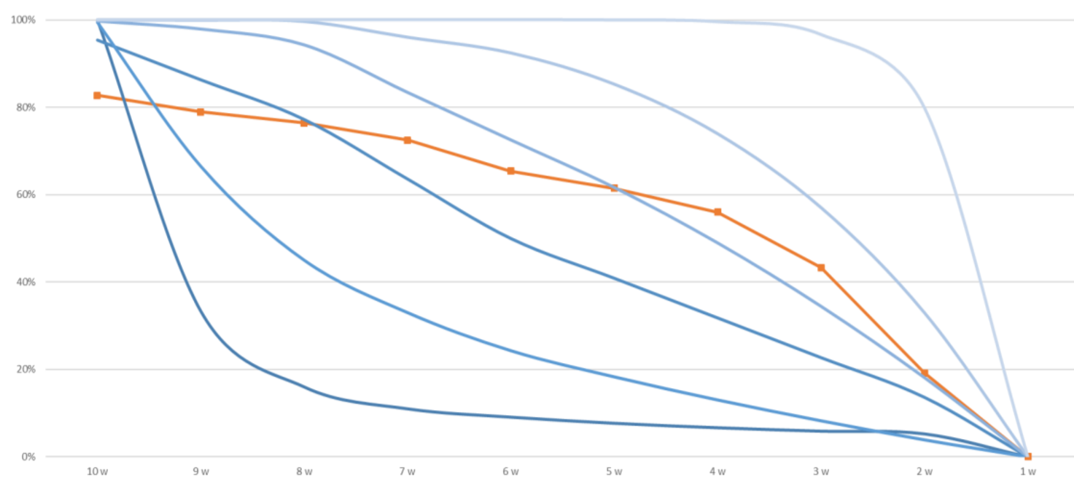

Advanced Analytics to Mitigate and Manage Supply Chain Effects of Demand Variations Communicated in Delivery Schedules

A Case Study of a Supplier in the Automotive Industry

Master's Thesis in the Programme of Supply Chain Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
Report No. E2020:069

MASTER'S THESIS E2020:069

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Cover: A MAPE-profile of forecast accuracy scores of the case company, 5.1.2

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Abstract

The aim of the study is to find how a case company is affected by changes in their delivery schedules from their customers. It is supposed to relate clusters of demand variations to different supply planning processes within the case company. The study should explore possibilities of measurements and visualization to benefit and increase performance of the supply planning processes.

The approach is a broad mixed method approach to find the most relevant effects of variations. The goal is to define the processes and mapping the capacity and flexibility of the production lines and material supply, to compare against forecasts and delivery schedules. How, what and why should one measure forecast accuracy? Different measurement methods yield different results. Which results is relevant and why is it relevant? The discussion about measuring forecast accuracy of items, item groups or customers is covered, and the results is that it depends on the context and the bottlenecks of the company.

Results show that forecast accuracy and biases is closely related to the customer, and the customers that is perceived bad according to the planners also show worse forecast accuracy and larger biases in measurement tools. The most common bias is overestimations that could occur due to that the customers want to secure capacity and create a "buffer" at the supplier in case of a rise in volume. The customer/production planners and the material planners at the case company spend a large part of their working time handling effects and issues related to variations in delivery schedules. The report suggests new models in the enterprise resource planning system that could help the supply planners to get an overview of the planning process. It could help prioritize and sort between changes in delivery schedules to allocate the most important resources to the most important issue. With the use of the forecast accuracy tools, the decision-making process could be improved. However, whether you act on the information or not is up to the case companies' internal policies around tied up capital and service levels.

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1 Introduction

1.1 Background

As have been seen in the computer industry with Dell and Compaq, built to order (BTO) supply chains can have advantages over built to stock (BTS) supply chains. As the automotive industry also strive for competitive advantage, a shift towards BTO have been seen and complications follow (Meyr, 2004). With a demand for short delivery lead times to customers, lean methodology, low buffers and inventory, this puts pressure on the whole supply chain (Gunasekaran & Ngai, 2009). In a production environment where the most parts of the original equipment manufacturers' (OEM) products is produced by external suppliers, to get ahold of the latest technology and exploit core competencies, communication through the whole supply chain across companies is critical (Sako, 2005). One common thing in the automotive industries planning processes is set long term agreements of volumes, and the use of delivery schedules. The delivery schedules, however, is based on forecasts and changes occur which creates inaccuracies. These forecasts also include compensation for former inaccuracy which could create a pendulum effect. The available stock in the supply chain is non-transparent so overestimations of the forecasts is a possible solution for OEM to guarantee availability at the suppliers. (Schwede & Thissen, 2014) (Martinsson & Sjöqvist, 2019)

This MSc thesis focus on a 1st tier supplier and its use of delivery schedules. As supplier-customer relationships in automotive supply chains requires flexibility, they use quantity flexibility (QF) contracts, where OEM update their delivery schedules (planed orders) every week with the latest available information (Tsay A. A., 1999). When planned orders are inaccurate, it leads to variations and uncertainty in the respective delivery schedules (Huanng, Hsieh, & Farn, 2011). When the supplier and customers informal agreements allow changes in the delivery schedules as soon as 48 hours before shipping, this brings issues to the production capacity planning and material supply planning process. As the master production schedule (MPS) is set before this time firefighting occur to adapt to the change in demand. Material supply issues is related to lead-times towards raw-material and component supplier. The longer lead times, the harder to handle. This situation will force the company in question to keep a safety stock of both raw-material and finished goods to deal with variations. Actions have been taken in order to deal with the problem through analyzing the forecast accuracy and the systematic forecast errors (biases) of the delivery schedules. The tools to measure accuracy and bias is called Forecast Accuracy Index (FAI) and Weighted Tracking Signal (WTS) and is presented in 2.1.1. The German Association of the Automotive Industry (VDA), which is a member of the European Automobile Manufacturers Association is an interest group of the German Automotive industry that have written reports on forecast accuracy in delivery schedules, is also the predecessor to FAI. (VDA, 2010) However, some variations have much lower operational risks than others, and the feeling is that this is not represented in the forecasts.

Internally within a company, multiple critical decision points exist weeks prior to production of goods and is controlled by different people and processes within the organization. These decision points differ from company to company, but in general, around 10 to 30 weeks prior, decision to purchase raw material and tools must be taken, then 3 to 9 weeks prior decisions about start of manufacturing must be taken. Further, less than 2 weeks prior to production, final operation decisions must be taken. (Jonsson & Mattsson, 2009) In some cases, a lot of delivery schedule variations is just present in one of these decision points. For example, if a customer changes the color of its car, it will not affect the total number of cars sold so top management will not notice any change in order stock and it will not affect production because they will produce as many body in whites (BIW) as usual. But one planner will have a lot of alerts from variations in delivery schedules, as the number of cars with one color decreases and will send an alert, while another color increases and will send an alert. In some cases, this would not need any alert at all, the production might just be able to change color before painting. This study focuses on visualizing and mitigating such demand variations at a first-tier supplier in the automotive industry.

1.2 The case company studied

The case company studied is a Swedish leading automotive technology company which operates as a tier 1 supplier to multiple OEM companies. It is referred to as “The supplier”, “The case company” or “The company” from here. It designs, compiles and sells software, hardware and systems. The supplier has production plants and engineering sites in Europe, US and Asia. The case company have net sales of over $2 billion by 2018 and over 9000 employees.

1.3 Aim

The aim of the study is to find how the case company is affected by changes in delivery schedules, which means to find patterns how delivery schedules vary from OEM to the case company and relate demand variations to their effects of different supply planning processes within the case company. The supply planning processes in question are the production capacity process, the material supply planning process and the customer planning process and decisions around these. It explores gaps between measurements in the planning software and operational inefficiencies.

A good total forecast could lead to top management unawareness of forecast quality issues. The methodology is shaped to structurally evaluate the supplier and find the most and least dangerous alerts to further enhance the visualization software tool to increase the clearness and decrease the workload of the planners. This is done by qualitative interviews with the supplier, and evaluation of the production lines in coordination with material supply planners and production capacity planners.

The study should evaluate the effects of variations in delivery schedules and explore possibilities of measurements and visualization to benefit and increase performance of the supply planning processes. Performance is defined as speed, cost, efficiency and effectiveness with a high certainty.

1.4 Delimitations

The thesis is not covering other supply chains than automotive and delivery schedules only represent one specific supplier in the automotive industry. Generic modelling is excluded for further research. Pilot tests at the case company as well as further planned observations at the plant is also excluded due to a pandemic outbreak at the time of writing. The variations of delivery schedules analyzed has been divided into three parts, which is 0-2 weeks prior to shipment, 2-8 weeks and 8 weeks or longer. This is due to that different questions that appear from these time fences. This report focuses on the time fence concerning issues that appear when the delivery schedule is changed 0-2 and 2-8 weeks prior to shipment. Due to restrict data policies at the case company, some data was not possible to include in the research, for example inventory data related to certain item groups to conclude further information about economics of poor forecast accuracy. Salary data and labor cost is also uncollectable, and assumptions have been made with support of public sources online.

1.5 Limitations

The largest limitation of the report was the lack of data and the question of data quality. There was an uncertainty about the data supplied to the project and questions rose if the data was correct. When handling large amount of data, validation is a large part of the task which limited the analyzing part. Data validation was very time consuming and as time also was limited for the report, the results might be weaker. Accessibility of complementing data for the analysis to conclude economic effects of delivery schedule data was also an issue, due to that the data was classified and parts of the analysis had to be done with estimates and generalizations, which harm the results.

1.6 Research Questions

A hypothesis is that different customers have different amount of delivery schedule changes and different types of forecast quality inefficiencies, for example late variation, random variation and systematic variation. Another hypothesis is that variations in delivery schedules is increasing costs for the supplier in terms of inventory levels, express shipments, overcapacity, overtime and supply planning time.

1. How do delivery schedules vary from customers to the case company within the automotive industry from 0 to 8 weeks prior to delivery and how do different clusters of demand relate to/affect production capacity and material supply planning?

As the time horizon from 0 to 8 weeks, it is of importance that delivery schedules is accurate due to production planning and supplier lead times. It is a general feeling that inaccuracies are creating a lot of trouble to the planners when the delivery schedules are changes within this time frame.

2. How do variations in delivery schedules from 0 to 8 weeks prior to delivery affect the supply chain planning processes (material and demand/production planning) at the case company's plant in Sweden?

Apart from how changes within delivery schedules affect the planning process, it is also of importance to consider how it affects the actual production line and its processes. What does it mean in practice, to revise production schedules as soon as 0-8 weeks before delivery date?

3. How do variations in delivery schedules 0 to 8 weeks prior to delivery affect the production process at the case company's plant in Sweden?

As there always is room for improvement in planning processes, it is desirable to explore possible solutions to show delivery schedule inaccuracies and find a solution that can handle variations. The perception currently, is that delivery schedules are not perfect, but it is not clear what is causing the inaccuracies, and why. There is a need to illustrate the fact how delivery schedules vary, and there is a wish to improve the planning process.

4. How could measures or visualization be used in customer planning, production planning and material supply to improve planning performance?

5. Could measures and visualization support decision-making in daily operations within production planning and customer order planning of the case company?

2 Literature background

The literature background is divided into three larger parts, where the first is a presentation of the research project and what has led the research to where it is today. After that a review of forecasting is done and explanation of different forecast quality measurements. Further, a description of operations planning & control concepts is presented. The order is shown in Figure 1.

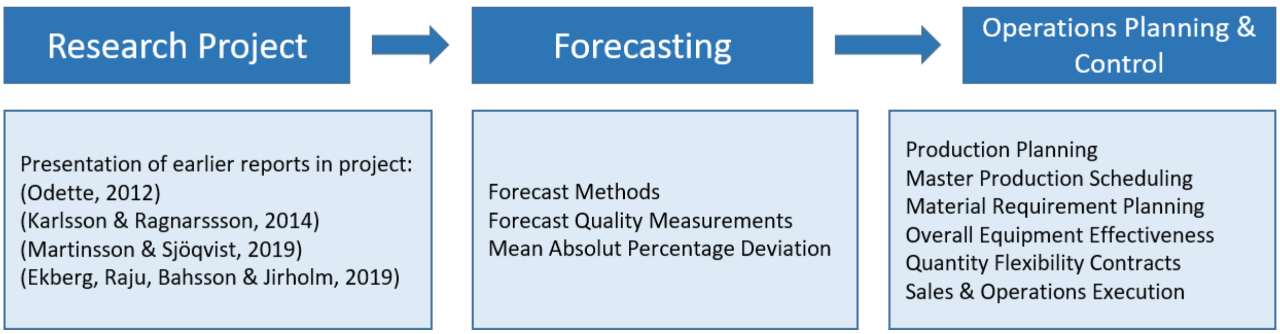

FIGURE 1, AN ILLUSTRATION OF THE LITERATURE BACKGROUND PART OF THE REPORT.

2.1 Earlier parts of research project

The study is part of an FFI (Fordonsstrategisk Forskning och Innovation) project "Future of sharing schedule information in automotive industry supply chains using advanced data analytics". The project is divided in six parts, where the first is a survey study of the current situation in automotive supply chains, the second part is a data analytics part where a lot of delivery schedules has been received, and patterns and variations among them has been identified. The third part is a cause and effect study of delivery schedules with low accuracy and high variations. The fourth part build machine learning models for visualization and forecasts. This thesis relates to part three and focus lies in identifying clusters of delivery schedules variations from customers to a case company. The aim is to apply knowledge from earlier research to practical use at a case company. (Chalmers, 2019)

2.1.1 Measurements of forecast accuracy and systematic errors in delivery schedules

During a research project from 2010 to 2014 with the organization Odette (Organization for Data Exchange by Tele-Transmission in Europe), two measurements for assessing forecast accuracy and systematic errors in delivery schedules where established. These two are called FAI (forecast accuracy index) and WTS (weighted tracking signal). FAI is a measurement between 0% to 100% where 100% means perfect forecasts, and 0% means that the forecast where more than 100% wrong up or down every week until the last week before delivery. WTS is a score between -1 to 1 where 1 and -1 means overestimation or underestimation of delivery schedules of more than 100% compared the actual order. 0 means no bias at all but is not ensuring perfect forecast. If you have equal number of underestimations as overestimations, the WTS is 0. (Odette International Ltd, 2012)

2.1.2 Development of a Sales and Operation Planning process

During 2014, Ebba Karlsson and Annie Ragnarsson conducted MSc thesis research within the project that is seen as a predecessor to this research project, and a case study was conducted of multiple suppliers in the automotive industry. Their sales and operations planning processes were mapped and compared to Grimson and Pykes S&OP maturity framework. (Grimson & Pyke, 2007)

Sales & Operations Planning is according to Grimson & Pyke (2007) a process that links the strategic plan of the company to the daily operations, to better match supply and demand. The view off S&OP differ in literature but many views S&OP as *"a process to build a consensus-based operations plan to meet the forecast demand"* and some has the view as *"a real-time technique to adjust quickly to changing market and operating situations"* (Grimson & Pyke, 2007).

The conclusion of their research is summarized as most of their case companies have a lacking S&OP process with room for improvement and that the FAI application could help in some cases to support the S&OP process. (Karlsson & Ragnarsson, 2014)

2.1.3 Causes and effects of poor demand forecast accuracy

The MSc thesis research of Martinsson and Sjöqvist is the third part of this project, with the aim to identify the current situation of forecast accuracy in the Swedish automotive industry between multiple OEMs and a single supplier. A database of delivery schedules where analyzed using FAI and WTS and the result of the study where poor forecast accuracy compared to VDA guidelines (VDA, 2010). The causes lied both in the sales forecasts as well as in the customers MRP system. Inaccurate delivery schedules are currently handled by buffer inventory of material and finished goods at the supplier. The report showed a clear picture of how a unproportionally large amount of inventory was held at the suppliers, instead of at the OEMs. The FAI value was better when acting as a tier 2 supplier than as a tier 1, and the conclusion was drawn that the tier 1 supplier acts as an extra buffer, for the supply chain. With better forecasts, the supplier is expected to be able to lower their inventory and release tied up capital. However, the investment must be done by the customers, which would benefit the suppliers, which they don’t have incentives to do currently. (Martinsson & Sjöqvist, 2019)

2.1.4 Evaluation of KPIs and their effect on the supply chain visibility

Another addition to the project was provided by Ekberg, Raju, Bahsson, & Jirholm, (2019). They evaluated five KPIs to variations in delivery schedules and connected them to how they can help improve performance in supply chain visibility (SCV) (Jonsson & Kjellberg, 2019). These are late variation, random variation, systematic variation, scheduled nervousness and backorder. A model from Somapa et al (2018) have been used as framework for SCV. The framework describes the functions of SCV as well as its first order effects, which is completeness, accuracy, timeliness, operational efficiencies and strategic competencies. The result of the study found that backorder is not affecting performance on any of the five effects, and the timeliness aspect is not proved to improve performance by any of the five KPIs in question. By measuring and visualizing following KPIs, you might improve SCV by these aspects: (Jonsson & Kjellberg, 2019)

- Late variation: Completeness, Operational efficiencies and strategic competence
- Random variation: Accuracy and operational efficiencies
- Systematic variation: Completeness, accuracy, operational efficiencies and strategic competence

- Scheduled nervousness: Completeness and operational efficiencies

TABLE 1, THE RESULTS OF HOW FORECAST KPI'S AFFECT SUPPLY CHAIN VISIBILITY (EKBERG, RAJU, BAHSSON, & JIRHOLM, 2019)

Characteristics	Informational			Transformational	
KPIs / Effects	Completeness	Accuracy	Timeliness	Operational Efficiencies	Strategic Competencies
Late variation	x			x	x
Random Variation		x		x	
Systematic Variation	x	x		x	x
Scheduled Nervousness	x			x	
Backorder					

