lie in order to avoid fluctuations. Since the production has a strict upper limit, it may not be possible to catch up with the budgetary volume if producing at a low pace for some amount of time. In order to plan production out of actual demand, one interviewee argues that it is required to change these incentives. Furthermore, the supply chain currently attempts to avoid any buffer over the organizational boundaries in order to minimize capital cost. This is described in the interviews to be mainly because no one wants to pay the capital costs for products in stock, and that the organizations view inventories as something negative and expensive. It is also described how the new philosophy with buffers could be challenging for OEMs and suppliers to understand since this is not part of the current situation in the supply chain. At the same time, the global management of AeroCo stresses the importance of OEMs accepting and trusting the DDMRP system in order to have an optimal flow in the entire supply chain.

Regarding the forecast data for DDMRP used to calculate the ADU, the demand plan is proposed in the interviews to be used as ADU as it is the closest to the actual demand. However, consensus about this has not been reached in the organization. At another AeroCo site in the United States implementing DDMRP, the OEMs' MRP signal for the three upcoming months is used. They believe that this is the most reliable data since changes in the market cannot be captured in historical demand calculations.

We do not take any consideration to past demand in calculating the ADU since the customer purchase orders are more reliable and also shows changes at the market that cannot be captured in historical demand calculations. - Employee, DDMRP project in United States

However, global management believes that the forecast used as ADU should include past performance since they mean that the past can say a lot about the future. Nevertheless, it should also consider involving qualitative analysis in the forecast as well, in order to predict changes in the market.

How the SIOP process will be affected by the DDMRP implementation is seen differently throughout the organization. Many believe that there will be two parallel systems, one long term demand plan for the SIOP process which is used to balance capacity since many years are required to receive a new machine and/or educate new staff. In the short term, MPS will be the process to handle the ADU. One interviewee believes that the production plan will not be eliminated with the implementation of DDMRP, as a production plan is required for financial follow-ups and inventory management. However, he states that it would be good to combine the production plan into DDMRP. Thus, the SIOP will be used for the long term and DDMRP for the short term. This is summarized by one of the interviewees.

DDMRP is taking care of short-term variation, but the SIOP is handling demand variations on a more aggregated level. - Employee, Global Management

Finally, the global management team states one delimitation with the DDMRP method concerning the method mainly being used for mature products. Ramp-down products have too low volumes and do not fit with the use of DDMRP. The same goes for space products at AeroCo, where the volumes are also very low.

6. Discussion

The discussion chapter contains a discussion about the empirical findings based on the literature presented in the theoretical framework. The discussion is structured based on the research model, which also shows the main topics of the discussion (see Figure 19). However, the third and fourth steps are merged into one discussion regarding the current production planning as well as the future state including DDMRP. The discussion finishes with a sub-section regarding the implications of further research.

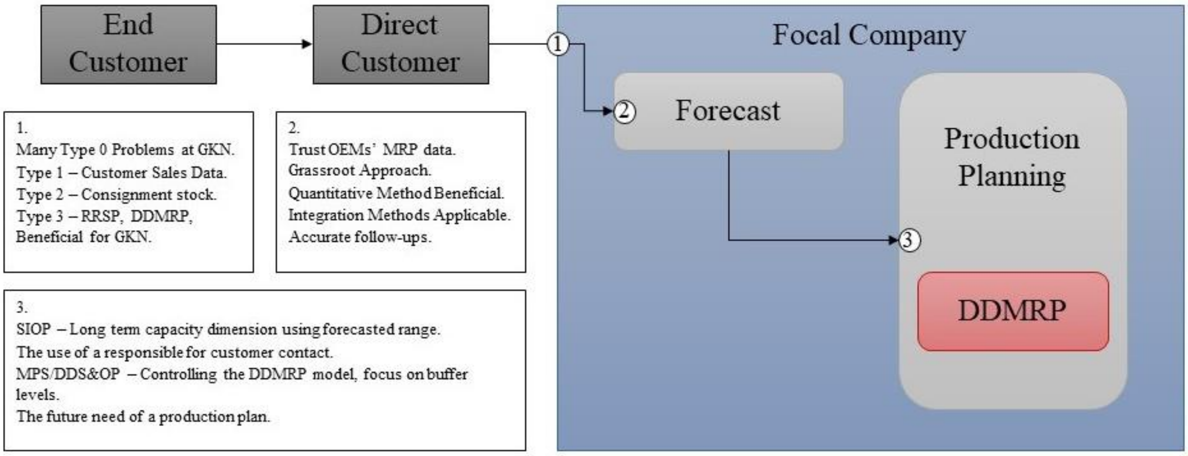

Figure 19. Research Model - Discussion.

6.1. Supply Chain Transparency

In order to set the input variables and specifically set the ADU, an anticipation of the future demand has to be done. As described by Fildes & Kingman (2011) there are two sources of demand uncertainties where one of them refers to the uncertainty about the demand generating process. This source of variation can be reduced by changing the customer order process or increase the collaboration in forecasting. In the aerospace industry, the end-customer has a very transparent demand and the demand generating process is clear towards their customers. However, the demand generation process from the OEMs, there MRP data, is not as reliable as can be seen in Figure 14. This MRP data is at AeroCo trusted as the main input to the demand plan, further seen in Figure 16, but is at the same time question to be accurate by the interviewees.

In the interviews, different reasons were given for the OEMs' MRP data to be wrong. Reasons which are also mentioned in the literature for the Type 0 Traditional Supply Chains presented by Holweg et al. (2005), where the human mind is tempted to order some extra as safety stock. The first reason is the rationing and shortage gaming described by Jonsson & Mattsson (2009), where customers tend to increase their orders when the suppliers do not deliver in time. Something that is described to cause a bullwhip effect in the supply chain (ibid.). The interviews confirmed the theory when describing how this behavior was something that takes place at the OEMs. Furthermore, the bullwhip effect tends to increase when having long led times (Chen et al., 2000) and few customers (Jonsson & Mattsson, 2009). Two characteristics that fit the aerospace industry. Moreover, a present problem in AeroCo's supply chain, also confirming the theory is the issue of non-aligned planning and control activities described by Jonsson & Mattsson (2009). This is described as having an MRP system that, in case of a demand change, not only forwards the increase in demand itself but also recalculates the needed buffer levels. It thereby increases the demand towards the supplier even more than the actual change in demand from the end-customer (ibid.). Considering the many changes in OEMs MRP signals and the non-consistent communication from them described in the interviews, this cause can also be seen to be present for AeroCo. The fact that the OEMs can communicate different information could also be seen as a reason for the MRP signal not being accurate enough since if there are different opinions, it is not clear which is the right one.