Another contribution from the research was a proposed dashboard of mean absolute percentage deviation-profiles (MAPE-profiles) in combination with the KPIs affecting supply chain visibility. The purpose of the dashboard is to visualize demand variations and show dangerous variations with red colored dots and other variations with green dots. The size of the dots shown also is large or small if the demand is an increase or decrease respectively. Large red dots could generate capacity issues and small red dots could give a sign of inventory buildup. An example of the mape-profile chart looks is illustrated in Figure 3, where the y-axis represent MAPE for each customer/address/product/demand date-combination and the x-axis represent weeks before delivery. (Ekberg, Raju, Bahsson, & Jirholm, 2019)

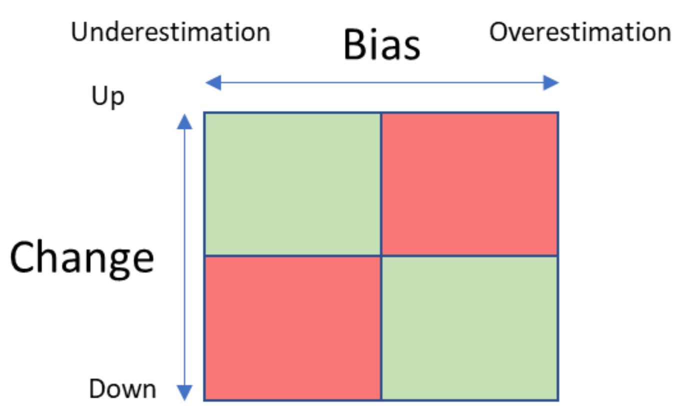

FIGURE 2, A 2X2 MATRIX TO DECIDE WHETHER A VARIATION SHOULD BE RED OR GREEN (EKBERG, RAJU, BAHSSON, & JIRHOLM, 2019)

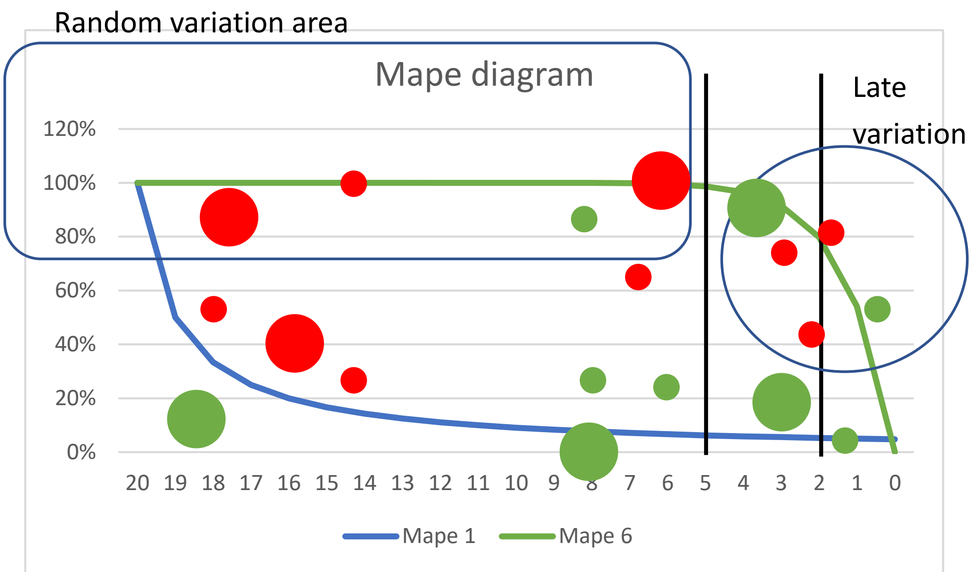

Figure 3, An example of the dashboard with alerts (Ekberg, Raju, Bahsson, & Jirholm, 2019)

2.2 Forecasting

The ability to make predictions about the future have always been of great importance for corporations. In order for any type of planning to take place one must first logically have considered what the future might look like (Jonsson & Mattsson, 2009) (Abolghasemi, Gerlach, Tarr, & Beh, 2019).

2.2.1 Forecasting methods

One common way to group forecasting methods is between quantitative and qualitative forecasting methods. The report is also covering software-based forecasting as it is industry standard. Quantitative forecasting means using data and facts to try to estimate what the future will look like. Examples of this is using historical sales with trends and mathematical models to predict what the upcoming demand pattern will look like. Common tools to add a trend to the forecast are different type of moving averages, like exponential or simple moving average, where exponential is the more aggressive method which can react fast to large demand variations, and the simple moving average is better filtering away outliers and noise but worse catching up with rapid demand variations. (Gilliland, Sglavo, & Tashman, 2016) (Jonsson & Mattsson, Manufacturing Planning and Control, 2009)

Qualitative forecasting is the soft values of forecasting which is as important in most cases. Examples of this is when you ask a sales manager how much he/she think the company will sell next month. Sales personnel often have experience and makes good guesses, so adding all sales personnel together often gives a good total amount, but at the same time they are subject for biases. (Jonsson & Mattsson, Manufacturing Planning and Control, 2009)

Advanced Planning Systems (APS) is a software-based planning method that calculates statistically how much of each product that will be sold based on historical data and parameters which the user can set. Then depending on what service level you choose and how much standard deviation you can accept, it gives you a forecast on how much it thinks you will sell in the future. APS is very good to use when historical data describes the future well and when you have seasonality or trend patterns. (Jonsson & Mattsson, Manufacturing Planning and Control, 2009)

2.2.2 Forecast quality measurement

Since forecasts are estimations about the future, the ability to measure the accuracy of that estimation is important before acting on the estimation. Literature (Jonsson & Kjellberg, 2019) (Viet, Behdani, & Bloemhof, 2018) (Jonsson & Myrelid, 2016) (Barratt & Oke, 2007) have identified five KPIs related to quality of forecast measurements of delivery plans within the automotive industry. These are late variation, random variation, systematic variation, scheduled nervousness and backorder.

Late variation can take the form of changing the delivery date of an already existing order or adding a new order close to the demand date. The definition of late variation according to literature is changes within the freeze time. The freeze time is a period before demand date where the customer orders are locked and cannot be changed according to an agreement between the supplier and the customer. (Jonsson & Mattsson, 2009)

A late variation is an issue for material planning and production planning since the possible actions available becomes limited based on lead-time from higher tier supplier and production capacity. Depending on the freeze time agreed between OEM and supplier precautionary measures needs to be taken in order to deal with the risk of late variation. The most common solution is to keep a safety stock of finished goods which is associated with inventory carrying cost (Jonsson & Mattsson, Manufacturing Planning and Control, 2009). The value of the KPI is created as the company gets aware of how often the order is changed in last second. An order with no historical late variation could imply that the order is correct earlier before demand date. Another value is created when it is used as basis during discussion with customers, to enlighten the issue and strengthen the feelings by the planners with facts and data. By making the effects of late variations clear to the one making the changes potential to improve the transformational characteristics emerge. Further, this communication would in turn affect the strategic competencies since the discussion is an investment in the relationship leading to increased trust and understanding between supplier and OEM (Ekberg, Raju, Bahsson, & Jirholm, 2019).

Random variation refers to the amount and degree of changes made in a delivery plan inside the time frame 0-20 weeks from demand date. Literature recognises *Mean absolute percentage error* (MAPE) as a way of measuring the random variation (Chase, 2016).

EQUATION 1, MEAN ABSOLUTE PERCENTAGE ERROR

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \quad where \quad \begin{matrix} A_t = Actual\ demand \\ F_t = Forcasted\ demand \end{matrix}$$

Earlier reports in the project (Ekberg, Raju, Bahsson, & Jirholm, 2019) suggest that MAPE can be used when planning by categorizing part numbers by earlier patterns in variation in to different MAPE-profiles. Further, Ekberg, Raju, Bahsson, & Jirholm (2019)

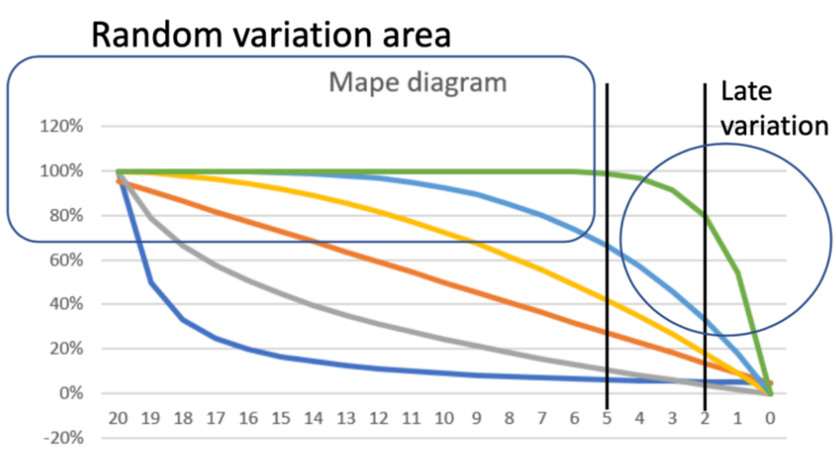

FIGURE 4, SIX EXAMPLES OF MAPE-PROFILES

presentes the five profiles in a similar way as Figure 4 below. Once profiles have been established, you can categorize items after which profile they follow and it could work as a decicion basis when planning for future production capacity and material supply. The basepoint for this idea comes from Jonsson & Kjellberg (2019).

The KPI *scheduled nervousness* measures the degree of how frequently specific orders demand date is changed back and forward in time.

FIGURE 5, VISUALIZATION OF DELIVERY SCHEDULE NERVOUSNESS (JONSSON & KJELLBERG, 2019)

Its quantified for visualization purposes though the denotation gap between 0 to 1. The higher the number the less nervous. There are many ways of measuring nervousness and it is broadly studied in literature. In this report, only one way is presented. Jonsson & Kjellberg (2019) visualized scheduled nervousness as shown in Figure 5 by denoting planned volumes grater that zero with black. The historic nervousness could be used to prioritize the importance of a change since changes of known nervous groups could be seen as irrelevant (Ekberg, Raju, Bahsson, & Jirholm, 2019).

The last KPI proven to have an effect is *systematic variation* (Ekberg, Raju, Bahsson, & Jirholm, 2019). This is also referred to as BIAS. This KPI measures the systematic over or under estimation made by customers over a span of demand dates. In practical terms it means that a customer's initial estimation of the needed demand is consistently changed up or down on the demand date.

2.2.3 Overfitting

When evaluating forecasting accuracy, the problem of overfitting must be considered (Vermorel, 2009). It is often brought up in the context of machine learning as a crucial part. The problem arises when a model with the intention of predicting future events is modeled too strict on historic data (Vermorel, 2009) . This means that the model is well adapted to get good results on the data available during a back test but however include a lot of noise in the data as “correct data”. The more accurate historical model, the higher the probability of noise fitted as parameters. Anup Bhande (2018) visualizes overfitting with three graphs, as shown in Figure 6, visualization of overfitting, Figure 6.

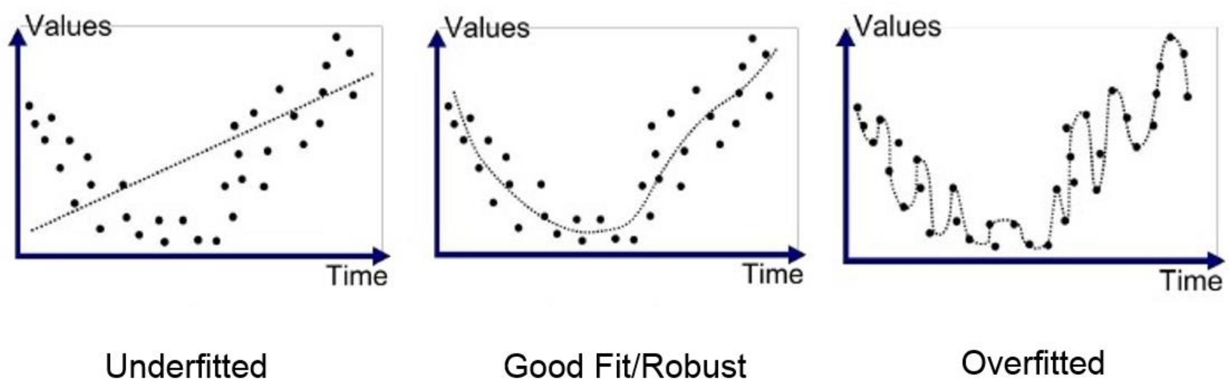

FIGURE 6, VISUALIZATION OF OVERFITTING, (BHANDE, 2018)

This might decrease the robustness of the model and decrease the accuracy in future predictions. Its therefor more desired to have a more generalized outcome of the back test illustrated in Table 7.

2.3 Operations Planning and Control

Figure 7 from Jonsson and Mattsson describes a framework of material and capacity planning on multiple planning horizons and what decisions that generally occur within operations planning and control environments. The parts of concern of that framework is described in the following sections.

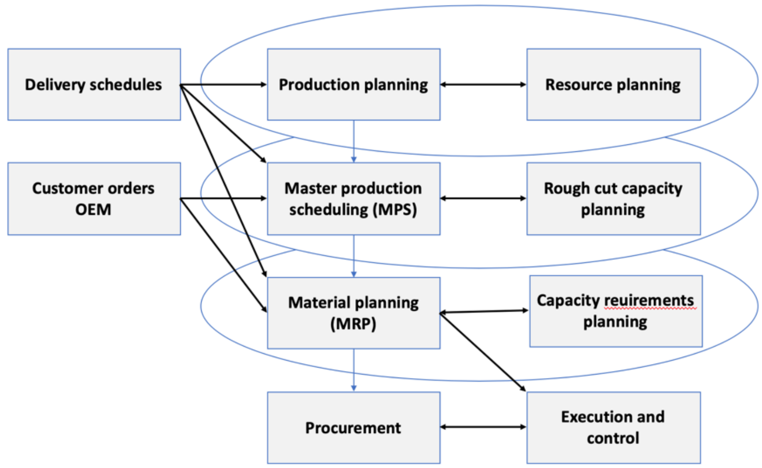

FIGURE 7, A FRAMEWORK OF RESOURCE AND CAPACITY PLANNING (JONSSON & MATTSSON, 2009)

The different levels in the hierarchy represents different aggregation levels of planning objects, horizons, planning frequency and different period length, which is illustrated in a table from Jonsson and Mattson in Table 2.

TABLE 2, PLANNING FUNCTIONS AND GENERAL ATTRIBUTES (JONSSON & MATTSSON, 2009)

Function	Planning object	Horizon	Period length	Planning frequency
Sales and operations planning	Product group	1-2 years	Month	Monthly
Master production scheduling	Product	0.5-1 years	Week	Weekly
Order planning	Item	1-6 months	Week/day	Weekly/daily
Production activity control /execution & control	Operation	1-4 weeks	Day/Hr	Daily

2.3.1 Production Planning

Production planning plans what and when something should be produced, given conditions of materials, labor and machines available to satisfy customer demand. A goal is to produce a reasonable mix of products to minimize inventory and at the same time allocate large enough batches to consider setup times for machines.

2.3.2 Master Production Scheduling (MPS)

The MPS is a plan for how much of each individual product within a company should be produced. It defines production, staff and inventory to note how much of each is demanded and when. Today the most MPS plans are created by computer software and changed by humans when errors occur, or an outlier event is recognized. The MPS takes input variables like lot sizes, forecasted demand, production lead time and other (Berry, Vollmann, & Whybark, 1988). Whether you set the production schedule on forecast or order depend on what production environment you have, as Figure 8 shows from Berry et al. (1988)

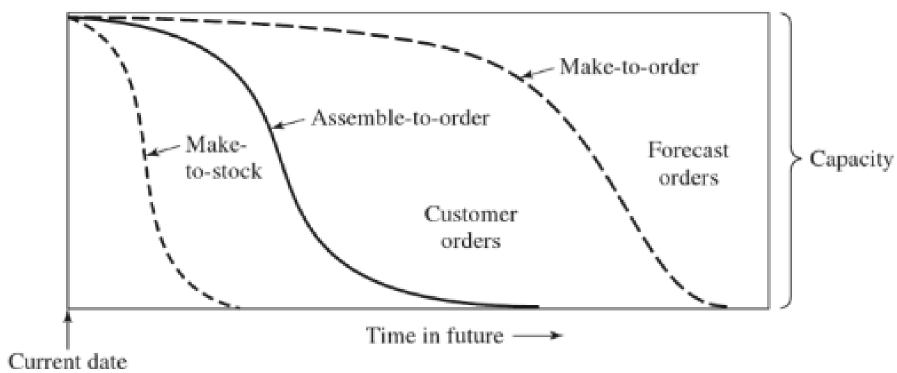

FIGURE 8, DIFFERENCE BETWEEN FORECAST AND CUSTOMER-ORDER DRIVEN PRODUCTION (BERRY, VOLLMANN, & WHYBARK, 1988)

MPS is closely related to the process of Sales & Operations Execution, as MPS is acting in the same aggregation level as S&OE is forecasting, which is described in an own section in the literature background.

2.3.3 Material Requirement Planning (MRP)

The MRP system is supposed to ensure all raw material is available for production when production should start, and that finished goods is available for customer delivery. At the same time, to lower the inventory carrying cost, the MRP optimizes service level against low inventory rates. Historically, MRP was planned by hand but today almost all MRP systems are software-based and calculated by computers with human surveillance.

2.3.3.1 Bill of material Data

The bill of material (BOM) is the structure how products are built up by smaller components and quantity of every item. It is often described as a recipe or formula of products, to link product demand to specific component demand. Sometime components have subcomponents and the BOM looks like a tree structure and could get very complex. When subcomponents are part of many different components, they must share inventory, in theory the lower you go in disaggregating products the more inaccurate forecasts you get. By combining forecasts of multiple depending products with similar subcomponents, you might smoothen the forecasts. (Jonsson & Mattsson, 2009) (Watts, 2015)

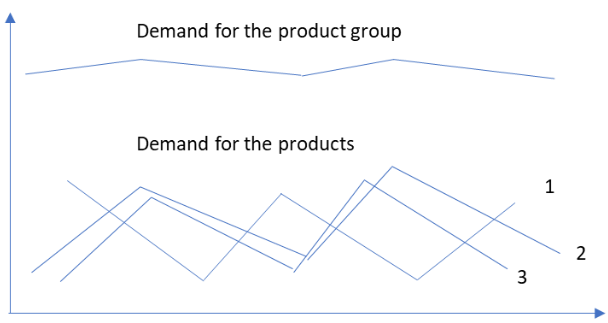

FIGURE 9, AGGREGATING MULTIPLE FORECASTS HIDES VARIATIONS

2.3.3.2 MRP Nervousness

Nervousness in material requirement planning systems is a phenomenon where small changes high level can create huge changes in a lower level perspective. It origins from uncertain demand, uncertain supply of components and different lot sizing algorithms optimizing lot size as new delivery schedules come with more accurate forecasts (Li & Disney, 2017). (Blackburn, Kropp, & Millen, 1985) The Wagner-Whitin algorithm is one well known solution to a dynamic lot-size problem given that future quantities are known but comes with implications. Many products today have complex BOM structures, it is large hierarchies of multiple components and sub-components, and the Wagner-Whitin algorithm optimizes all these hierarchical levels as they were independent of each other, which they obviously are not. (Carlson, Jucker, & Kropp, 1979) (Wagner & Whitin, 2004) (Tsay A. A., 1999)

With suppliers in the automotive industry that has signed QF-contracts regarding quantity, it allows for customers to change their delivery schedules if they stay within the total agreed capacity over the period. This leads to that the customers MRP system recalculates the required quantity every week to optimize their costs and is creating MRP nervousness, as the system always optimize with the latest most accurate information, (Tsay A. A., 1999) Carlson et al states that:

"There is a feeling that although the optimality of the solution provided by the Wagner-Whitin algorithm is valuable, its price is too high - that price being the cost of changing plans. Many managers would rather live with nonoptimal but stable plans." (1979)

The cost of nervousness is to be balanced against the cost of a non-optimal master production schedule to decide how much nervousness to tolerate. (Carlson, Jucker, & Kropp, 1979)

2.3.4 Rough cut capacity planning

The aim with rough cut capacity planning is to pinpoint key resources from the MPS and forecasts to requirements, key resources could be supplier capacity, labor and machine time depending on the company. (Jonsson & Mattsson, Manufacturing Planning and Control, 2009)

2.3.5 Capacity Requirements planning

When an organization is planning whether to expand their production or contract long term, it uses capacity requirements planning. Having too much capacity is costly and generates waste, but having just right amount of capacity could be a problem when the market demand rises unexpectedly. To have efficient long term forecast as well as a strategic business plan is crucial to plan capacity. The capacity of an organization is dependent on efficiency and utilization of its resources, which means that by producing more efficiently could rise capacity without the need for investing in new machines or staff. (Jonsson & Mattsson, 2009) A measure for how efficient a manufacturing operation is performed is overall equipment effectiveness (OEE) and is described in 2.3.6.

2.3.6 Overall Equipment Effectiveness

The formula for measuring OEE is based on three factors, which is quality, performance and availability.

EQUATION 2, OVERALL EQUIPMENT EFFECTIVENESS

$$Quality \times Performance \times Availability = OEE\ (\%)$$

Quality means how many items produced lives up to the standards of finished goods and how many is scrapped. Performance means the speed of the actual process divided by the theoretical maximum speed of the process, where cheaper machines might be slower than expensive high-quality machines. Availability stands for how much up-time the machine has and how much time for service and reparation it uses. A common problem is that investments in new machines have a theoretical much higher OEE but in the beginning before you get everything to run smoothly, OEE might be lacking. This is common when automating processes, before the robots are calibrated and optimized OEE might be much worse than with human manual manufacturing. The three factors of availability, performance and quality is often divided into the "six big losses". (Muchiri & Pintelon, 2008)

TABLE 3, THE SIX BIG LOSSES OF OEE

Availability	Performance	Quality
Planned Downtime	Minor Stops	Production Rejects
Breakdowns	Speed Loss	Rejects on Start up

2.3.7 Execution and control

2.3.7.1 Order release

Jonsson and Mattsson describes order release control as the order of which manufacturing orders will be released to the shop floor to be executed. What decides which one gets executed first is determined by what kind of release methods you use. When releasing orders, consideration must be taken to material supply and production capacity, to ensure material and capacity is available for the order. (Jonsson & Mattsson, Manufacturing Planning and Control, 2009)

2.3.8 Quantity flexibility contracts

Suppliers to OEM: s in the automotive industry do not create their own forecasts in the sense that they are not in contact with the end consumer. Instead, the information about orders is acquired using electronic data interchange (EDI) sent from OEM. There EDI:s together forms what is called a delivery schedule. However, on a long-term horizon forecast must be done. The relationship between the OEM and the supplier will pan out over a longer time period which allows for some unique opportunities. Since investments from the supplier side will have to be done in order to facilitate the OEM: s demand commitments is necessary. This commitment takes form as an agreed quantity over a longer time period. These quantities are then spread out over time. As supplier-customer relations in automotive supply chains requires flexibility and visibility, the use of quantity flexibility (QF) contracts have been put in play, where OEM updates their delivery schedules every week with the latest available information. The delivery schedules are often based of a 52-week forecast from the OEM how much they will order. When the OEM's forecasts are inaccurate, this leads to variations and uncertainty in these delivery schedules. (Huanng, Hsieh, & Farn, 2011) (Tsay A. A., 1999)

2.4 Sales and Operations Execution

Sales and Operations Planning is explained in 2.1.2 with the cover of Karlsson & Ragnarsson earlier work in the research project (2014) and literature has covered this topic well. (Grimson & Pyke, 2007) However, a connecting planning process called Sales and Operations Execution (S&OE) is not widely covered in literature and a recently explored subject.

Sales and Operations execution is in some literature also referred to as Demand Control. It is something that comes with the ability to receive more data, quicker. The stream of demand signals gets improved for every day and new tools is developed to collect and take use of the data. This brings up a demand for planning processes in companies. (Bower, 2018) Jeff Bodenstab writes about Sales and Operations Execution (here fore called S&OE) as the bridge between the S&OP and actual execution. What you plan for might not be the same as what happens. The task of S&OE is to compare actual demand to the forecasted demand, and then secure that production can produce. (Bodenstab, 2016)

Sarah Hippold at Gartner writes about the issue of many companies that see S&OP and S&OE as the same thing and the same process which could bring planning problems. S&OP should focus on 3-24 months and S&OE is process that should cover the near term, less than 3 months. She also writes that a good way to understand S&OE is like “the middleman that receives, interprets and forwards information between the operational and strategic levels”. (Hippold, 2019)

Elementum states that supply chains without a defined S&OE process have unrealized potential and deflated plans. They suggest the following S&OE loop to increase efficiency in operations in these four steps:

1. Make it easy for teams to capture supply chain incidents
2. Centralize incidents to facilitate weekly review
3. Collaborate across teams and partners to quickly resolve
4. Analyze root cause to prevent future problem. (Elementum, 2020)

Brian Hoey from Flexis pinpoints the most common pitfall in implementing a S&OE process is lack of visibility to the planners. The IT infrastructure needed to give the planners insight in each other’s processes, which is possible with enough data and if you can get out of the decision-making silos. (Hoey, Sales and Operations Execution 101, 2019) This is also one of the reasons that S&OE is a new topic, that it needs access to data. With the industry 4.0 era, it is possible to access much more data in real time to be able to implement a robust S&OE process. This was not possible 30 years ago. (Hoey, 2020)

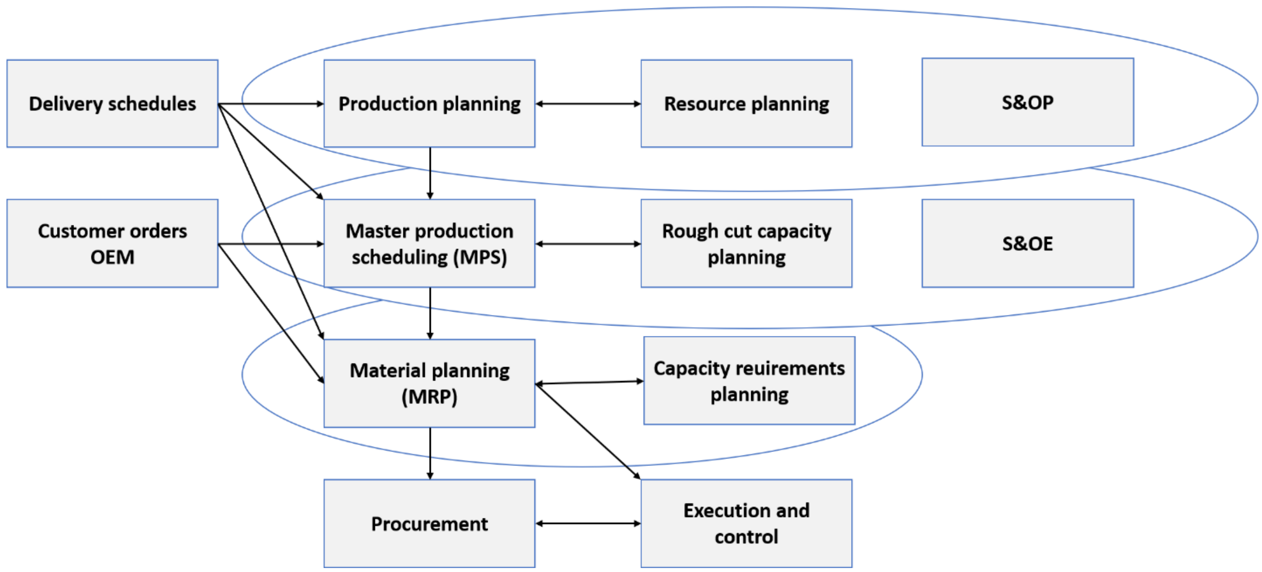

FIGURE 10, AN EXTENDED OPC FRAMEWORK INCLUDING S&OP AND S&OE

To summarize, many firms states the importance of having a 0-12 weeks planning process that is divided from the long-term S&OP process which should have a 3-24 months planning horizon. S&OE is supposed to support the MPS with forecasting, analyzing and problem solving. An illustration is presented in Figure 10, where the OPC framework from Jonsson & Mattsson (2009) is extended with S&OE to visualize its role and relationship to other planning processes and how it is closely linked to MPS. S&OP is covered by Jonsson & Mattsson and included in their literature in this framework and is not added by this research. S&OP is not shown in Figure 7 since focus lies on showing the links between the planning processes.

2.5 Literature background relationship to research questions

The operations planning and control framework from Jonsson & Mattsson (2009) divided in material and capacity handling is presented as it gives a view of the different supply planning processes covered in the report in RQ1 and RQ2. It shows how production planning is linked to master production scheduling and material planning. It also divides it in material and capacity handling processes which is covered in the report. Important concepts presented under the part operations planning and control is presented to increase understanding when presented in the report, the main concepts are OEE, MPS, MRP, Bill of material, QF Contracts and S&OE. These concepts is used in all research questions in the report.

The Odette report (2012) is presented as it gives an introduction to the FAI application that is a tool used in the research. The report from Karlsson and Ragnarsson (2014) gives an introduction to S&OP planning processes in the automotive industry and also introduces S&OP. S&OP is closely related to S&OE which is supporting RQ2, RQ4 and RQ5. A cause and effect study were conducted by Martinsson & Sjöqvist (2019) and is covering the same industry and is providing fundamentals for this research, mainly for RQ1. Their analysis is also supporting this analysis through cause of high or low FAI and WTS scores.

The KPI evaluation reports of Ekberg, Raju, Bahsson, & Jirholm (2019) and Jonsson & Kjellberg (2019) relates to RQ1 and RQ2 in terms of concepts like MAPE-profiles and key KPIs used in this report is originating from this literature. Measures and visualization related to RQ4 and RQ5 is also supported by this work. Ideas of combinations of bias and delivery schedule variations is coming from the report and presentations of this literature which is used in analysis and discussion chapters. It is also contributing to the forecasting part of predicting a dangerous scenario before it occurs.

Forecasting is also covered with literature from multiple authors (Gilliland, Sglavo, & Tashman, 2016) (Abolghasemi, Gerlach, Tarr, & Beh, 2019) (Viet, Behdani, & Bloemhof, 2018) (Barratt & Oke, 2007) to provide support for RQ4 and RQ5, where one part of improving supply planning performance is to forecast planning issues, to starting planning to handle the problems before they occur. Then different type of forecast methods and KPIs need to be covered and evaluated. Examples of forecast quality measurements covered is late variation, random variation, scheduled nervousness and systematic variation.

3 Methodology

This section describes the research approach, data collection, analysis and quality. Research approach describes the project process and briefly the methods needed to answer the research questions, what data that was needed and how it was acquired. Data collection describes the way data was collected, how the interviews were used and how they were shaped. Analysis describes the method of analysis and research quality describes why the report is valid and what risks that come with statistical insignificance.

3.1 Research approach

The approach chosen for this report is a mixed method approach that vary between a qualitative part and a quantitative part. The scope starts as broad and exploratory because the task is to find how the case company is affected by variations in delivery schedules. The qualitative part is necessary to get the in-depth knowledge of the case company's processes and the automobile industry's different standards. Another qualitative measurement the research needs is the feelings of the employees that handles the issues and how do variations in demand affect their daily work. How does the practical work of these business unit differ from literature? These processes, standards and feelings researched should be connected to each other and how effects of different changes in delivery plans affect them. The quantitative part of the study consists of mapping the capacity and flexibility of the production and material supply, to compare against forecasts and delivery schedules. To be able to visualize and estimate how variations in delivery schedules affect the case company, a conceptual model of the internal OTD and production process has been done. Parameters that the model have to consider is presented from a material supply and production capacity perspective. A simplified model of the production environment has been constructed in excel to visualize effects of variations and be able to measure costs of different scenarios. This in order to support the planners on how dangerous actual changes in delivery schedules might be.

Jonsson & Mattsson describes the trade-offs between forecast quality, capacity flexibility and inventory levels and this is illustrated in the Figure 11. (2009)

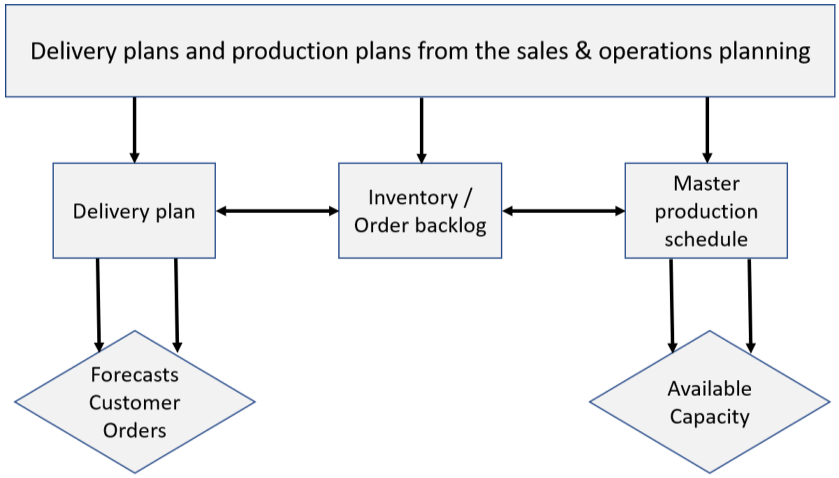

FIGURE 11, RELATIONS OF S&OP, CAPACITY AND DEMAND (JONSSON & MATTSSON, 2009)

The historical delivery schedules were given as input to the research project, which gives an image of the demand side. These are analyzed and a model to plot them in a chart after demand date is built in VBA and Excel. What is left after the demand side is the production capacity side, material supply and to locate the planning issues. Therefore, by discussions with the strategic supply planner, qualitative interviews with the customer planner, production planner and the material planner has been conducted. Interview with production managers from the production lines has also been conducted to get an idea of their decision points, their issues and how variations in demand is handled.

3.2 Data collection

The data collection process has followed the one illustrated in Figure 12. For the first phase, qualitative data collection is done by conducting semi-structured interviews with people connected to the issue at hand. (Munot & Bairagi, 2019) The main source being a representative at the supplier. This selection of concerned people is determined using the *Snowball approach* with a starting point at the supplier's contact person. The key to successfully conducting an interview using this approach is by the end asking whom may have more/new information concerning the topic (Easterby-Smith, Thorpe, & Jackson, 2015). Locating interviewees using the *Snowball approach* allows contact with relevant people and information in an environment unknown to the researcher (Munot & Bairagi, 2019).