Even though dealing with lots of problems associated with the Type 0 Supply Chain, some elements of a Type 1 Supply Chain of information exchange can still be seen at AeroCo. One of them is the fact that the OEMs are sharing their Point-of-Sales data. This is something that can both reduce the bullwhip effect (Jonsson & Mattsson) increase forecast accuracy (Syntetos et al., 2016) and reduce demand uncertainty even without full supply chain visibility (Holweg et al., 2005). However, a question can be raised to which extent this data is used today by AeroCo since the demand plan is seen both in interviews and Figure 16 to rely significantly on the OEMs' MRP data. Thus, the study shows that it is not sufficient to only increase the information exchange in the supply chain, but this information also has to be taken into consideration in the creation of the forecast. Furthermore, the aerospace industry has not taken the step to perform a collaborative forecast. This is something that strengthens the statement of Syntetos et al. (2016) arguing that collaborative forecast has made slow progress in many industries. Holweg et al. (2005) also describe how many customers do not have the processes in place to perform this collaborative process. Something that is also shown in the interviews where it was described that there are too many engine parts suppliers for the OEMs to be able to spend time giving more accurate information than the MRP signal. Thus, it would also be hard to find time to align the planning and control activities. However, increased collaboration and communication with other suppliers taking part in the RRSP deals were proposed in the interviews as a solution to increase forecast accuracy.

Another way to get more accurate demand information may be to calculate the demand out of the ingoing storage data at the OEMs as done by one of the responsible for customer contact. This would be possible to do also for other products where AeroCo has an RRSP deal and thus have access to this information. To use this storage as a buffer in the DDMRP system is also proposed in the interviews, even though a question is raised regarding the industry in general having a negative attitude towards inventory, where no one wants to take the risk by owning the stock. However, considering the RRSP deals where AeroCo still owns the products until sold to the end-customer, there should in these cases be no questions regarding who owns the stock. Thus, AeroCo should also be able to decide about the storage levels. Anyhow, it is important to differentiate between the use of consignment stock and Vendor Managed Inventory (VMI) as described by Holweg et al. (2005). The difference is that in a Type 2 Supply Chain with VMI the task of generating replenishment orders is given to the supplier. In this way, the inventory needed to retain customer service level can be reduced (ibid.). Thus, AeroCo has to make sure that their deals in RRSP contracts contain not only the agreement of consignment stock but also VMI in order to reach the full benefit. Besides, there is an issue with the internal incentives in the company where the income is made budgetary already when shipping the product to the OEMs, which connects to the question regarding consignment stock or VMI.

In order to move to the Type 3 Supply Chain of full synchronization, VMI by itself is not enough, but has to be accompanied by collaboration on the production planning (Holweg et al., 2005). It is only then, the full benefit of the collaboration can be achieved, and both inventory and the bullwhip effect can be reduced (ibid.). These effects are also argued by Holweg et al. (2005) to be the greatest in industries with few customers, for products with long lifetime and stable demand where high capacity utilization and low inventory levels are important. Characteristics that are all fulfilled by the situation of AeroCo. Thus, for the company to achieve a synchronized supply chain, one way is by the collaborative planning, forecasting and replenishment (CPFR) described in five principles by Jonsson & Mattsson (2009). The first and fifth principle of having collaborative partnership relations and risk sharing is for AeroCo fulfilled in the RRSP deals. The second principle of a common forecast is discussed in order to reach Type 1 Supply Chain. The third principle of having the most suitable actor performing each activity can be further developed by AeroCo taking responsibility for VMI as discussed in order to reach Type 2 Supply Chain. For these two principles, the DDMRP method can help in turning the two decision of inventory replenishment and production planning into one. By the use of a net flow equation to plan the production based on the buffer level, the information at the OEMs is better incorporated in the production planning. Having these two decision points merged into one, is what is required for a fully synchronized supply chain, according to Holweg et al. (2005). Thus, the only principle left is the fourth of a common performance measurement system. In establishing this system, AeroCo would also be able to solve the internal problem with mixed incentives to both avoid storage and deliver according to budget. It can also solve the problem with the whole industry trying to avoid owning inventory if redesigning the Key Performance Indicators (KPI).

In similar way, improvements in the collaboration with the suppliers of AeroCo can be achieved. It is described in the interviews how the suppliers require forecasts for a long time ahead. It is further argued that in order for the suppliers to be more responsive to changes, a price premium will most probably have to be paid. Here the company needs to decide what is most important; keeping unit price to a minimum or avoid high inventory levels. If moving to a more synchronized supply chain, the fourth principle of CPFR to have a common performance measurement system can help in prioritizing between the two. Further, the second principle of a common forecast can work as the long term plan that is communicated to suppliers. However, this may not need to be as fixed as it is today but instead can be inspired of the demand plan used in the Demand Driven Adaptive Enterprise model presented by Ptak & Smith (2008) containing an expected interval rather than a fixed forecasted number. However, it requires the supplier to accept such a plan and thus it is essential to explain to them how the demand from AeroCo's customers is not a fixed schedule. This is easier in the case of synchronized supply chain where a demand plan containing a range is commonly agreed upon and is a standard in the industry. Until then, AeroCo may struggle introduce such a change and have to continue to communicate the fixed expected demand plan.

6.2. Forecast methods

The second source of demand uncertainty stressed by Fildes & Kingman (2011) is the forecast method chosen to understand the demand. AeroCo currently has two different types of forecasts, one long term forecast called R10 and one for the short term called demand plan. R10 is among others used as input for the long- and medium-term financial forecast. However, R10 does not affect the DDMRP system more than being used as input in creating the demand plan.

For the demand plan, no specific forecast tool is used, which means that only qualitative judgment and information from the OEMs are taken into consideration when conducting these forecasts. When analyzing the demand plan, it was shown that the forecast accuracy was quite low, around 60-70% for all forecast horizons measured. It was also shown in figure 15 that the forecasted volumes in the demand plan increases over time. This trend could be because of a ramp-up in the industry that has not been fully predicted. However, it can also be because of the behavior seen in figure 16 where the demand plan is seen to rely heavily on the OEMs' MRP data within the horizon of this data being communicated. At longer time horizon, when no MRP data is available from the OEMs, AeroCo only uses their own judgement based on earlier experiences to forecast the demand. Although, these forecast as seen in Figure 16 tend to be lower than what is later communicated by the OEMs' MRP data. When this data is made available, AeroCo tends to increase the predicted volumes to match the OEMs' MRP data and leaves their own judgement of the forecast behind. This stresses that the forecast is highly dependent on the accuracy of the information from OEMs. However, as shown in figure 17, this data differ from the demand calculated out of the ingoing stock of material to the OEMs' production. Considering the inconsistency in the OEMs' MRP data discussed in the earlier chapter, it is thus questionable if this is the best method to use. Consequently, the alternative chosen at the site in the United States, to use the OEMs' MRP data as ADU, can also be questioned.