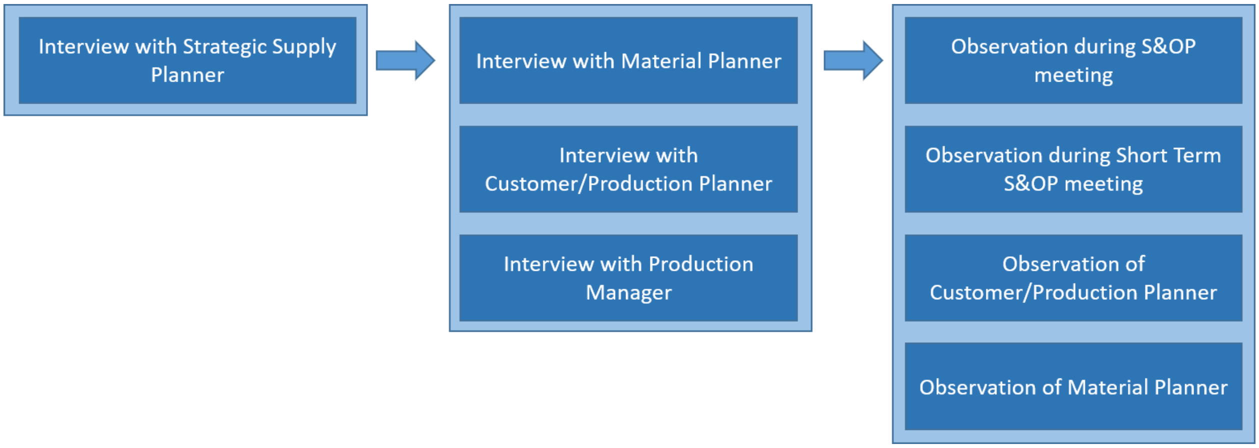

FIGURE 12, MODEL OF QUALITATIVE DATA COLLECTION THROUGH INTERVIEWS AND OBSERVATIONS

In order to solve the problem at hand, logically, an understanding of where the problem arises and identify the affected employees at the supplier is a starting point. The first step is to get a rough idea about the process of planning from both the material and capacity planning on all different horizons. The reference model for this is the one developed by Jonsson & Mattsson (2009) precented in Figure 7.

This rough idea was provided by the contact person at the supplier whose role is strategic supply planner. The interview with the strategic supply planner lead to information about the company, a rough idea of the planning process is collected and information about whom to interview next is collected. Once the simplified process of transforming orders to finished products had been established a better view of the involved personnel was clearer and crucial decisions points were established. With this information in mind the contact suggested interviewing the following personnel more thoroughly; Production planner, customer planner, Material planner and a production manager. The aim of the interviews is to establish the following; Responsibility, daily operations, how they experience and deal with the stated problem and limitations. Another aim with the planner interviews is to locate who spends the most time handling effects that comes from variations in delivery schedules. With this information, it was easier to understand the factors that affect the decisions which makes it easier to understand what visualization of information is valuable.

As the research approach partly have a set goal, the interviews conducted are be semi structured, as the research should be open to new areas of discussion with this employee at the supplier. The questionnaire is not static as everyone have their own area of concern and the study focuses on their actual planning issues. (Munot & Bairagi, 2019)

The research is also covering an exploration of production capacity which is done by interviews of the production managers as well as the strategic supply chain planner. The capacity and flexibility of each production line is to be found as well as the interlinkage between the production lines, with dependence and connections to raw material inventory. Do any of the lines share critical raw material and how do variations affect the production and decisions? As preconditions of the study is delivery schedules sent from customers to the supplier over a period, this data is secondary collected quantitative data. The other part which is unknown is production capacity and material supply policies, which is safety stock levels and inventory carrying costs.

Observations is conducted at the supplier as well where the researchers have observed during a long-term Sales & Operations Planning (S&OP) meeting and a short-term S&OP meeting, and the task is to get an image of what decisions is taken and issues the meeting cover. Another goal is to collect data about who attends the S&OP meetings (long term and short term). S&OP is described with definition in literature background. What horizon do they plan at and who participate? Further observations include sitting down with a material planner and a customer/production planner to try to map their tasks and decision points in their daily work. The purpose of observing is to find decisions taken that the planners them self might not be aware of, to link them together to find dependencies in the planning environment. The data from the observations include planning objects and decision points that is important for the work.

3.3 Analysis

Due to the mixed method approach of qualitative and a quantitative approach. The analysis is a comparison of the findings from the quantitative data and the qualitative data. The report has tried to find contradictions and alignments. The analysis process has been an iterative process where as soon as data is collected, it should be connected to the subject and analysis should be done simultaneously, to call upon further data collection as new knowledge is found. (Bryman & Bell, 2011)

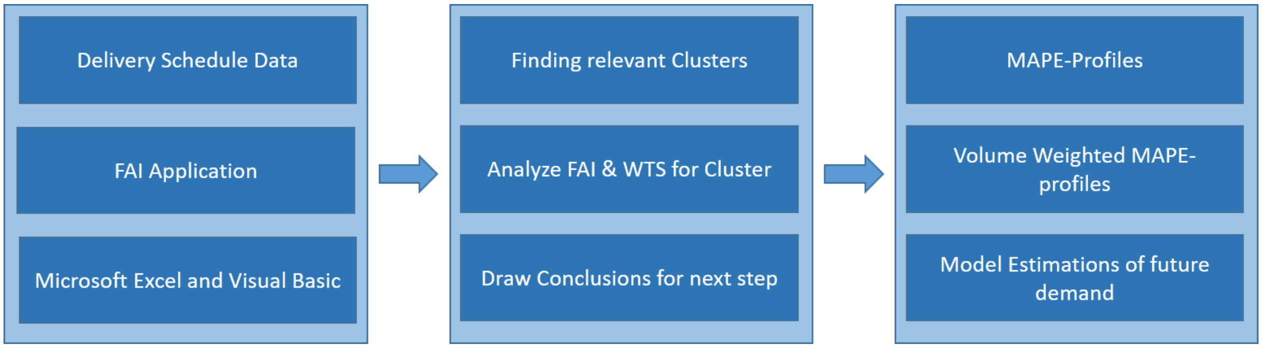

FIGURE 13, THE ANALYSIS MODEL FOR THE MIXED METHOD ANALYSIS

Within the frames of the first research question, clusters of demand variations are supposed to be found and analyzed according to how they relate to production capacity planning as well as material supply planning. To be able to analyze the flow through the supplier a simulation has been done. The two different planning areas has been analyzed individually and then linked together to how they affect each other. Which planner decides what and how does that affect other planners? Decision points has been mapped up and linked within the case company. Effects is analyzed to find answers to research question two and three, to find how variations in delivery schedules is affecting planning processes and production.

The research has connected literature of operations planning and control with the expressed feelings and issues from the different planning levels. Gaps has been searched for and contradictions or similarities has been evaluated. Proposed solutions to the problems of each planner respectively should be considered and problems and trade-off has been conceptualized. The quantitative data has been analyzed with Visual Basic, Microsoft Excel and the data visualization tool QlikSense. The data has first been validated, to come up with what variables that affect the data and what data points to neglect or remove. (Bhatia, 2018)

The aim of the analysis is to come up with ideas to support decisions for the planner, to reduce workload and stress and to improve decision-making for long term sustainability. This relates to research question four and five. This is a qualitative methodology of analysis as the decision supports planners in their way of thinking and making decisions which is highly subjective from planner to planner, and the analysis has been based on interviews of the planners from the case company, i.e. their subjective feelings of issues. Other planners in the same planning environment might have other issues that they need support for in their decision making. (Bhatia, 2018)

The analysis and discussion is also supposed to cover data measurement discussions, to evaluate how the data have been evaluated and present pros and cons about the measurement technique. All types of measurements have its positive and its negative sides and it is important to cover how and why the measurements have been conducted the way it has.

3.4 Research Quality

Validity is from Bryman & Bell defined as if you would conduct the study repeatedly, would you get the same results? (2011) This study has focused on a case company's specific demand data and is not supposed to represent the whole automotive industry. The methods used in this report is designed to give an accurate and detailed image of the case company in question. Further studies could be conducted to create a generic model and assumptions for the industry. A large amount of real historical data has been analyzed to try to find variations of demand information.

Trochim (2020) states four types of validity in research, which are internal validity, construct validity, external validity and conclusion validity. External validity is the degree of accuracy a generalization of the findings is. That means, if the study would be conducted at another company in another time, with other people, would you get the same result? (Trochim, 2020) This research is focused on a case company and generalization of the issues is excluded from this thesis and is up for further research.

Internal validity is to what extent the actions cause your outputs or results. There might be other causes that the researcher doesn't see that create the observations. (Trochim, 2020) One famous example of this is conceptualized as the Hawthorne Effect and comes from a study of productivity related to changes in environment lightning. Changes in workers environment where made and productivity increased, however, what the researcher didn't expect was that it was not the environment that increased productivity, but the fact that the workers were observed that caused the increase. (MBA Learner, 2018)

Construct validity is another type of validity related to generalization, but instead of comparing the research observations to other places, times and people, the observations and conclusion in practice is related to the conclusion in theory. Professor Trochim (2020) writes, “You might think of construct validity as a “labeling” issue. When you implement a program that you call a “Head Start” program, is your label an accurate one? When you measure what you term “self-esteem” is that what you were really measuring?”.

Conclusion validity is according to Trochim (2020) the most misunderstood type of validity but the most important one, where Trochim states, “Conclusion validity is the degree to which conclusions we reach about relationships in our data are reasonable.” Finding relationships in a world with very much noise is hard and it is common to think a relationship exist between two factors, but it doesn’t, or vice versa. (Trochim, 2020)

In this case company, the aim is to find tools for improving decision making. Testing and observing comes with the risk for the Hawthorne effect is present which might compromise the internal validity and has been a factor of concern in the analysis. Depending on what parameters you choose to include in the simulation, you will get different results, this is a limitation Roger D. Smith mentions as well as the availability of data. Boundaries and constraints of the simulation has been presented, and it is not supposed to represent the exact system. (Smith, 2003) In this case company, demand data for one year is available, which removes the possibility of analyzing seasonal patterns. This could be important as there are many different parts of the year where the forecasting might be harder, for example prior to vacation where volumes has been very low.

In the interviews, the interviewees have been asked qualitative questions to estimate how much percentage of their time they spend on handling variations. This brings multiple possible cognitive biases that can affect their answers, for example anchoring or availability heuristic. Anchoring means that people tend to depend heavily on numbers they recently heard when making judgments. If the interviewees are asked how much time they spend on handling variations, and they happen to see 5% somewhere in the room or on the screen, the answer might be closer to 5% than it should because 5% acts as an anchor.

(Tversky & Kahneman, 1974) Availability heuristic is a bias where people tend to overestimate or underestimate things, they do a lot and have a closely in memory. This could affect interviewees in the aspect of that when the interview topic is delivery schedule variation and they have talked about it, it is closest in memory and availability heuristic might occur and the data might be unreliable.

4 Empirical Results

4.1 Case Description

The supplier studied is a Swedish leading automotive technology company. It acts as a supplier to multiple major OEMs in the automotive industry. The supplier has production plants and engineering sites in Europe, US and Asia. The supplier has net sales of over $2 billion by 2018 and over 9000 employees.

To get a better understanding of the capacity limitations a modeling of Figure 14 that shows one of the products produced by the supplier.

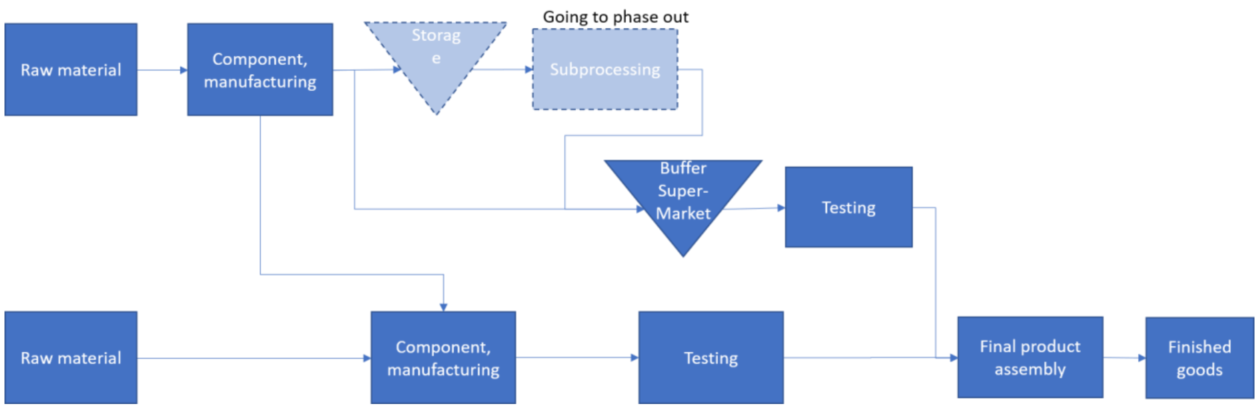

FIGURE 14, A MODEL OF THE PRODUCTION LINE OF PRODUCT A

4.1.1 The Planning Processes at the Supplier

The material planning goes as far ahead as 5 years before demand, based on sales forecasts which is revised quarterly. The upcoming 3 months is based entirely on Electronic Data Interchange (EDI) messages and after that it is only sales forecasts. However monthly meetings Is held with the sales business unit (BU) together with the strategic supply and capacity planners to produce new sales forecasts and compare the old one with current EDI according to Figure 15. (Strategic Supply Planner, 2020)

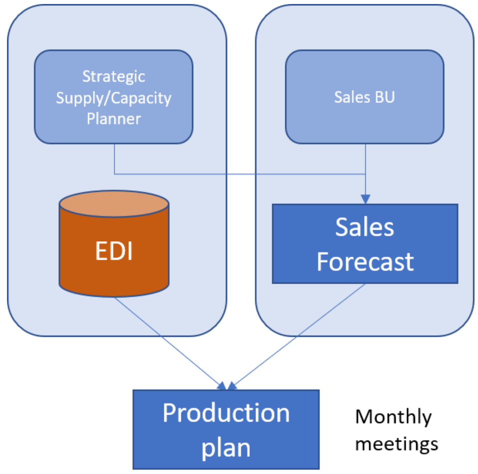

FIGURE 15, THE SALES FORECAST PLANNING PROCESS

The production planning is planned long term on monthly meeting called S&OP, where capacity and material is discussed on a horizon of 3-9 months. Delivery plans are shown either to year end or 12 months forward. Sometimes, more urgent matters are also covered on these long-term meetings, but it should not. Decisions are taken about high level production capacity reallocation questions; it is also about conducting a risk analysis when a production line is moved. The meeting is cross-functional and the participants on these long-term S&OP meetings are:

- CEO
- Head of logistics
- Logistic controllers
- Procurement
- Technical managers
- Production managers

On a weekly basis another meeting called 'short-term S&OP' is held discussing eight weeks prior to delivery with a purpose to update the production plan. On these meetings the production planner presents a plan for the following eight weeks. Also, decisions are taken about overtime. The production managers present the six last months of production including eventual backlog and actions that have been taken to manage the backlogs on respective production line. Discussion about OEE also occur. The participants on the short-term S&OP meetings are:

- Production Managers
- Production Planners
- Industrialisation Leaders

Area	Aggregation Level	Frequency	Horizon
S&OP	Business Area Level	Monthly	2-12 Months
Production Planner	Item Group Level	Weekly	8 Weeks
Planning Software	ArticleNo Level	Weekly	2 Weeks

FIGURE 16, THE PLANNING HORIZONS AT THE CASE COMPANY

To conclude, monthly long-term S&OP meetings occur to discuss a horizon of 2-12 months. Short term S&OP meetings occur weekly to discuss an 8-week production plan as well as a 2-week locked production plan. This is illustrated in a table in Figure 16.

4.1.2 Production and customer planning

This section contains a more detailed description of how the demand sent from OEM is translated in to manufacturing orders. The EDI:s are sent on a weekly basis and are automatically sent into the ERP system. Some customers demand is controlled by the customer planner before being released. What decides customers that are being controlled have multiple reasons with the main one being historically bad accuracy. This control process takes place once every week. Followed by this is the production planners' weekly update of the 8-week production plan. This is done using a production planning software where the production planner checks on an item group level to see if the demand is fulfilled. If not, capacity is allocated by opening production units until the desired days on hand is achieved. When this is done, the planning software optimized the manufacturing sequencing on item-level.

4.2 Interview Data

The purpose with the interviews was to find the effects of demand variations related to the supply chain planners daily work as well as what happens in the production line. Therefore, a selection of multiple material planners, customer/production planners and production managers where chosen and interviewed to find their decision points and problems related to demand variations. The customer and production planning are done by the same employees and therefor they have been covered during one section.

4.2.1 Interviews with Material Planners at the Supplier

The material planner will in this section be called the planner. The task for the planner is to supply production with raw material. The inventory with raw material and components is supposed to always cover 1 week of safety stock for all finished products. The MRP system sends a rolling 11 months delivery schedule to their suppliers with a mix of fixed orders and forecasts. When customer demand changes, the MRP changes its orders, however, sometime demand increases within the lead time of the suppliers, and then a decision has to be made if express delivery should be ordered or if the production planner are able to revise its plan to something for which materials is in stock.

A large part of the daily work is to identify items which will go out of stock. The current setup is if inbound deliveries would occur in two weeks, would we go out of stock with the predicted demand? If the company would they get a list of all those risk items. These items are then handled manually, and two questions are asked:

1. Does the system not see inbound deliveries that already is planned?
2. Ask suppliers for more material with express deliveries

The material planners are also handling messages from suppliers when they want to notify about supply problems that will cause delays or cancelled shipments. Then decisions must be made to purchase from other suppliers if the material is critical. When asked how much time is spent managing the issues originating from variations in delivery schedules the answer was on average 40%. The planners feel powerless because of skewness in power balance. Often both the customers and tier 2 suppliers have more power than the supplier in question, which sets them in different position when it comes to negotiation. The importance of the customer is too high which limits the supplier's room for negotiation. The supplier is also not the largest customer to their tier 2 suppliers, which brings problems with negotiation on that end as well.

When a change in a delivery schedule occurs that demands more material, the process to handle it is as follows:

1. Check internally on the logistics department on the supplier if this demand is correct and if it is something that could be done internally to handle this material shortage.

2. Ask the tier 2 supplier if they can send their shipments earlier or send more material.

3. Ask other production plants of the supplier if they have extra material to share.

4. Turn to the procurement department at the supplier to see if they can purchase it from another tier 2 supplier.

5. Go back to the production planner and discuss about the situation.

4.2.2 Interviews with Customer/Production Planners at the Supplier

The customer and production planner are here for referred to as the planner in this section. The delivery schedules from customers are received in an ERP system through EDI messages. With that data, the production plan is set with 8 weeks horizon and is updated every week on a rolling schedule. The production plan also includes 2 weeks contracts which is supposed to be frozen. The contracts are set to total quantities, so the customer can switch between products within the quantity. However, this is not desirable as two products could consist of different raw materials which will affect the material planner if components are not in stock. When a change like this happen, the planner will have to communicate with the customer as well as the material planner. Does the customer really need the product so early or do they have a safety stock they could use instead, or are the material planner able to order the components earlier at a reasonable cost?