The forecast method AeroCo uses have similarities to the grassroots approach mentioned by Jonsson & Mattsson (2009). This method means that those employees that have contact with the customers make a judgement of the future demand, that is then gathered to create a joint forecast (ibid.). This is similar to what is done at AeroCo where the program division, who are responsible for long term customer contact, creates their demand plans. These plans are then discussed at the demand review meeting. However, the responsible for customer contact in the value streams are not as involved in the creation of demand plans as should be the case with a grassroots approach. This method is by Jonsson & Mattsson (2009) described to increase forecast quality. However, it requires more time than other approaches (ibid.). Another qualitative method is the sales management approach. This method can be argued to have many disadvantages compares to the grassroots approach. Since the top management team has limited understanding of the OEM's information and does not have the same contact with the OEMs as the commercial team. However, a judgement from the top management team is also necessary in order to have a broader view of the demand. During the interviews, it was mentioned that the management team tends to give their inputs of the future at the demand review meeting. Therefore, the qualitative method that is used today seems to be a reasonable way to perform the judgmental part of the forecast.

At AeroCo, demand can be both dependent and independent. The dependent demand refers to the production of new engines at the OEMs, which generates demand of AeroCo's parts. The independent demand could, for example, be the spare parts where the parts are used in already existing products. To understand the amount of independent demand in the aftermarket, OEMs perform a quantitative analysis of the fleet size and probability of breakdown. This analysis is then used at AeroCo. This is a sign of acceptance of quantitative forecast methods indicating that it would be possible to use such methods also for the dependent demand. As described by Jonsson & Mattsson (2009), dependent demand usually can be calculated straight out of the demand for the main product. However, it can be seen as insufficient in AeroCo’s case. Thus, qualitative forecast methods could be one wat to try improving the forecast accuracy. In table 4, the forecast errors of various quantitative method was compared against the demand and production plans at AeroCo. It was shown that both the methods moving average and exponential smoothing performed better than the best performing demand and production plans. One of the reasons mentioned in the interviews for AeroCo not yet introducing statistical tools was that the company is not aware of the potential benefits. However, the results in table 4 stress the importance of including a quantitative aspect for AeroCo when conducting the forecast. The second reason mentioned in the interviews was that the company think it works well as it does today. This can be argued against both by the results of AeroCo's own forecast accuracy follow up and based on the findings that AeroCo bases their forecast on inconsistent MRP data from the OEMs. The quantitative methods also have drawbacks, for example not considering systematic trends in the historical data (Jonsson & Mattsson, 2009). However, the exponential smoothing has the benefit of weighting the most recent demand more than the older demand, and thus react faster to trends than moving average (ibid.).

Moreover, many researchers stress the importance of using a combination of both qualitative and quantitative approaches (Jonsson & Mattsson, 2009; Sanders and Ritzman, 2004). Also, one of the four main consideration of sizing the ADU for DDMRP, means to integrate a past-looking and forward-looking forecast (Ptak & Smith, 2008), that is combining qualitative and quantitative forecasts. The reason behind using a combination of the two methods is that qualitative forecasting is beneficial when it comes to quick changes in demand information, but do not consider intrinsic biases (Sanders and Ritzman, 2004). AeroCo uses only a qualitative approach of the forecast today, which do not perform as well as quantitative approaches. Therefore, to use an integration method of both types of forecast is highly essential for AeroCo in order to improve their forecast accuracy but at the same time be able to react to changes in demand. Sanders and Ritzman (2004) introduces four integration methods to use when combining a qualitative and quantitative approach. The first method using qualitative reasoning to adjust already existing quantitatively generated forecast is an applicable integration method at AeroCo. A benefit of this method mentioned by Sanders and Ritzman (2004) is that it creates a higher sense of ownership, which is a crucial factor for AeroCo in order to increase the credibility of the forecast. AeroCo is currently highly reliant on their qualitative forecast, and the qualitative forecast has a high authority in this first integration method. Thus, it could be of great importance for the company to retain the sense of ownership. The second integration method implies to use quantitative approaches as a correction to the qualitative approach in order to reduce bias (ibid.). This method means to determine the forecast numbers according to the quantitative approach. Therefore, quantitative approaches will have a higher authority in this method. Of that reason, this method will create a low sense of ownership since the person creating the qualitative forecast at the beginning will feel to be judged or corrected. However, this method is essential if elimination of bias from the qualitative forecast is the main problem. It is questionable whether this method will be applicable for AeroCo since the sense of ownership most probably is an important factor for AeroCo since the company is currently highly dependent on the qualitative forecast. This method could be seen to be a too big step to take. The third methodology means to combine two individually produced forecast. The combination can be conducted objectively with a simple average, or subjectively (ibid.). This method is highly beneficial since it diminished biases and forecast data errors. However, likewise, the second method, to switch from AeroCo's current qualitative forecast to an equally divided combination of both qualitative and quantitative forecast method might also be a too big step to take at the moment. Lastly, the fourth integration method is to use qualitative reasoning in the selection and development of a quantitative forecast (ibid.). This method means to leave qualitative judgement behind after having designed the quantitative forecast (ibid.). This is not fully applicable for AeroCo since there is a need for a long term qualitative forecast since there is minimal data regarding the future. Thus, the first and third integration methods, seems to fit the case of AeroCo the best.

In the interviews, it was described how the company has started to follow up the forecast accuracy during the demand review meetings in order to improve the forecast accuracy. However, it is arguable whether AeroCo's measure of forecast accuracy using OEMs' MRP data as the primary input for calculating actual demand, is right to use. From the interviews, it was stated that the OEMs' MRP does not fully represent the OEMs' actual demand. This confirms the statement of Jonsson & Mattsson (2009) arguing that it is difficult to find the actual demand since the available calculated demand data does not fully represent the actual demand. However, in this case, the AeroCo has access to data regarding OEMs' ingoing stock of material to their production which can be used to better calculate the actual demand. When comparing this data with OEM's MRP, it has shown that these data do not match. Thus, it is of great importance to gather information regarding the ingoing stock at OEMs also for other products than the one done today. Both to use this data as a base for the quantitative forecasts and to follow up the forecast accuracy.

6.3. Demand and Production Planning in DDMRP

At AeroCo, as in theory with the S&OP, their SIOP process is the core in the demand planning. The difference is that AeroCo's SIOP process is not as iterative as the S&OP described by Jonsson & Mattsson (2009). This may have to do with the RRSP deals where AeroCo is a partner in the engine program, which means that AeroCo is obliged to fully satisfy the needs of their direct customers, the OEMs. Thus, AeroCo cannot adjust the demand according to the supply and instead have to focus on the capacity dimension in order to be able to meet the demand of the OEMs. However, there are different opinions on how this process will look in the future. The most common opinion of having the SIOP process looking at a longer time horizon and an MPS taking care of setting up the DDMRP variables compare well to the Demand Driven Adaptive Enterprise (DDAE) model described by Ptak & Smith (2008). The authors describe a model where the Adaptive Sales and Operations Planning (Adaptive S&OP) process is used to take feedback from the DDMRP system as well as changes at the market into consideration when taking strategic decisions about new markets and capital investments. In AeroCo's case where the demand is seen as something that cannot be affected, the capital investments in dimensioning the capacity will be important.

Further, in the model proposed by Ptak & Smith (2008), Demand Driven Sales and Operations Planning (DDS&OP) is the process to set the input to the DDMRP model and works as the interface between the Adaptive S&OP and the Demand Driven Operative Model, i.e., the process where the DDMRP method is used to generate supply orders (ibid.). This can be compared to the MPS process taking care of setting up the DDMRP variables as proposed in the interviews for AeroCo. Additionally, Ptak & Smith (2008), describes how the DDS&OP process differ from the MPS in that it can contain a range for the demand plan from an optimistic to a pessimistic scenario. This is made possible since the DDMRP system in contrast to more traditional MRP does not require a specific production plan (ibid.). This is also in line with the recent change at AeroCo where the focus is moved from fixed numbers to the underlying assumptions during the SIOP demand review meeting. However, this change can go even further with changing from communicating a number to communicating a range. A first step is to not only communicate the expected number, as in the demand plan, but also include the upper bound communicated to the PIMs, also at the demand review meetings. It is though important to also find an IT-system that can handle ranges and that top management, as well as the owners, accept this form of communication.

Communicating a range could also help to deal with the lack of trust within AeroCo where the operations function does not fully trust the information in the demand plan made by the commercial function. This is a common problem in companies described by Jonsson & Mattsson (2009) to take place because of too high expectations of forecast accuracy and can lead to some divisions performing their own forecasts. It is important for everyone to understand that a forecast is only an assessment of future demand and not an exact prediction, which can be made clear by the communication of a range. A further reason for this misalignment between divisions may be the conflict of interest described by Jonsson & Mattsson (2009). This conflict of interest can be due to the sales department wanting to secure the capacity by an optimistic forecast, while the production department wants to avoid idle time and thus wants a pessimistic forecast to reduce the risk of over-capacity (ibid.). In communicating a range, both the optimistic and pessimistic scenario can be contained in the same demand plan. By working with the DDS&OP process as a bidirectional tactical agreement as described by Ptak and Smith (2008), this also allows for a discussion of the underlying assumptions of the demand plan in order to reach acceptance from all divisions. One way mentioned in the interviews for increasing the trust from the operations division towards the demand plan was the use of a responsible for customer contact placed in the value streams. This could also be seen as a reasonable organizational change in order to mirror the structure at the supplier side of the company, where one person responsible for the contact, the material planner, is placed in the value stream to handle the operational contact with the supplier. Thus, it could be natural to have a similar structure also at the customer side of the company. It may also help in allowing the IPTs focusing on the long-term communication and the creation of a demand plan instead of the communication about late deliveries, as asked for in the interviews. However, it is important that a sufficient amount of people is appointed to this task since the workload in many interviews were mentioned as a problem for implementing this role.

If the MPS process is replaced by the DDS&OP process, where the input variables to the DDMRP model will be set, the question is what will happen with the current activities of the MRP process. Since AeroCo, in contrast to the theory described by Jonsson & Mattsson (2009), uses the same level of detail concerning aggregation level when planning the production at both SIOP and MPS level, there is no scheduling activity taking place at the MPS level, only at SIOP level. Instead, the MPS process is about prioritizing between customer need, based on the available capacity. As stated in the interviews, the MPS process is thus an easy process to go through if the SIOP process has been able to take the right decisions in dimensioning the capacity. However, this is not always the case. With the use of the DDMRP method, the needed prioritization will then be easier, since this can be done just out of the color signals given by the method. A drawback of this is thought that the material planners, for example, will not have the same control of the replenishment as earlier when they were arbitrarily choosing the buffer levels. It is thus essential to give the method time to find the right levels in order for the material planners to be able to trust and understand the logic behind the system. In addition, the LOB will no longer be used in the same way when implementing the DDMPR method. When planning the production and deliver products based on the buffer levels at the OEMs there will no longer be a need to communicate the balance towards the OEMs MRP signal. It will also be more obvious how the production is performing since there will always be possible to see the color of the buffers. Thus, the tradeoff between visualizing the backlog and rescheduling the production plan described in the interviews will no longer be a problem.

The remaining question is thus whether the production plan still will be needed or not. Today, the production plans at AeroCo consider vacations and quality errors, and this will have to be taken into consideration also when using the DDMRP method. However, quality errors can be taken care of by increasing the variability factor to mitigate the effect of delays caused by quality errors. Concerning the vacations, this can be planned for with the demand adjustment factor (DAF). Thus, there is, for this reason, no need to do a production plan but rather to set the input variables right in the DDS&OP process. Finally, the production plan at AeroCo also described working as a long-term plan for the suppliers, a promise from production towards the IPT's, as well as to forecast budget costs. For the first application of communicating with the suppliers, this can be done through a common forecast in the supply chain. For the second application, as a promise towards the IPTs, a question can be raised whether this is needed or not. As the deals of AeroCo works today, the demand has to be met by the production. This implies that the production cannot promise anything else than the volumes in the demand plan, something that is also stated in the interviews. Thus, the demand plan should also work as the promise from operations towards the IPS or the ADU calculated with a DAF in order to also incorporate the vacations into the promise. In addition, the promise should in the future be more focused on what is in the buffers rather than what volumes that will be the delivered each week. However, in order to be able to promise this, and also in order to create cost budgets, the capacity calculations need to be done. The capacity calculations are today based on the production plan, and thus these plans still have to be made until AeroCo can find a way to base these calculations on the ADU containing the DAF. How to perform these calculations based on the ADU is however outside the scoop of this study.