However, some items have the same components, but they are manufactured different in the production line. Then a change will not affect the material planner, but the production will notice the changes. The planner releases the production plans weekly, which means that the production never sees individual items further away than 1 week. Changes between items after 1 week will therefore the production never notice.

To find deviations in demand, the ERP system notices when new delivery schedules deviates too much from the previous and alerts the planner about the variation. The supplier is using a deviation model based on % of quantity that changes and time to delivery, the further away from delivery, the larger deviation is accepted before the deviation is caught by the ERP.

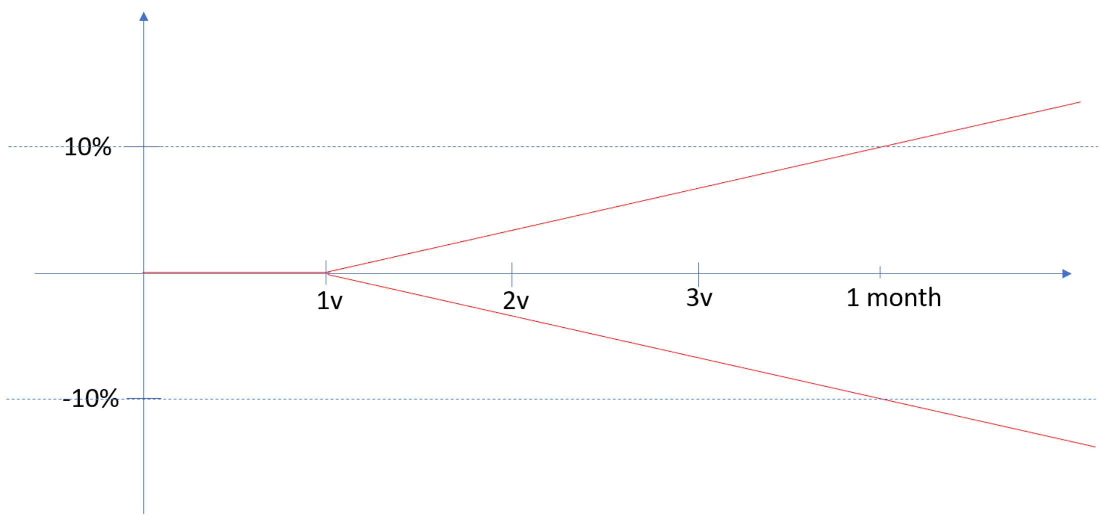

FIGURE 17, THE CURRENT DEVIATION MODEL FROM THE CASE COMPANY

4.2.3 Interviews with Production Managers at the Supplier

The production managers have responsibility of the staff at the production lines and to meet production targets set by the short-term meetings of 8 weeks planning horizon. The production managers have daily communication with production planners to follow up daily goals and discuss eventual action plans if not. They also attend the weekly short-term S&OP meeting to discuss the two-week contracts set by the planners, and one week into the contract they follow up the past weeks progress. The production managers have a time horizon of 8 weeks planning to decide whether they should hire extra consultants and educate or if they should reduce some staff.

Decisions of overtime is also taken on the weekly S&OP meetings but is also decided daily depending on when the variation occurs. The absolute worst customer variation according to the production managers is when production rate is reduced or moved further away in time. Then they must reduce staff and end consultant contracts. Hiring new people affect OEE a lot as they have a learning curve and will not have the same experience as the trained staff have. According to the production managers, the actual capacity looks like Figure 18 when production rate is moved down and then up again, due to the learning curve of new staff.

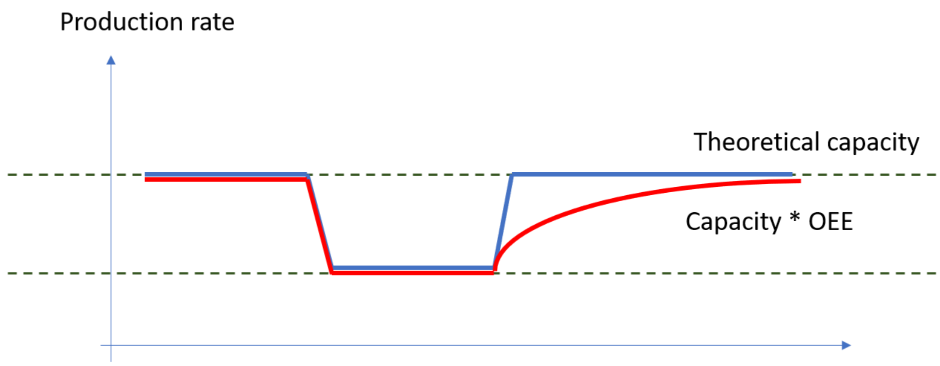

FIGURE 18, ACTUAL PRODUCTION CAPACITY AFTER VARIATIONS IN PRODUCTION RATE

The availability is something the production managers can affect, and it is not only the learning curve of the staff, it also depends on how you get the machines to run as smooth as possible. To get technicians to faulty machines as soon as possible is an important factor to increase the availability.

Another problem with demand variations is that some for the customer interchangeable products (Product A and Product B), where Product A consists of twice as many subcomponents as Product B. The subcomponents are also produced inhouse and a change between these two might of course affect the capacity of the production line of the subcomponent. They also differ in cycle time and which production lines that can produce them. Product B can be produced on all lines, but Product A only on 2 of 4 lines.

The production managers state that OEMs can help them to increase capacity and shorten lead times from the suppliers, due to that OEMs have more power than the supplier itself. One example of this occurring is with electrical components. One supplier for the case company has a revenue of over \$200B, the case company has \$2B and one of the customers has a revenue of over \$170B. This makes the case company just make out 0.5% of the total value of the chain.

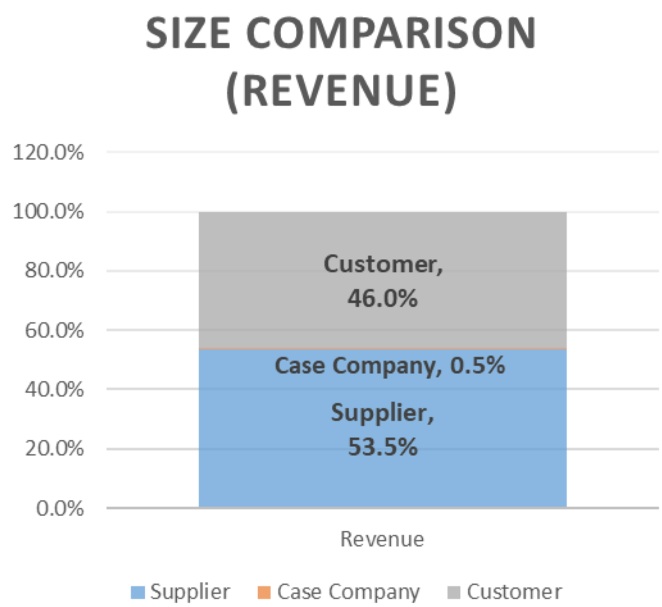

FIGURE 19, SIZE COMPARISON BETWEEN THE SUPPLIER, CASE COMPANY AND THE CUSTOMER

When the case company asks their supplier to shorten the lead time, the suppliers answer is usually that it is not possible. However, if the customer is asking the supplier to shorten the lead times for the case company, then the chances of a shortening is higher according to the production managers.

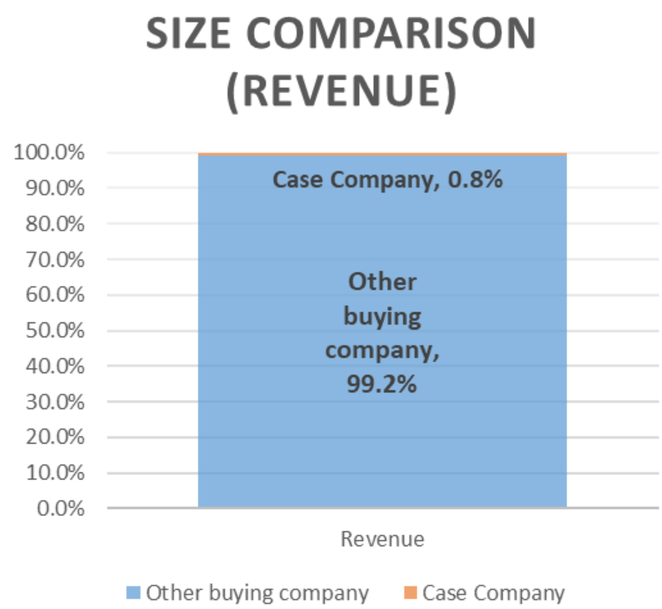

FIGURE 20, SIZE COMPARISON BETWEEN TWO BUYING COMPANIES OF THE SAME SUPPLIER, WHERE ONE OF THEM ARE THE CASE COMPANY

Another thing that was mentioned was the size of the competitors that also buys components from the case company's suppliers. "As a supplier with this type of addressable market. Which customer would you please and which customer would you prefer to lose?" Is a question that is mentioned during interviews to clarify the dominance of the buying competitors. The purpose of Figure 19 and Figure 20 is to show a size comparison of three companies that act within the supply chain. The visualization is not a visualization of revenue within the supply chain, but company size and that the case company is small in comparison to their customers as well as their suppliers.

The decisions that comes from the production managers is what they are going to produce and when. The production planners come up with suggestions of a plan and the production managers accepts it or not. It is the production managers that know what their staff and machines are capable of.

The biggest problem with production occurs when the demand is just on the border between two different shift levels. It is too high to have the lower level, but it is very expensive to move up to the higher shift level. This results in stress to not be enough staff with no margin of safety or almost overstaffed if the production moves up a shift level.

5 Analysis

The analysis is divided into four parts, the first part is related to forecast accuracy and biases in delivery schedules from the customers. The first part relates to RQ 1, 2, 4 and 5. The second part is related to a model for handling variations in delivery schedules and is related to RQ 2, 3, 4 and 5. The third and fourth part of the analysis covers economic and social costs respectively, related to changes in delivery schedules and is related to RQ 2 and 3.

5.1 Biases in delivery schedules from the Suppliers customers

Related to RQ1, to locate where the perceived problems from the planners might come from and how different customers' delivery schedules vary, delivery schedules were analyzed in terms of forecast accuracy and bias. As a start the products were clustered into item groups, where all items like each other were clustered to one item group. All item groups from the case company with available FAI data over the period of 2019 where included in the study. In some cases, items in the same item group go to different customers. In these cases, a total FAI and WTS is presented as well as for the individual customers, to be able to find differences between them. All item groups shown in Figure 21 shows a pattern of overestimation, and its only in Item group H for two customers, that underestimation occurs.

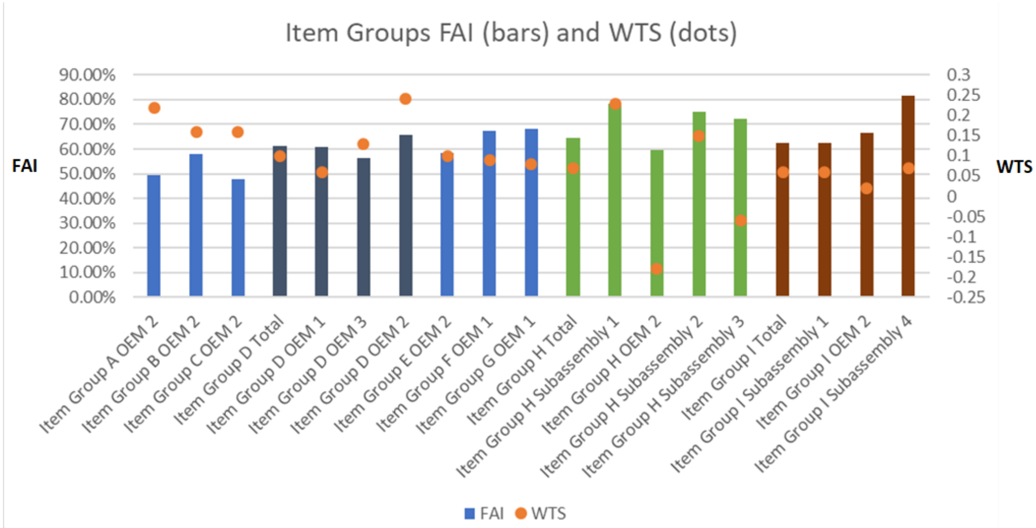

FIGURE 21, % OF AVERAGE FAI AND WTS (OVER OR UNDERESTIMATIONS) IN THE HIGHEST VOLUME ITEMS FROM AN AVERAGE OF 2W, 4W AND 6W PRIOR TO DELIVERY

As Figure 21 and the Table 4 shows, 5 of the 6 worst FAI averages belong to OEM 2, and 4 of the 6 best FAI averages belong to Subassembly companies to OEM 2.

TABLE 4, ITEM GROUPS FAI AND WTS SORTED BY FAI, LOWEST TO HIGHEST

	FAI	WTS
Item Group C OEM 2	47.70%	0.16
Item Group A OEM 2	49.30%	0.22
Item Group D OEM 3	56.20%	0.13
Item Group B OEM 2	58.10%	0.16
Item Group E OEM 2	58.40%	0.1
Item Group H OEM 2	59.70%	-0.18
Item Group D OEM 1	61.00%	0.06
Item Group D Total	61.40%	0.1
Item Group I Total	62.50%	0.06
Item Group I Subassembly 1	62.50%	0.06
Item Group H Total	64.70%	0.07
Item Group D OEM 2	65.90%	0.24
Item Group I OEM 2	66.60%	0.02
Item Group F OEM 1	67.30%	0.09
Item Group G OEM 1	68.20%	0.08
Item Group H Subassembly 3	72.20%	-0.06
Item Group H Subassembly 2	75.20%	0.15
Item Group H Subassembly 1	78.20%	0.23
Item Group I Subassembly 4	81.60%	0.07

If the data is sorted by WTS instead, 4 of the 6 customers with largest overestimations, it is OEM 2. OEM 1 always lie around +-0.1 WTS. OEM 2 also have some item groups (E and I) where they manage to stay within +-0.1 WTS.

Table 5, Item Groups FAI and WTS sorted by WTS, highest to lowest

	FAI	WTS
Item Group D OEM 2	65.90%	0.24
Item Group H Subassembly 1	78.20%	0.23
Item Group A OEM 2	49.30%	0.22
Item Group C OEM 2	47.70%	0.16
Item Group B OEM 2	58.10%	0.16
Item Group H Subassembly 2	75.20%	0.15
Item Group D OEM 3	56.20%	0.13
Item Group E OEM 2	58.40%	0.1
Item Group D Total	61.40%	0.1
Item Group F OEM 1	67.30%	0.09
Item Group G OEM 1	68.20%	0.08
Item Group H Total	64.70%	0.07
Item Group I Subassembly 4	81.60%	0.07
Item Group D OEM 1	61.00%	0.06
Item Group I Total	62.50%	0.06
Item Group I Subassembly 1	62.50%	0.06
Item Group I OEM 2	66.60%	0.02
Item Group H Subassembly 3	72.20%	-0.06
Item Group H OEM 2	59.70%	-0.18

Conclusions by this data is that FAI and WTS is related to customers rather than Item groups, and that some OEM manages to hold better FAI and WTS than others. This is interesting as the OEMs have a larger total volume than others and OEM 2 have a higher volume than OEM 1. Martinsson & Sjöqvist (2019) concludes that higher volume customers generally manage to have a better FAI-score than lower volume customers. This is in line with theory of mean absolute percentage deviation (MAPE), as the MAPE value tend to be unstable and unproportionally large with low volume items, as the reference demand quantity is closer to zero. This report shows the opposite, low volume customers have a better FAI score than high volume customers, and of OEM 1 and OEM 2, OEM 1 has a lower volume but better FAI-score. This implies that the differences in FAI scores is related to customers and not item groups.

5.1.1 The Supply Planner workload related to customer demand variations

Related to RQ2, how variations in delivery schedules affect the supply chain planning process, the supply planners at the case company was asked to estimate how much of their working day that is spent on handling demand variations from changed delivery schedules of customers. The standard activities of the material planner that are generated from variations is described in section 4.2.1. The material planner states that their main task is monitoring, meaning reacting for variations and changes. If plans always were perfect, and no errors occurred, the system could basically work on its own. It is not only changes in delivery schedules that is included in monitoring, it is also handling system errors and deviations from the normal. The answers were different between planners and the average answer from the material planner at the case company is 40% of their time. From the customer and production planners, the average time spent was 33% of their time. The customer planner that have a focus on OEM 2 spends on average 50% of their time handling variations and the customer planner that have a focus on OEM 1 spend 15% on average handling variations in demand.

5.1.2 MAPE Profiles of the Case company

Related to RQ4 and RQ5, how measures and visualization could be used to improve planning performance and support decision-making in daily operations, it is important to discuss what measurements that is relevant to use. The average FAI from 2, 4 and 6 weeks before delivery gives an estimation of forecast accuracy from the customers. Another way to include much more data is to use MAPE profiles of the items. An issue with measuring the items forecast accuracy is that different customers might order the same item and as the conclusion is that customers are affecting FAI and WTS, that data might be irrelevant (due to that other customers inaccuracy is included in the items total MAPE-profile). However, by comparing the customers MAPE-profiles, the planner would get an image of the customers general inaccuracy. But the customers average inaccuracy would neglect low volume products, and as high and low volume products might have different MAPE-profiles, it is of interest to look at both (low- and high-volume products). Also, MAPE-profile might show bad data on single items because of switching of items between a single item group. It could also show irrelevant data due to the lack of data. The planners plan on an 8-week horizon on an item group level and switching between items is not relevant. Therefore, MAPE-profiles of item group level is interesting, that can neglect changes within the item group.