6.4. Implications for Further Research

In performing this study, the authors have been limited when it comes to the availability of data. Thus, for future research, some additional data can be further researched. First, it would have been interesting to have more data concerning the OEMs' stock of ingoing material. With this data, further analysis of the difference between the calculated demand and the demand using the company's definition could be done in order to investigate companies' knowledge of their customer demand. In addition, the analysis could then be able to look into the ability of the quantitative tools to predict the future for longer time horizons. In doing so, the argument of qualitative forecast methods being better to capture future changes at the market could have been strengthened or disproved. It would then also be possible to investigate the best setup regarding the frequency, length, horizon and aggregation level of the forecast as well as to create a rule for generating an ADU alert. Also, seasonal demand and other trends would have been able to investigate. Second, with historical quantitative forecast data, the strengths and weaknesses of the different forecast integration methods could have been further researched. With this data, the effect on forecast accuracy of using the four different integration methods would also have been possible to analyze. Third, with more data regarding the situation at the OEMs, further analyzes regarding which data to rely on in performing both the quantitative and qualitative forecast could have been researched. For example, sales data, building plans and end-customer demand. Additionally, other factors that may affect the demand that is not directly connected to the companies, such as the economic cycle or fuel prices would be interesting to incorporate in a forecast model, for example, by using multiple linear regression.

Further, some additional aspects in connection to the DDMRP system would be interesting to research further. For example, it was mentioned in the limitations how the study do not consider the financial impacts that forecast errors have on the DDMRP system and how this compares to a traditional MRP system. Since a forecast error in DDMRP do not generate an order, but only result in a higher buffer level, forecast errors possibly should not have as much impact on the performance. There is also a need to research how capacity calculations and budgets will be performed using the DDMRP model. With no production plan available, there have to be new ways to perform the calculations and budgets based on the ADU instead.

7. Recommendations to AeroCo

In this chapter, the practical recommendations towards the company studied in the case will be presented. The recommendations are summarized in figure 20 according to the research model.

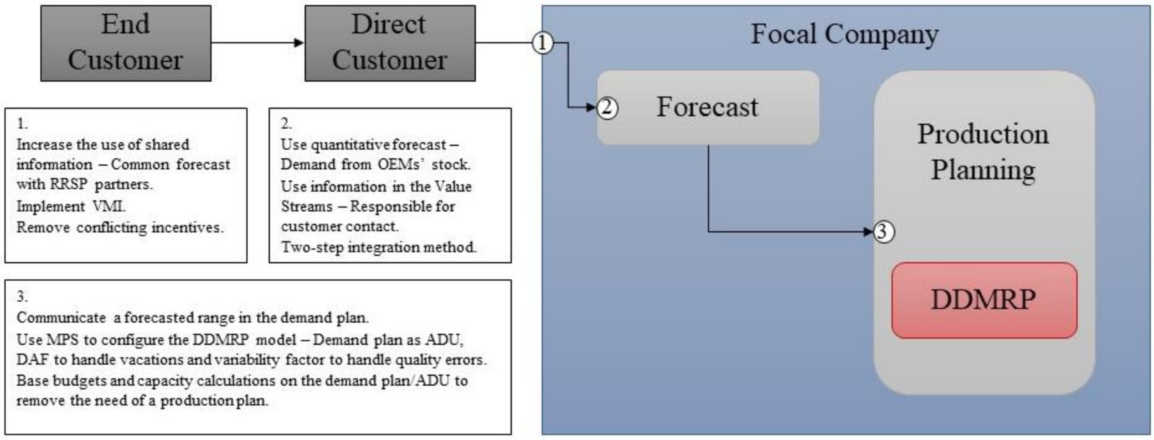

Figure 20. Research model - Recommendations.

7.1. Supply Chain Transparency

Regarding supply chain transparency, AeroCo is recommended to strive for a Type 3 supply chain, since the company matches most of the criteria needed to benefit greatly from this improvement. Furthermore, many of the problems in AeroCo's supply chain can be derived from being a Type 0 supply chain. Still, there are some indications of AeroCo moving towards collaborating on both production planning and inventory replenishment.

To achieve further improvements on the collaboration concerning production planning, the company is recommended to further use the information made available through the RRSP deals such as point-of-sale and inventory data, since this could increase the accuracy of the company's forecasts. Taking the collaboration a step further, a common forecast in the supply chain would be beneficial. However, considering the OEMs' lack of commitment to communicating the demand, this may be hard to achieve. AeroCo could instead improve the collaboration with other partners in the RRSP agreements, either to increase the knowledge of the partners' ability to meet the OEMs demand and thereby increase the accuracy of the forecasts or in order to put pressure at the OEMs to conduct a common forecast. Such a forecast could also facilitate the communication with AeroCo's suppliers when changing the ordering behavior in line with the DDMRP method.

Considering the collaboration on inventory replenishment, AeroCo has to ensure that the RRSP agreements not only means that AeroCo owns the inventory at the OEMs but also have the possibility to decide about it. Thus, this stock would have to go from only being a consignment stock to work as a vendor managed inventory (VMI). However, to get the VMI to work, it is also essential for AeroCo to remove the internal budgetary incentives of always reaching the budget independent of the OEMs' actual demand as well as the external incentives of all companies trying to avoid owning inventory.

7.2. Forecast Methods

The forecast method used at AeroCo today is not sufficient regarding forecast accuracy. This may be due to that AeroCo in their judgmental forecast rely heavily on the OEM's MRP data, which is not consistent with the actual demand of the OEMs. Thus, it is recommended to use OEM's ingoing stock as a base for the forecast. This information is available but not saved by AeroCo and the company has to come up with a standardized procedure to take care of this data. As it is today, this information is gathered by a person responsible for customer contact in the Value Stream. This person should be further involved in the creation of the demand plan since he holds a strong relationship with the OEMs and has unique information regarding the OEM's actual demand. Involving this person in the creation of demand plan is also a step towards fully using the grassroots approach where all employees with information about the OEMs' demand should be involved. Thus, this role is also important to implement in other Value Streams in order to gather all the information about the OEMs' demand. Such a change could also increase the trust of the Value Streams towards the demand plan.

Furthermore, it has shown that the quantitative methods forecast OEM's actual demand better than the qualitative forecast method AeroCo is today using. Of that reason, a recommendation to use quantitative approaches such as exponential smoothing would be beneficial for AeroCo. However, in order to retain trust in the forecast and to keep a high sense of ownership, it is also recommended to use an integration method to combine both quantitative and qualitative approaches. Moreover, to produce an efficient integration forecast method and to conduct a change in the organization which is comfortable for the employees, a two-step method could be necessary to use (see figure 21).

The first step includes an implementation of the first integration method, to use the qualitative forecast as adjustment of the quantitative forecast. This method means to compare the result from exponential smoothing or other quantitative forecast methods with their IPTs own qualitative forecast conducted with the grassroots approach. The quantitative forecast is then adjusted according to the qualitative judgements. This method is a good start for the organization change since the method will still give the IPTs high sense of ownership and trust towards the forecast. However, there is a risk that AeroCo automatically adjusts the forecast according to the qualitative judgement without any consideration of the quantitative forecast. Thus, in order to avoid this behavior, AeroCo should implement the third integration method where a quantitative forecast and a qualitative forecast are valued as equal. By implementing this method as a second step in the transformation means that the commercial function will have had the opportunity to become familiar and trust the quantitative forecast before having to fully rely on it.

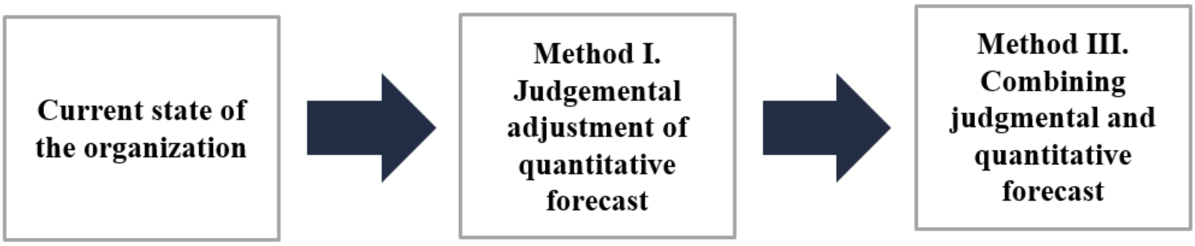

Figure 21, Two-step integration method.

7.3. Demand and Production Planning

In order for AeroCo to design their SIOP and MPS processes to handle the DDMRP system, some changes are recommended. For the SIOP process, no major changes are needed and will continue to handle variations at a longer time horizon. However, an increased focus on a forecasted range, rather than a fixed number is recommended. By communicating a forecasted range, it is made visible that the demand plan is only an anticipation of future demand and not a decided number. The first step towards this could be to start communicate the upper bound of the demand plan at the demand review meetings.

Regarding the MPS process, it will still be a process to handle short term variations. However, it will not be done using a production plan. Instead, it will be the process to set the DDMRP input variables. Today, the production plan is taking care of vacations, quality errors and other factors that affect the productions ability to meet the demand plan. This will now have to be made using the DDMRP input variables. In the model, the demand plan is recommended to be used as average daily use (ADU) since both ADU and the demand plan aims to represent the customer's actual demand. On top of this, a demand adjustment factor (DAF) is recommended to be used to handle vacations and capacity constraints. For the quality errors, this will be handled with a higher variability factor.

Today, AeroCo uses the production plan as a promise towards the IPS of what will be delivered. However, due to the RRSP agreements, AeroCo is obliged to deliver what is demanded by the OEM's. Thus, on a high level, the demand plan, or the ADU containing the DAF, should be possible to use as a promise of what will be delivered. However, AeroCo is recommended to move the focus towards a promise of what should be held as buffers rather than what should be produced. This is also true for the budgetary incentives which will need to be changed in order for the DDMRP to work properly. Today, budgets incentives are focusing on delivering according to budget and the use of production hours based on capacity calculations out of the production plan. Thus, AeroCo has to find an alternative way to perform these calculations without the use of a production plan. However, this is outside the scope of this thesis.

8. Conclusions

In order to answer the first research question about *what is required from the supply chain transparency in order to use DDMRP*, it can be concluded that DDMRP goes hand in hand with reaching the Type 3 Supply Chain described by Holweg et al. (2005) and the implementation of collaborative planning, forecasting, and replenishment (CPFR) described by Jonsson & Mattsson (2009). As has been discussed, the first and fifth principle of CPFR is easily achieved by a risk and revenue sharing agreement. However, it is essential to also have an agreement in place that enables a vendor managed inventory (VMI). VMI representing the third principles of CPFR and is a cornerstone for the DDMRP system to be able to plan the production out of the customers stock of ingoing material. This is also facilitated by having standard performance measurement in the supply chain as in the fourth principle of CPFR. For example, to avoid contradictory budgetary incentives. Finally, to fully achieve the benefits of DDMRP, using a collaborative forecast, representing the second principle in CPFR, is vital, in order for the suppliers to accept the changed ordering behavior. Thus, it is crucial not only to look at the relationship between a customer and a supplier as is the focus of the method presented by Holweg et al. (2005). Instead, also the relationships with suppliers further up in the supply chain as well as other actors in the supplier network have to be taken into consideration in increasing the transparency in the supply chain.

For the second research question regarding *how a forecast should be conducted in line with using the DDMRP method*, an integration method of a quantitative approach and a qualitative forecast should be applied. It is not sufficient to only rely on the historical data since this data does not include future changes at the market. However, to only perform a judgmental forecast has seen to not perform well enough. Nevertheless, it is crucial to still have trust in the forecast conducted. Therefore, depending on the amount of quantitative and qualitative forecast an organization is used to, four various types of integration method can be implemented. Concerning the qualitative forecast method, the grassroots approach described by (Jonsson & Mattsson, 2009) has theoretical benefits in forecast quality. However, it has been seen that it is sometimes hard to incorporate all information about customer demand, since there is not always enough communication between the different divisions of the company. A solution can then be to place a responsible for customer contact at an operational level in the production organization. For the quantitative forecast method, the study confirms the theory in emphasizing the importance to base the forecasts on the right customer data which best helps the company to assess the future demand. Thus, the high supply chain transparency is important also in this regard.

Considering the third research question of *how the demand and production planning processes should be conducted in line with the DDMRP method*, it can first be noted that the S&OP process does not have to go through any major changes to correspond to the adaptive S&OP process described by Ptak & Smith (2008). The only change is that the S&OP will now focus on communicating a forecasted range rather than a fixed number. When it comes to moving from a MPS process towards a DDS&OP process, there are some changes to be made. First, this process will now have to take care of setting the input to the DDMRP model. Secondly, it also means that there will be no need to reschedule the production since the DDMRP model gives signals based on the current buffer levels independent of any schedule. Thus, there is no need for a prioritization activity either, since this is done strictly out of the DDMRP signals. For the financial forecasting, a company implementing DDMRP has to come up with a method to base the financial forecast on the forecasted ADU rather than capacity calculations based on the production plan. However, how to perform these calculations is outside the scope of this study.