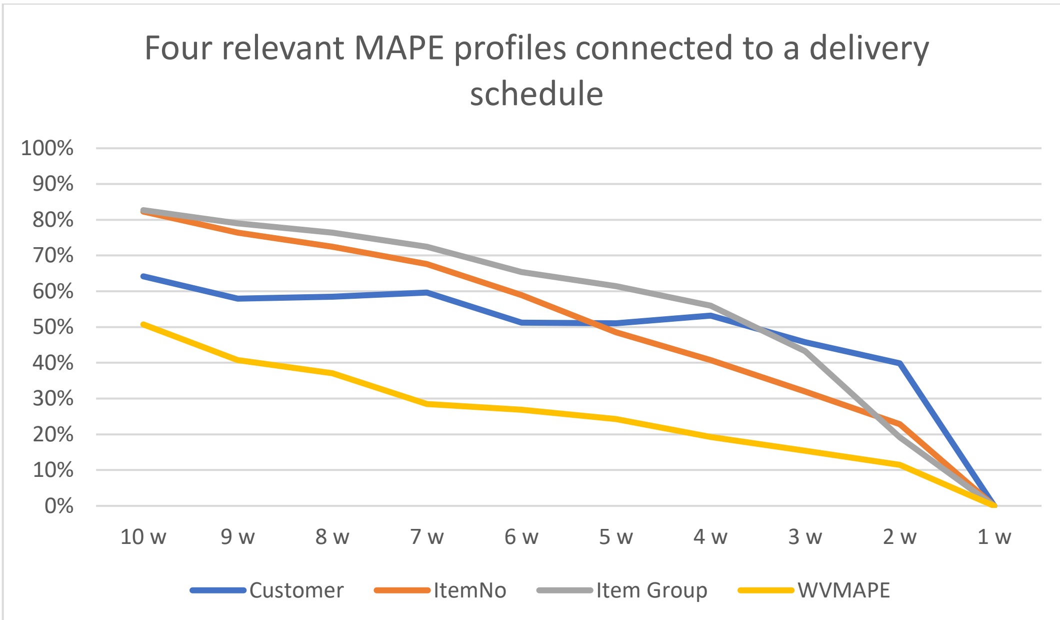

FIGURE 22, FOUR MAPE PROFILES CONNECTED TO ONE ITEM

Figure 22 consists of four different MAPE profiles. The blue profile, which is named "Customer" is defined as an average MAPE profile from the customer. The sum of the demand of a given week from the customer is compared to the sum of the lags from the given week. The average of all weeks generates the "Customer" MAPE profile. The orange profile, which is named "ItemNo" (which is the same as item) is defined as an average MAPE profile for the item. The sum of the demand of a given week from the item is compared to the sum of the lags from the given week. The average of all weeks generates the "ItemNo" MAPE profile. The grey profile, which is named "Item Group" is defined as an average MAPE profile for the item group. All the MAPE profiles for the items within the group is generated as "ItemNo" and an average of that profile is then calculated to give the "Item Group" MAPE profile. The yellow profile, which is named "WVMAPE" is defined as the Item Group seen as one unit. The sum of the demand of a given week from all the items in the item group is compared to the sum of the lags from the given week from all the items within the group. The average of all weeks generates the “WVMAPE” MAPE profile.

As is seen in Figure 22, let say you receive a delivery schedule from a customer about an item. The item in question tend to change just above 20% 2 weeks prior to delivery. However, the customer that sent this delivery schedule usually change 40% 2 weeks prior to delivery. At the same time the volume weighted MAPE profile for the product is just 10%, which might indicate changes within the product group which is not dangerous for the supply chain planners.

5.1.2.1 Volume weighted MAPE Profiles within clusters of items

The usual way to calculate the total MAPE-profile for a cluster of items is to calculate a MAPE-profile for every item and calculate the average profile for the cluster of items. If you want to weigh the importance of the item after volume(quantity of items), but also remove the uncertainty within the product group, then you can summarize the total demand for all items within the item group before you calculate the MAPE-profile. This leads to volume weighted mape profiles, and a mape profile that does not consider changes within the item group between items. This is useful when you only plan on an item group level on these horizons. The difference between the normal mape profiles and the volume weighted is shown below in three figures, Figure 23 and Figure 24, where you can see examples from the case company, where the volume weighted mape profile lies above and below the same level as the normal mape profile.

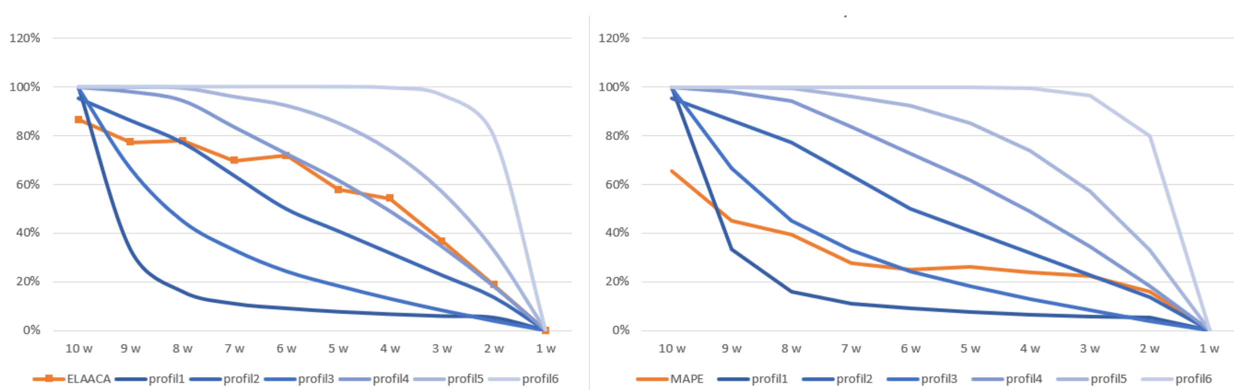

FIGURE 23, ITEM GROUP X, A VOLUME WEIGHTED MAPE-PROFILE (RIGHT) WHICH IS LOWER THAN THE AVERAGE MAPE PROFILE (LEFT)

Figure 23 shows a graph of the expected MAPE-profile, which is lower than the average MAPE profile. The reason why this is expected is that MAPE-profile tend to escalate with lower quantities and the volume weighted MAPE-profile is calculated on a way that always give higher quantities than the regular profile. Another reason why this is expected is that high-volume items represent a larger proportion of the volume weighted and the large volume items is expected to have a lower MAPE-score than the low volume items. A third reason why the volume weighted MAPE-profile is lower than the regular is that changes within the item group is neglected and not visible, which decreases total amount of changes in the volume weighted MAPE-profile.

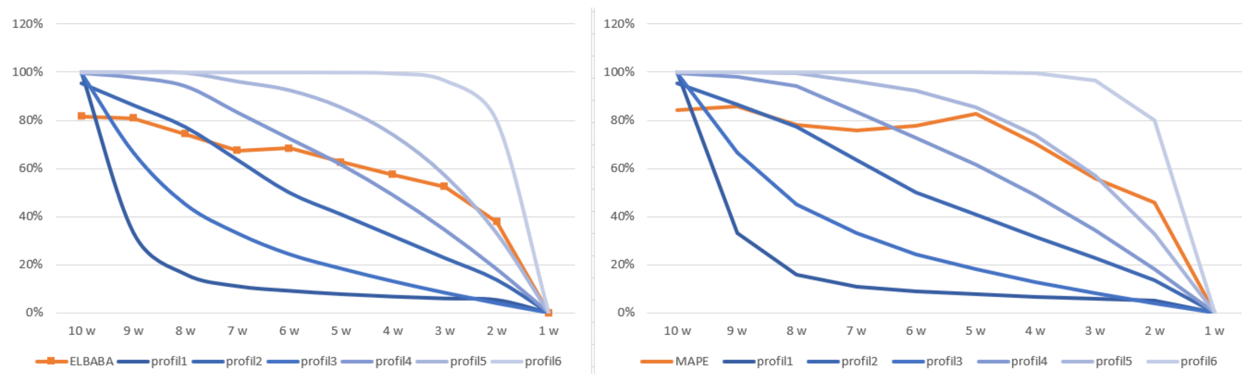

FIGURE 24, A VOLUME WEIGHTED MAPE-PROFILE (RIGHT) WHICH IS HIGHER THAN THE AVERAGE MAPE PROFILE (LEFT)

Figure 24 shows a graph of a volume weighted MAPE-profile for item group Y that is generally higher than the regular profile which is not expected. Because this profile is unexpected, a cause was desirable. To be able to understand cause, the underlying items had to be analyzed. The item group in question consists of only 4 items, which is one probable cause that creates the MAPE-profile, the lower number of items, the more the MAPE-profile is expected to behave like a single item. The item group with the greatest number of items consists of 40-50 items and the average item group consists of around 10-20 items.

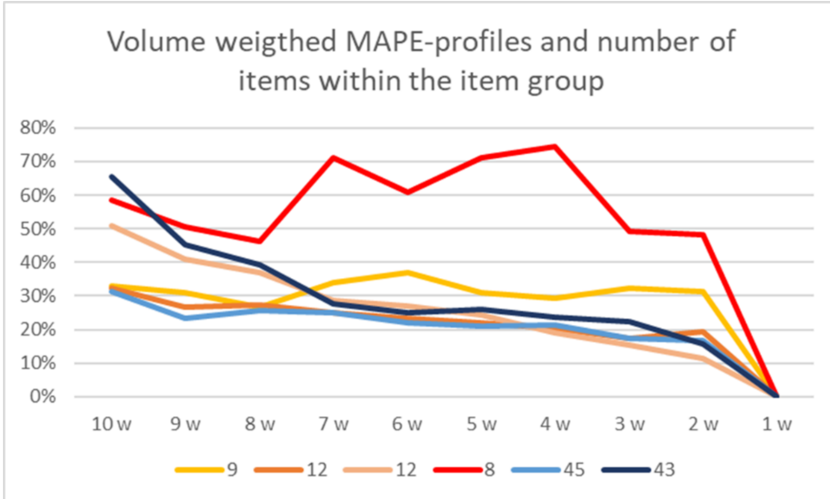

FIGURE 25, HOW NUMBER OF ITEMS WITHIN AN ITEM GROUP AFFECT THE ITEM GROUP VOLUME WEIGHTED MAPE-PROFILE

Figure 25 shows volume weighted MAPE-profiles of six different item groups, and the legends tell how many items it consists of. It does not tell anything about total volume or quantities of the item group. The item groups chosen for this comparison is all item groups that gives reasonable mape-profiles. What can be seen is that the two item groups with lowest number of items (8 and 9) is having the highest volume weighted MAPE-profiles from week 7 to week 1. The other four item groups that ranges from 12 to 45 items is similar and no clear pattern could be seen. From week 8 to 10, no clear pattern could be seen either.

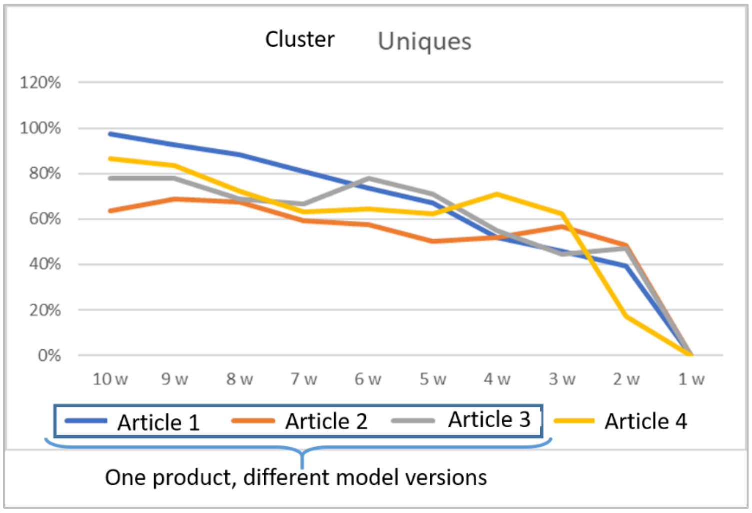

FIGURE 26, A GRAPH OF THE INDIVIDUAL ITEMS MAPE-PROFILES WITHIN THE ITEM GROUP Y

The individual items of the item group Y's MAPE-profile were plotted into a chart and they all are similar. Note that three of four items are basically the same items but different model versions. Three different model version might imply that these items have been phased in and out within the year (the data available is from one year). The quantity over weeks for the items within the item group Y was plotted to illustrate whether the products are phased in and out.

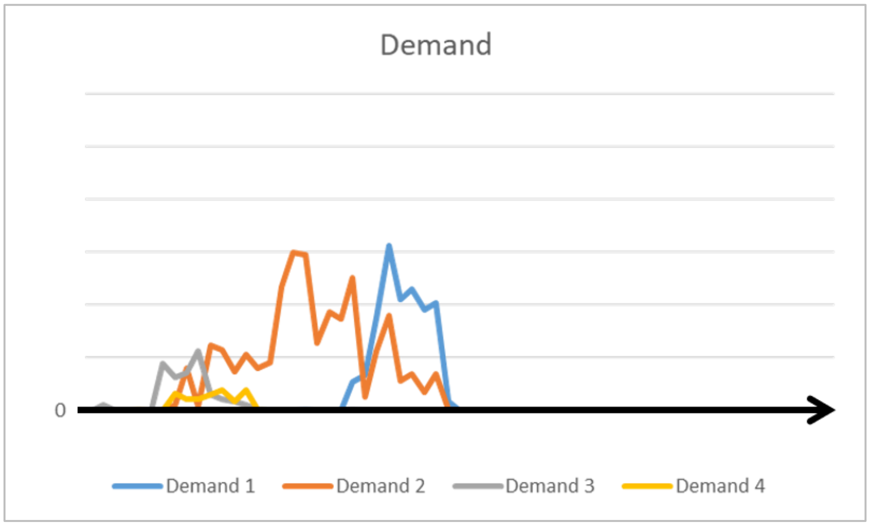

FIGURE 27, A GRAPH OF THE DEMAND OF FOUR ITEMS WITHIN AN ITEM GROUP

The demand for item 1, 2 and 3 within the item group Y, is clearly phased in and out during the period. Some overlapping occurs from both 1 to 2 and from 2 to 3. A hypothesis from now is that the total demand for all products should be even over the period, therefore the total demand was plotted as sum of all quantities within item group Y in Figure 28.

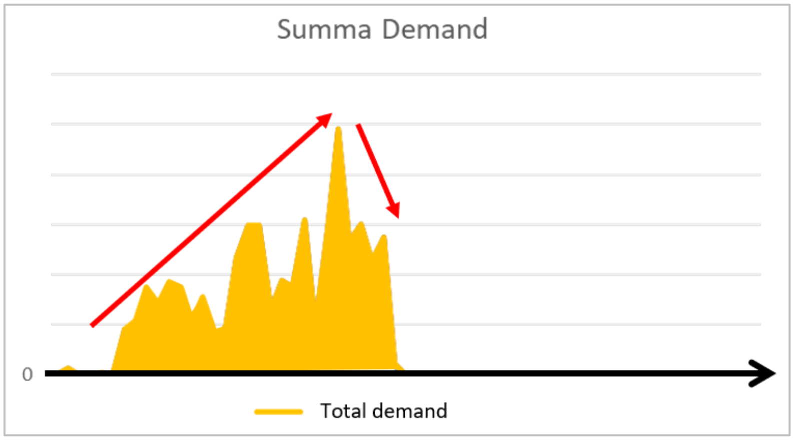

Figure 28, a graph of the total demand of the products within the item group

What is seen in the Figure 28 is that it is not an even demand over the period and the whole item group have a steep increase in volume at the beginning of the period to what seems to be a total phase out of the item group Y. This uneven demand and uncertainty around the phase in and out could be other causes for the unexpected MAPE-profile of the item group.

A follow up interview was conducted with the strategic supply planner regarding the odd demand patterns observed in Figure 28. The planner states that this odd demand probably relates to missing data in the delivery schedules. The sharp drop of demand indicates this and that the demand further weeks are zero. What is interesting is that even with zero demand, it should not affect the MAPE-profile as the results will just cancel out and is not adding any quantities to the final MAPE-profile. The sharp drop, however, could contribute to a faulty MAPE-profile if some data is missing. This also points out the importance of data validation and that data never is perfect and always is a subject of human interactions.

5.2 A model that describes dangerous variations in delivery schedules

Related to RQ4 and RQ5, how visualization could support decisions-making and improve planning performance, a simplified model of the production flow of the case company has been drawn. By building a model that looks like Figure 29, disturbances in the production flow could be noted and visualized continuously as delivery schedules changes are received. A change in the delivery schedules in the ERP-system is triggering material requirement, inventory levels, production plans and customer order handling, and if either one lacks capacity the respective box should light up red.