To finally conclude *what should be used as forecast in the DDMRP system in order to size the buffers*, it should be noted that the general aim of a forecast is to assess the best anticipation of customer demand. Thus, the DDMRP method should not have any further requirements than any other application of forecast. However, when incorporating the forecast into DDMRP as ADU, this does not have to incorporate expected quality errors as is needed in normal MRP, since this can be handled by the variability factor. Nevertheless, it still has to incorporate a demand adjustment factor (DAF) to take vacations and other capacity constraints into consideration. Thus, the ADU used in DDMRP should be the general forecast done in the company adjusted for capacity constraints with a DAF. The conclusions regarding the four research questions have been summarized according to the research model in Figure 22.

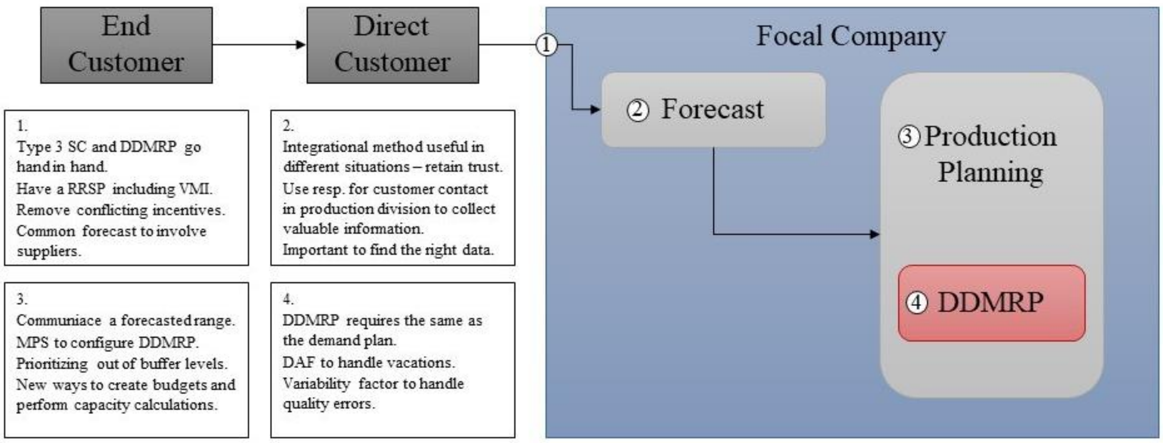

Figure 22. Research Model - Conclusions.

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Appendix

In this chapter, additional figures and tables are presented.

Appendix I – Interview Template

Introduction

- Introduce ourselves and explain why we are making this interview. Explain the thesis title - Understanding the Requirements of Forecast in a Demand Driven Material Requirements Planning.
- Explain what forecast means to us.
- Present the character of the interview - semi-structured in order for us to have an open discussion around topics.
- Explain that the responses will not be analyzed individually but as a group.
- Set the time frame expectations of the interview - around 1h.

General questions

- Are you okay with us recording this interview?
- Can you give us a brief description of your role at the company?
    - Earlier roles at the company?
    - Your role today?
- What have you heard about the DDMRP project before?
    - Explain shortly if they haven't.

Field of application

- From whom are you getting information concerning forecast?
    - How does the information flow work before that?
- To whom are you communicating information regarding forecast?
    - How does the information flow continues after that?
- To what do you use forecast in your daily work?
    - What information do you actually need to perform your work in the best way possible?
- If you had the opportunity to design this information flow, how would it then look?
    - What information would you want to have?
    - From whom would you get this information?
    - To whom would you forward this information?
        - In what purpose?
        - What would they use it for?

OEM transparency

- In what way do you communicate with other companies in the supply chain?
    - What information do you get from OEMs, customers, suppliers etc. concerning the demand of customers?
    - What information do you give to OEMs, customers, suppliers etc. concerning the demand of customers?
- How could AeroCo better use the information you as a company get from other actors to perform a more accurate forecast?
- What kind of additional information would be important to have in order to be able to create an even more accurate forecast?

    - From where could this information be collected?
    - What is required by AeroCo to get access to this information?

Needed accuracy

- How are forecasts done at the company today?
    - What information is used?
    - What kind of qualitative and quantitative methods are used?
- Do you think that the forecasts being done today are fairly accurate?
    - In what way are your daily work affected by forecast errors?
    - Where do you think forecast errors occur today?
    - How could these forecast errors be avoided?
- How does your job have an impact on the forecast?
    - In what way do you contribute to the forecast being made?
- How could you contribute to an increased forecast accuracy?

Conclusion/Feedback

- Do you have any additional information that we should be aware of?
- Is there anyone else you would recommend us to talk to?
- Could we contact you again if any confusion about the answer or follow up questions would appear?

Appendix II – Qualitative data analysis

Finding Regarding the Company's Current State	Findings Regarding the Communication in the Supply Chain	Finding Regarding the Company's Future State and DDMRP
Finance division	Contractual agreements	OEMs actual demand
Program division	Bullwhip effect	Buffers in DDMRP
Customer contact	Information regarding the end customers	Delimitations of DDMRP
Value Streams	Communication towards the customers	Forecast input to DDMRP
	Communication from the customers	SIOP in DDMRP

Finding Regarding the Company's Internal Processes	Finding Regarding the Company's Field of Applications of forecast
SIOP	Consequences of forecast errors
Demand Review	Forecast accuracy
MPS	Forecasting methods
Line of balance	Long term planning, R10
	Production plan