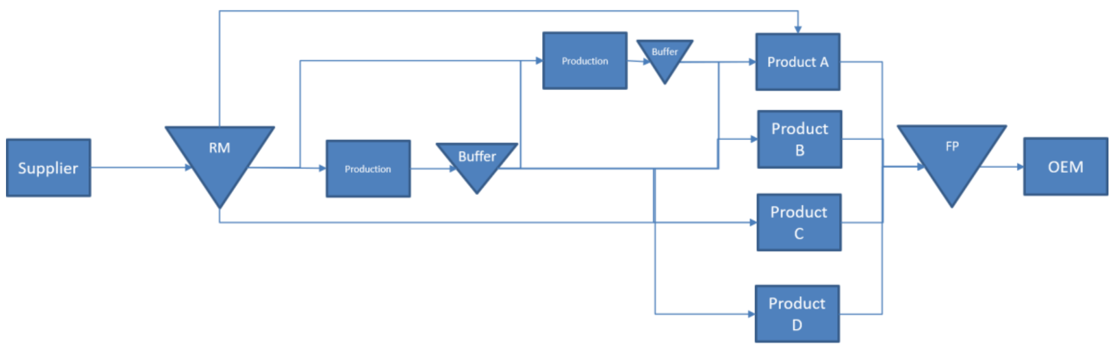

FIGURE 29, A MODEL OF THE PRODUCTION FLOW WITHIN THE CASE COMPANY

5.2.1 The mechanics of the model

The model is divided into four different object groups; Finished product (FP) manufacturing, semi-finished product (SFP) manufacturing, material supply and buffers. The manufacturing of finished products is driven by demand from OEM but is building towards buffers, like the case company. The manufacturing order for FP is translated into demand for SFP which in turn creates demand for material.

The object groups FP and the SMP demand needs to be translated in to manufacturing orders. This process is what literature refers to as master production scheduling (MPS). Factors that needs to be taken into consideration is production capacity and material availability. The production capacity side of the problem is handled in the following way; First, if the inventory is bigger than the goal inventory this gap is removed and the demand for the next week is reduced accordingly. The second step is to cheek the demand for eight weeks ahead and see if there is any free capacity for each corresponding week. If some demands for certain weeks is greater than the max capacity a check weather earlier week (before due date) have free capacity is done. Third, if the buffer goal is higher than the actual inventory when the current weeks demand has been fulfilled, the free capacity is used in order to meet this goal. The material side is planned in a similar way but the Leadtime from supplier is taken into consideration. Meaning, the manufacturing orders can't be changed within the Leadtime.

At the case company the buffers are only used in order to deal with pickups being once a week. So, they are therefor set to deal with a fixed goal in days on hand. All inventory over this fixed goal is considered excessive. The demand that is used when calculating this is the average for the next eight weeks.

5.2.2 Model visualization

In order to draw conclusions from the model, the problems that occur when using different demand patterns could be visualized. This was done by creating a simple dashboard that lets the user put in planning parameter in the yellow boxes and then step through the year, week by week. For each week the status of the system is given in the gray boxes. In order to show where problems arise in a convenient way, below the set up and status fields there is a simplified representation of the production. If the production capacity isn't enough to meet the demand but the buffers makes it possible to meet demand the box has been highlighted in yellow. If the buffers are not enough and backlog is created, they have been highlighted in red, which could also be considered as overtime.

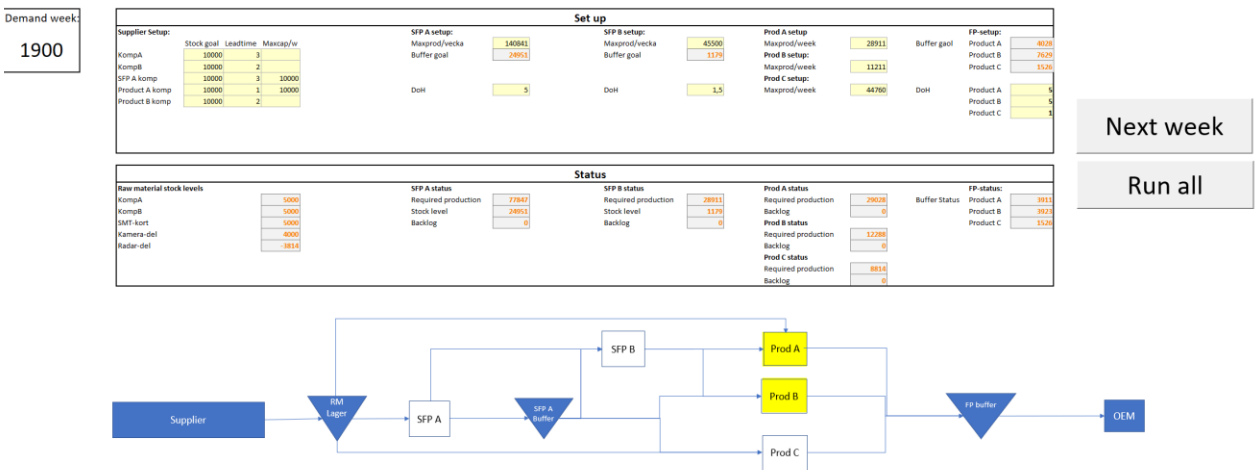

FIGURE 30, AN EXAMPLE OF A DASHBOARD CONTROLLING THE PRODUCTION MODEL

If deeper understanding is needed the datapoints for each week is stored and can be presented in different graphs depending on what the issue at hand is. An example of this can be seen in Figure 31 below.

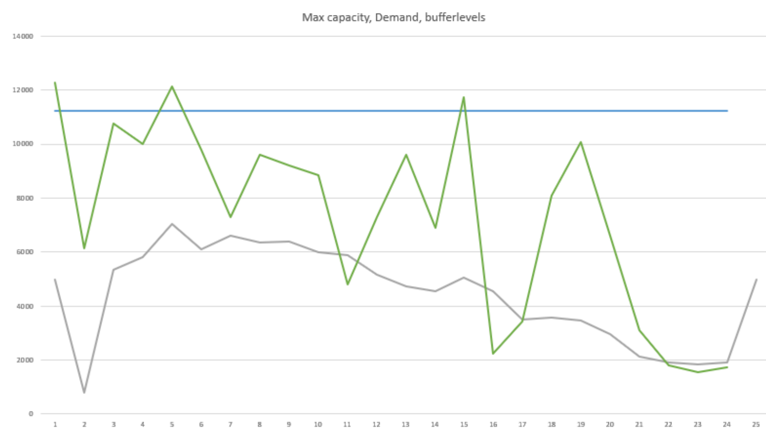

FIGURE 31, AN EXAMPLE GRAPH GENERATED BY THE MODEL OF CAPACITY, DEMAND AND BUFFER LEVELS

5.2.3 Scenarios the model will have to consider

Related to RQ3, how variations in delivery schedules affect the production process and material handling process. From the interviews with the production managers and supply planners, it is concluded that different scenarios affect the production capacity and material handling process differently. These different scenarios are presented in this section and how they affect the case company. Different scenarios could be used to trigger alerts to the planners, to handle the changes in delivery schedules. Instead of having alerts about a variation in demand as Figure 17 is showing, the alert should be marked as dangerous or not. Whether the change in demand is dangerous or not depends on the context. The report has found three different scenarios related to production capacity and a change of equal size but in three different contexts visualized in Figure 32.

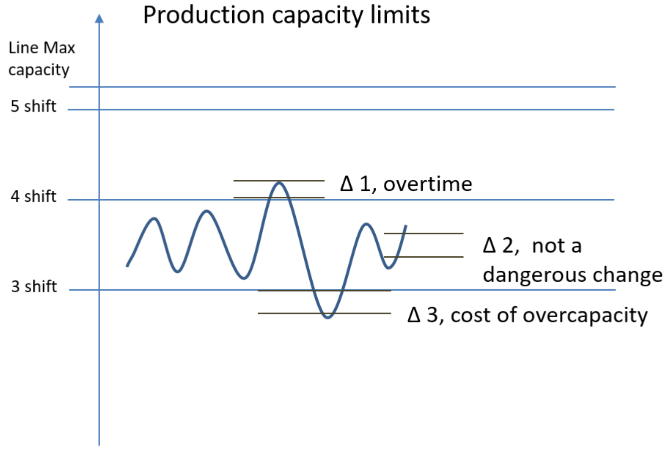

Figure 32, 3 different scenarios of a demand change and production capacity

The first change, $\triangle 1$ in Figure 32 is a rise in quantity which leads to capacity shortage at the given shift level. This leads to overtime at the line which brings a higher cost. The second change $\triangle 2$ is a change in demand, up or down, in the middle of shift range. If the material is not an issue, this is not a dangerous change in demand, and should not trigger an alert for the planner. The third type of change, $\triangle 3$ is a revision down where you go below the level of needing four shifts and you have a lot of overcapacity which brings a cost. This needs to be alerted to cancel material and replan staff.

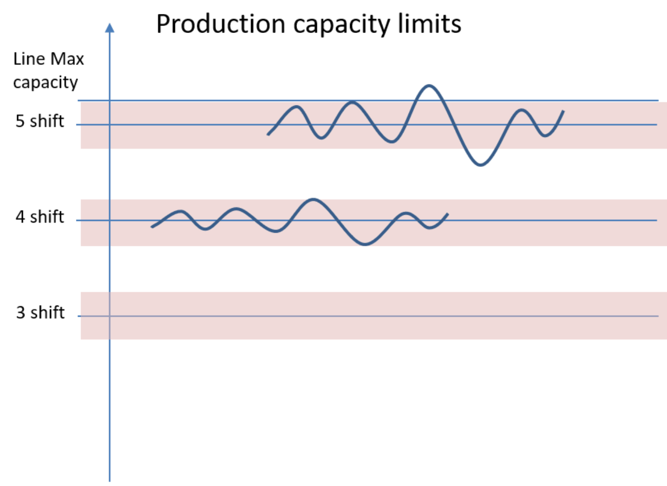

FIGURE 33, AREAS OF DEMAND WITH HIGH STRESS FOR THE PRODUCTION

Another scenario of concern is when the actual demand levels lies just in between two shift levels visualized in Figure 33. Then the production managers will feel a stress of having not enough capacity on the lower shift but having too much capacity if moved up a shift. This is an issue and when the demand lies around these intervals, then customer deviations must be closely monitored, and smaller changes must give alerts to the planners. Frozen plans are also an option to relief stress for the production. When working on a 5 shift, it means you only have 4 hours empty per week, and the production line runs very close to its theoretical maximum capacity. Every revision upwards in demand at these levels must be alerted, no matter how small they are. The model is supposed to treat different shift levels differently, as the danger of a variation in delivery schedules is much higher when reaching closer to maximum capacity.

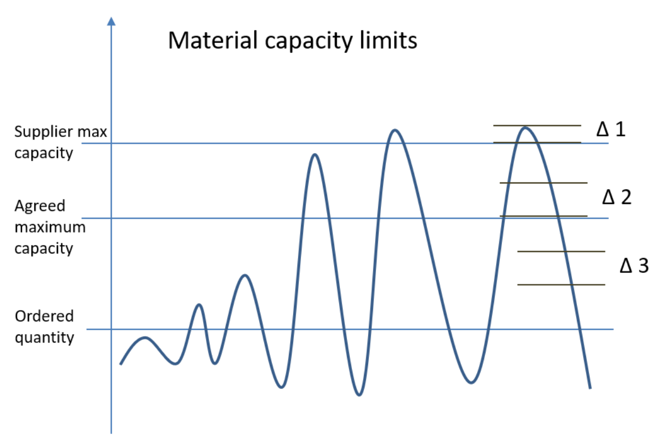

FIGURE 34, THE DIFFERENT LEVELS OF CAPACITY AT THE SUPPLIERS

When it comes to material planning, variations in customer demand also triggers the MRP to order an increased or decreased amount of material from the suppliers. In the automotive industry, delivery schedules are used, and this is represented by the ordered quantity in Figure 34. The case company and the supplier also have an agreed maximum capacity that they are supposed to be able to deliver to the case company, this is marked as the "Agreed maximum capacity" in Figure 34. In some cases, the ordered quantity and the agreed maximum capacity is the same level. A change in customer demand that triggers the MRP to order over this threshold which is marked as $\triangle 2$ in Figure 34, should trigger alerts to the customer planner as well as the material planner. However, sometime the supplier can ship more material that agreed as they have safety stocks or are able to free up capacity in their own production, by prioritizing within their deliveries. The next level which is illustrated as $\triangle 1$ in Figure 34, is when you have reached the suppliers maximum capacity, or simply when they say no, we will not deliver. This must be prioritized before any other variation as this is critical and needs rescheduling in production or anywhere else. The distance between the "supplier max capacity" and "agreed maximum capacity" differ from supplier to supplier and in some cases, it is the same line. This could be due to the suppliers prioritizing other customer, or that the agreed maximum capacity is the maximum capacity.

5.2.4 Predicting a dangerous scenario before it occurs

One way to improve performance related to RQ4 is to predict a dangerous scenario before it occurs, to gain more time to come up with a solution to the possible issue. The planners are planning on an item group level. For each item group, the planning horizon is 8 weeks. One way to forecast future events is to look at historical data. If a customer consistently tends to revise their delivery schedules the last week, they might do it the next week. The volume weighted MAPE graphs described in 5.1.2 gives an indication of change but does not alone clarify if the quantities is going down or upwards. However, combining MAPE and BIAS could give an indication for what the future might look. The reason for doing the analysis on the item group level is that clear capacity limits are set for different shift levels. The different items groups don't directly share capacity which allows for the planners to look at them separately.

To clarify the usefulness of MAPE and BIAS in combination a simple example of the thought process is illustrated in this section. For a certain item group, the constraints are given in Table 6.

TABLE 6, EXAMPLES OF SHIFT LEVELS AND FORECASTED DEMAND

Shift upper level	8000/week
Shift lower level	4000/week
Forecasted demand T-3	7000

Looking at Table 6, the parameters looks fine for the demand in three weeks. But if the MAPE profile for this item group indicates that a 20% shift in volume is expected 3 weeks prior to demand date there is a risk of this item exceeding the max capacity for the shift and a decision on overtime needs to be taken. The next step is to look at the BIAS profile in order to get an indication of the direction of the change. Using the FAI tool an overview of historical BIAS can be acquired, and an understating of the direction created.

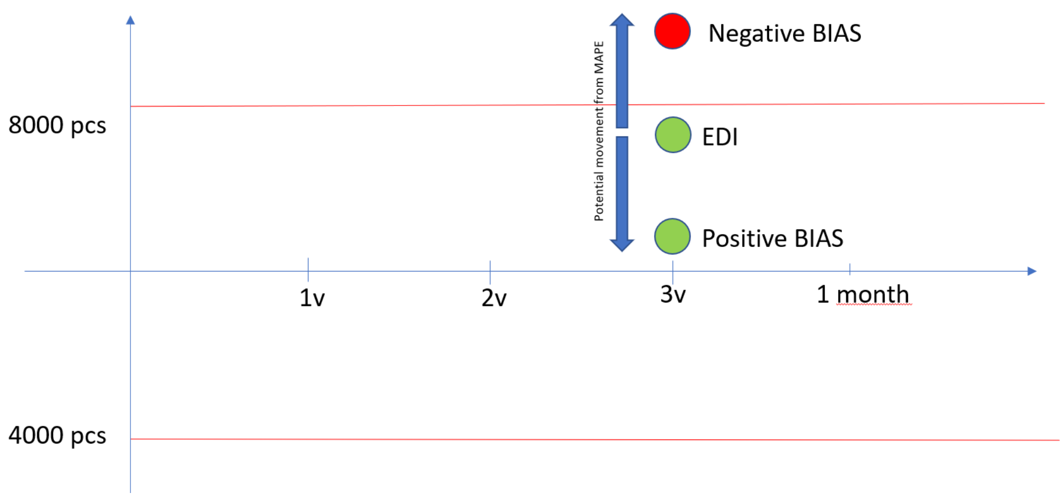

FIGURE 35, AN EXAMPLE SCENARIO OF COMBINING MAPE-PROFILES AND BIAS

However, as described in earlier segments there is more to consider than shift limits when deciding what changes is seen as dangerous or not. The red limitation curves seen in Figure 35 will look different depending on; Shift levels, raw-material stock levels, lead time to supplier of raw material and agreed max capacity from supplier of raw material. In Figure

36 an example scenario of what could be considered manageable changes meaning not running risk of backlog without the need for any action from the planners not considering costs.

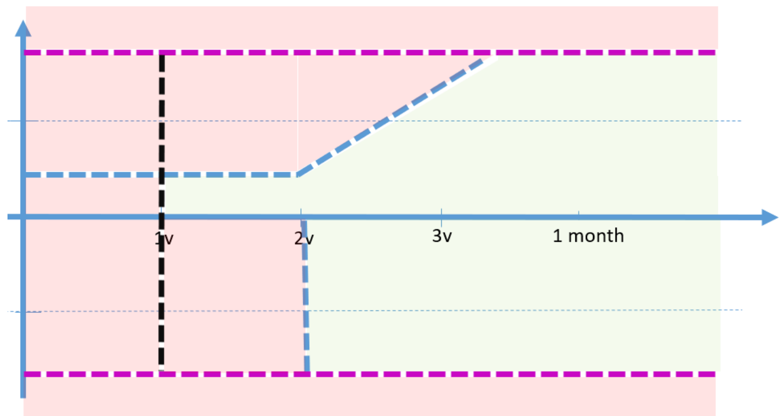

FIGURE 36, LIMITS FOR WHEN ACTION HAS TO BE TAKEN FOR A PLANNER

The blue line represents the material limitations which has both a fixed segment week 0-2 and an increasing segment week 2-4. The first part indicates that there is a small amount of buffer material that allows for some raise in demand. But the reason for it being flat is because of a 2-week lead time from supplier. From week 2-4, the incremental increase rather than a spike is explained by the agreed max capacity with the supplier. The purple lines illustrate the earlier mentioned shift limits. Lastly, in order to fulfill a demand production starts around 1 week before. This explains the black line and why it's a problem if the order is withdrawn within a week of demand date.