Appendix III – Forecast Accuracy Follow-ups

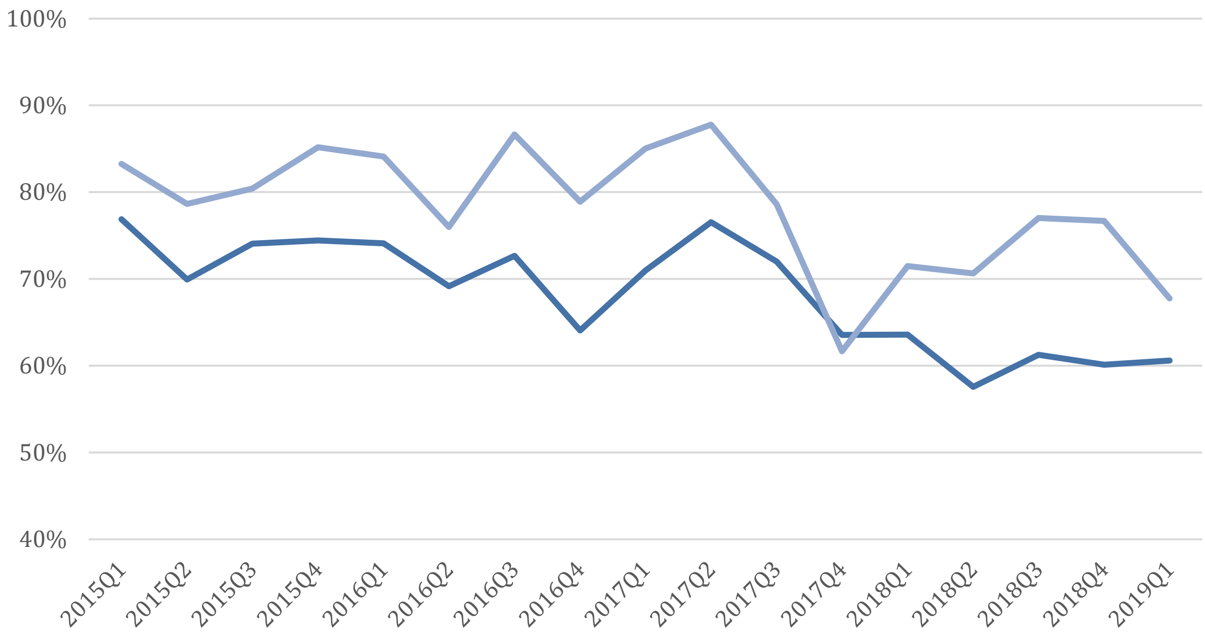

Figure A. Forecast Accuracy 6 months (dark blue shows average, light blue shows weighed average based on volume value).

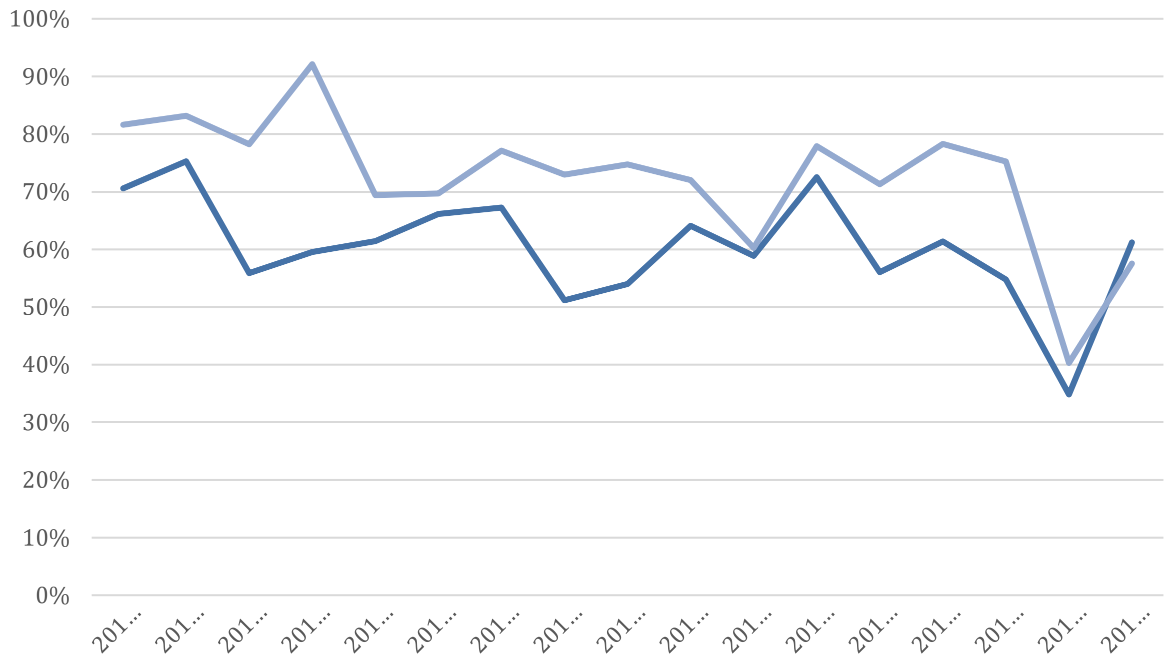

Figure B. Forecast Accuracy 12 months (dark blue shows average, light blue shows weighed average based on volume value).

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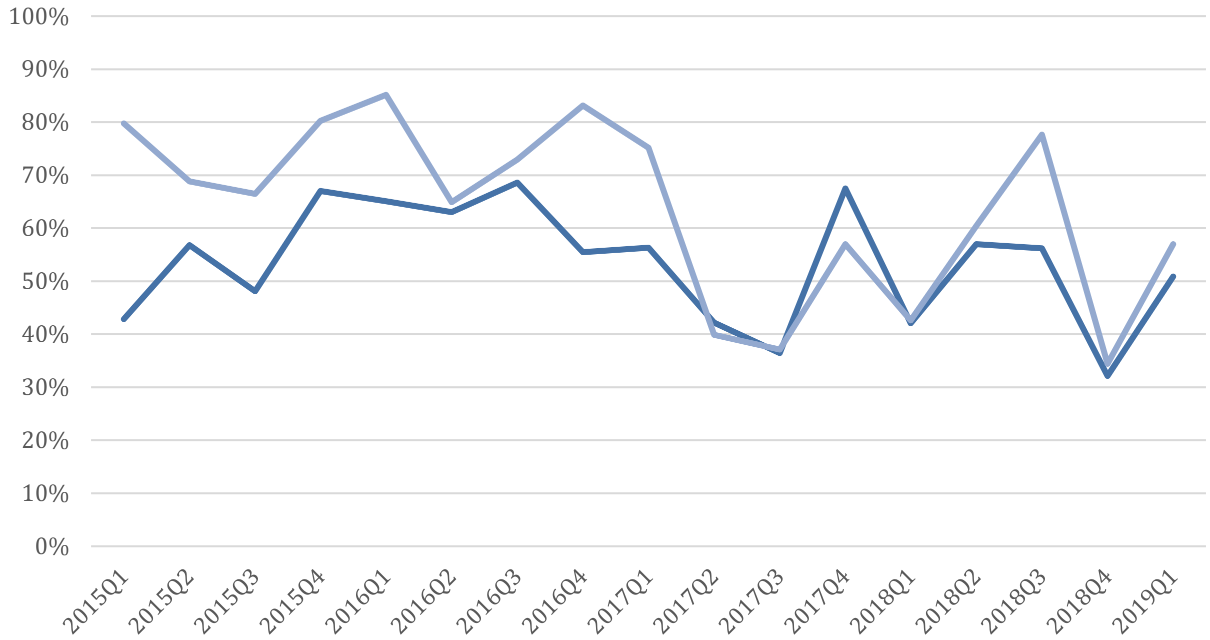

Figure C. Forecast Accuracy 18 months (dark blue shows average, light blue shows weighed average based on volume value).