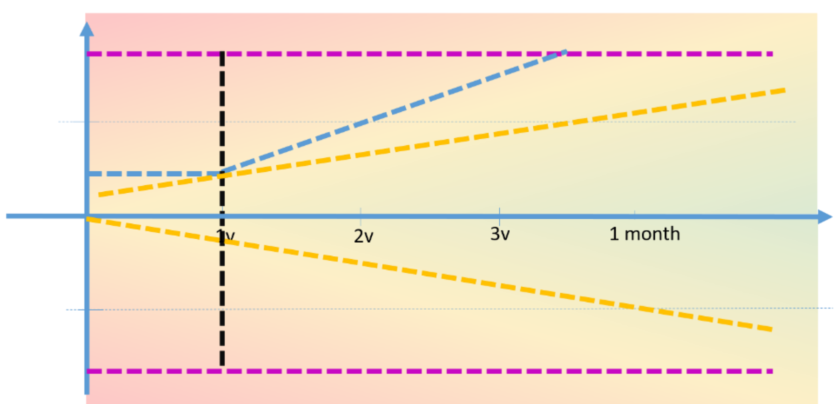

FIGURE 37, AN EXAMPLE OF A DYNAMIC DEVIATION MODEL

However, what is interesting is the effect of each change in delivery schedules. A deviation model should be designed to set a "price" on each variation, and the price should be defined as a mix of economic, social and environmental costs. The economic costs related to a variation in delivery schedules is a good start. How much over capacity will this variation result in? Will the company be forced to use an express delivery and what is the cost for that? What extra inventory does this change result in? All largest costs related to the change in delivery schedule should be possible to tie to a variation, and the variations could be sorted and prioritized after highest cost. Figure 37 tries to illustrate the task with a gradient from green (lowest cost) to red (highest cost) and lines are drawn to illustrate examples of constraints the model would have to consider.

5.2.4.1 Back testing the logic behind predicting a dangerous scenario

In order to make sure that the logic behind predicting what the quantity will be at demand date is accurate a back test based on delivery data from 2019 was done. First, the logic described in section 5.2.4 was applied and the estimation was compared to the actual demanded quantity for one item group. A representation of the absolute deviation from actual demand compared to the estimated demand for an item group is illustrated in Table 7. Green, yellow and red indicates 0-20%, 20-30% and >30% respectively.

Table 7, back testing of the model estimates compared to actual demand

Deviation of estimation x weeks before during 2019								
1	2	3	4	5	6	7	8	9
14%	18%	50%	49%	49%	38%	31%	31%	16%
11%	1%	18%	2%	3%	13%	20%	20%	43%
7%	11%	6%	8%	4%	10%	20%	41%	38%
3%	15%	25%	29%	25%	28%	34%	2%	31%
41%	26%	22%	22%	25%	24%	17%	36%	29%
7%	7%	6%	15%	11%	4%	4%	18%	26%
15%	65%	33%	27%	23%	17%	32%	30%	32%
12%	26%	40%	48%	55%	54%	56%	29%	36%
12%	17%	30%	34%	20%	35%	29%	30%	43%
1%	13%	18%	27%	33%	37%	37%	35%	54%
10%	16%	38%	52%	42%	42%	41%	57%	63%
16%	62%	39%	58%	54%	24%	26%	28%	15%
13%	19%	24%	29%	32%	32%	29%	28%	27%
19%	18%	12%	30%	30%	31%	23%	25%	40%
7%	15%	1%	20%	24%	20%	25%	27%	34%
14%	27%	33%	39%	39%	29%	34%	36%	51%
5%	8%	25%	29%	33%	19%	29%	28%	13%
27%	32%	21%	25%	21%	30%	27%	33%	41%
27%	4%	22%	15%	39%	59%	38%	43%	29%
18%	3%	11%	7%	3%	5%	11%	8%	13%
15%	23%	22%	22%	14%	15%	18%	22%	33%
6%	11%	13%	17%	17%	26%	27%	21%	9%
18%	12%	12%	19%	25%	31%	31%	11%	33%
4%	20%	15%	2%	1%	1%	0%	4%	9%
7%	23%	29%	18%	22%	24%	24%	19%	33%
7%	9%	24%	35%	29%	31%	36%	31%	19%
20%	24%	28%	4%	26%	10%	15%	12%	24%
6%	19%	28%	29%	33%	26%	19%	18%	33%
10%	10%	19%	32%	33%	33%	32%	38%	51%
6%	13%	27%	32%	25%	28%	31%	19%	33%

Average deviation from refrence per week before demand during 2019								
1	2	3	4	5	6	7	8	9
13%	19%	23%	26%	26%	26%	26%	26%	32%

A pattern that can be seen in Table 7 is how the model gets better and better to estimate actual demand the closer it is to demand week. This is an expected behavior as uncertainty rises the further away it gets from the demand date. An average for the columns of each week in Table 7 is calculated, and the results are plotted as a graph and compared to the original volume weighted MAPE-profile as well as the regular MAPE-profile for the item group in Figure 38.

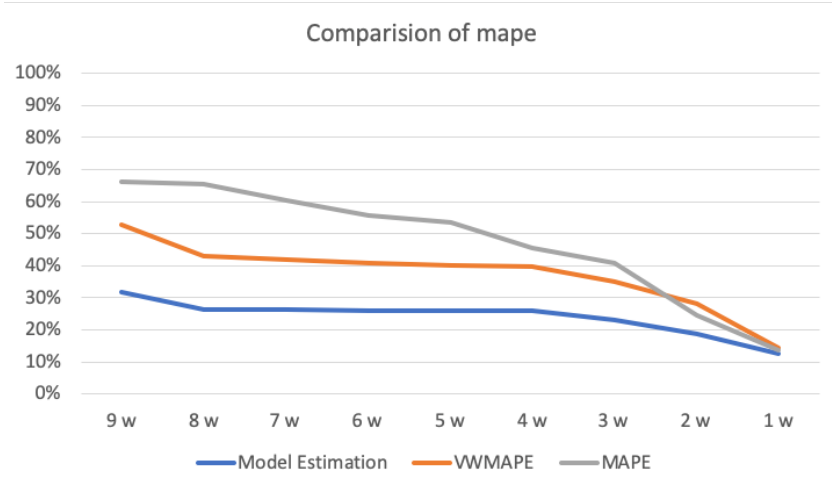

FIGURE 38, COMPARISON OF THE MODEL ESTIMATIONS AND RELATED MAPE PROFILES

5.3 Economical costs related to variations in delivery schedules from the customer

This section will handle all economical costs that is related to delivery schedules changing which is related to both RQ2 and RQ3. To precise, it should compare the financial situation if the supply chain consisted of perfect delivery schedules with no variations. The starting point was to look at buffer levels of inventory, express shipments, supply chain planners work time, production capacity costs and temporary employee costs.

To handle variations from customers an inventory is held. Both in raw material and in finished goods. Data for inventory levels at the case company is not available, so an estimate is done of their overall days on hand inventory using the annual report. On the balance sheet, inventory is divided in raw material, work in process and finished products. Days on hand is calculated by Equation 3, an own value for all three divided parts of the inventory.

EQUATION 3, DAYS OF INVENTORY ON HAND

$$Days\ of\ inventory\ on\ Hand = \frac{Inventory}{COGS} * 365$$

By calculating the days on hand for the case company's annual report of 2019 and 2018 and use the mean value an approximate of the days on hand is generated to compare with competitors in the market. The days on hand shown in Table 8 are total values for all plants of the company, and not just the Swedish plant.

TABLE 8, TOTAL DAYS ON HAND OF INVENTORY OF THE CASE COMPANY

TOTAL DAYS ON HAND	AVERAGE 2018/19
RAW MATERIAL	22
WORK IN PROGRESS	2
FINISHED PRODUCTS	14

By comparing the case company to two similar competitors within the automotive industry, conclusions could be drawn whether there are possible room for improvement or if the case company are best in business. This comparison is presented in Table 9.

TABLE 9, COMPETITION COMPARISON ON DAYS ON HAND

TOTAL DAYS ON HAND	RAW MATERIAL	WIP	FINISHED GOODS
CASE COMPANY	22	2	14
COMPETITOR 1	17	4	13
COMPETITOR 2	17	2	11

If the case company can reduce their inventory levels of raw material and finished goods to the closest competitor, it would be a decrease in 25% of raw material and 10% in finished goods. By calculating on an average inventory carrying cost of 25%, which is chosen due to a statement of the industry standard inventory carrying cost of Investopedia, this decrease would have a total cost of 6.2MSEK annually for raw material and 1.6MSEK for finished goods. (Tuovila, 2019) The competing companies have other business areas which is not comparable to the case company, but the comparison is used to give a hint if the case company is best in class or not.

Capacity costs are related to the amount of temporary staff that the company is using and compares the cost of temporary staff versus the cost of having everyone employed by the company. From the interviews, it is stated that around 22% of the staff on the production line are temporary staff from a staffing agency. Innovo Staffing states that the average markup on temporary staffing is 25% over salary. (Innovo Staffing, 2019) With perfect delivery schedules, an estimation is made that at best, 50% of the temporary staff could be exchanged by full time workers. If you reach 50% decrease in temporary staff, this would equal a value of 3% of all staffing costs.

Another cost that might occur is the express shipments, when a customer changes a delivery schedule that can't be handled by regular planning, express deliveries must be used which is a cost. However, the case company in question have no costs of express deliveries related to a change in demand from the customer. Another cost of express shipments are the express shipments of raw material from the suppliers to the case company. This express delivery costs are also neglectable for the case company.

Apart from shipments and inventory costs, changes in delivery schedules also takes work time from the supply chain planners within the company. Work time that could be used for other tasks is taken to handle changes in delivery schedules, which is a cost. The annual average salary for material and production planners is 426.000SEK according to Unionen. (Unionen, 2020) The costs of an employee to a company is estimated to around 1.7 times the annual salary, which is then 724.000SEK. There are nine supply planners at the case company's plant in Sweden which brings a total cost estimate of around 6.5MSEK. With an average of 41.5% of the planner's time spent on handling variations, the cost of this is estimated to 2.7MSEK annually.

5.4 Social stress related to uncertain demand

Apart from the economic issues of uncertain demand and late changes in delivery schedules, another effect related to RQ2 and RQ3, is the social factor, how it affects the workers daily life. It creates uncertainty, uncertainty about working hours as they don't know if they will work overtime or not even full time. The workers also do not know for how long time they will be employed which will affect their lifestyles. Not knowing what your salary will land on every month is stressing people's personal economy, either if people plan for the worst or the best-case scenario, it comes with stress about the uncertain. Frozen plans are something that would have eliminated this uncertainty, as the production managers would know earlier and could plan for the staff accordingly on a longer horizon.

The social aspect is presented from the interviews, as the hardest thing to handle for the production managers. Down revisions and postponements of orders are toughest to handle, because it might lead to them not rehiring staff.

6 Discussion

The discussion chapter is divided by research question and will handle them according to the model in Figure 39, some research questions are overlapping and therefore handled in the same parts.

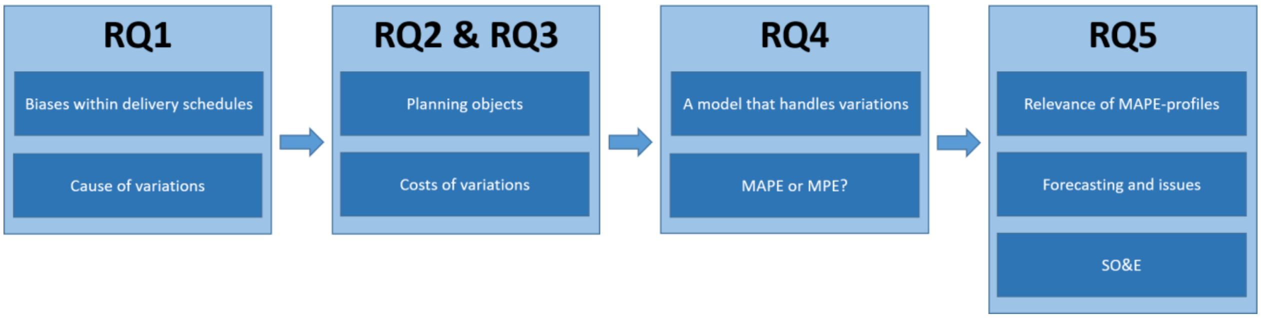

FIGURE 39, THE PROCESS OF DISCUSSION THROUGH RESEARCH QUESTIONS

When all research questions have been discussed, a recommendation of process is presented in 6.9 where it is summarized how to practically implement the findings from the report.

6.1 Biases within delivery schedules

Related to RQ1, the report aims to find how delivery schedules vary from customers. The report finds that the major OEM customers have a positive bias in their delivery schedules. All the largest item groups of the case company also have a positive bias in their delivery schedules. From the interviews, the planners described the automotive supply chain as very skewed in power balance. It is closely welded supply chains with a lot of dependencies. The supplier's items are often unique, and the OEM customers are often of a huge scale and represents a large part of the supplier's revenue which might create the imbalance (Inishukcu & Datar, 2016). The overestimations in the WTS scores, might relate to OEMs deliberately ordering more than they know they need, to "secure" capacity (Tsay & Lovejoy, 1999). And a few weeks before delivery, they can change the delivery schedules, as the agreements on frozen periods are unclear. It seems to be a lack of respect for the agreed frozen time periods.

6.1.1 Who or what is causing the variations in delivery schedules?

Literature and the results from the report arguably states that the variations in delivery schedules comes from a customer's planning process, which is either handled by their specific planning system, an MRP which brings MRP nervousness. (Carlson, Jucker, & Kropp, 1979) (Li & Disney, 2017) (Blackburn, Kropp, & Millen, 1985) It could also be people at the organization that consistently order to much or too little or change the orders randomly to optimize their own inventory levels or production planning. This might create bullwhip effects further down in the supply chains, which is a well discussed subject among other authors and a proved phenomenon. (Li & Disney, 2017) (Lee, Padmanabhan, & Whang, 2004) The report is limited to only looking at causes of delivery schedules variations from the supplier side, which limits the results in presenting what is causing the changes from the customer side.

6.2 What is a relevant planning object?

As the goal of RQ2 and RQ3 is to find effect of changing delivery schedules, it is important to know what objects that is planned manually and what objects that a computer plan. It is also important to know what production is planning and what the supply planner is planning. One interesting question to ask is, where are the case company's decision points and why are they there? The case company in question in the report is planning manually on an item group level but is alerted on a change on item number level. This is not always relevant as planning occurs on a higher level. Single item numbers are also set but released weekly to the production floor. These item numbers are easy to switch between weekly as it is the same components. However, setup times are long, so you want to produce the same item number in large batches. However, the production managers do not need to know beforehand what specific item number that they are going to produce on that specific line. The managers only need to know a total quantity of the production line per day, to plan for staff.

6.3 Cost of changing delivery schedules

Related to RQ2 an RQ3, about how variations affect the case companies planning process, economical costs are interesting to enlighten. By noticing a FAI scores of around 50% for some customers at the same time as the case company have no cost of express shipments, the costs of the change are taken up somewhere else. According to supply chain theory, changes in customer demand is handled by holding excessive amounts of inventory.

From the empirical results you can clearly see a pattern of low FAI scores in relation to a high workload on the planners. The planner for OEM 2 who has the lowest FAI scores, planners spend 50% of their time handling variations in demand, and for OEM 1, planners spend around 15% of their time handling variations.

Capacity costs is related to having temporary staff instead of full-time employees. An estimation is made that at best, 50% of the temporary staff could be exchanged to full time employees if the delivery schedules would be perfect. However, there are many other reasons to use temporary staff instead of full time. What if the actual volumes decrease and the company have to large number of full-time workers? A machine breakdown or stop over weeks could also lead to overcapacity in staffing, where it would be preferable to use temporary staff. Temporary staff is like an insurance against deviations in production capacity and volumes, which you pay a premium for. The assumption is made in the report that delivery schedule changes is one of the reasons that the amount of temporary workers is at the level of 22%, but how large impact it actually has is hard to estimate, and probably something that changes over time as the context is changing.

6.4 A model that handles variations in delivery schedules

The goal of RQ4 is to evaluate measures and visualizations within supply planning processes. This have led to that a conceptual model has been presented which is relevant for the case companies planning processes and production system. The importance of the model is visualization and defining boundaries of the system. The case company has mature processes for MRP and production planning which is connected to the ERP, and production capacity is known as well as material supply constraints. When a variation in demand is received today, the current deviation model is just alerting the planner if the change is more than 10% of what it was before. However, it is not necessary if it is in line with material and production capacity. The conceptual model is supposed to check production and material capacity, as well as inventory level. With all areas cleared, it is not supposed to alert the planner. The importance here is to enlighten that deviations could be dangerous to the case company in different contexts, for example if production capacity is running on its limit or not, or if material lead times are long or short, and it is not always about the size of the deviation that decides if it is dangerous or not. If a change occurs within an item group, between two item numbers, it currently sends two alerts, but it should probably not send out any.

The visualization part of the model is also important related to RQ5, if it is supposed to be used to support decision making in daily operations, to show where in the production system that danger occurs. If the model can use real time planning data, the planners would be able to see each other's production line, where they share material capacity, to see if a planned production order interferes with material that is needed somewhere else. However, if the MRP can order new material for this line within the lead time, the system could just plan for this and not send out alerts.

6.5 Difference between measuring with MAPE- or MPE-profiles

One important task of the report was to show how delivery schedules vary from customers (RQ1) and another was to evaluate measures to improve supply planning performance (RQ4). For RQ1, it is important to discuss how you measure customers variations because that will affect the results, it is also important to question for further studies to discuss what measurements that is relevant and what KPI's to use for this specific case company which relates to RQ4.

Until now, the industry standard for measuring forecast errors with FAI is the MAPE, which is mean absolute percentage error. This is a measurement that is not considering if the error is an overestimation or an underestimation. Would it be possible to create a forecast accuracy profile that consider bias as well? As seen in the empirical results, many customers tend to overestimate, but some not. The planners said in the interviews that underestimations and overestimations bring completely different problems and actions needed to solve and would be of interest to know about. Overestimations lead to unnecessary capacity and more inventory than needed, and underestimations might lead to late deliveries and overtime in the production. This section is supposed to analyze the pros and cons with using the MAPE profiles versus another similar measurement which is not absolute, the MPE which is mean percentage error.

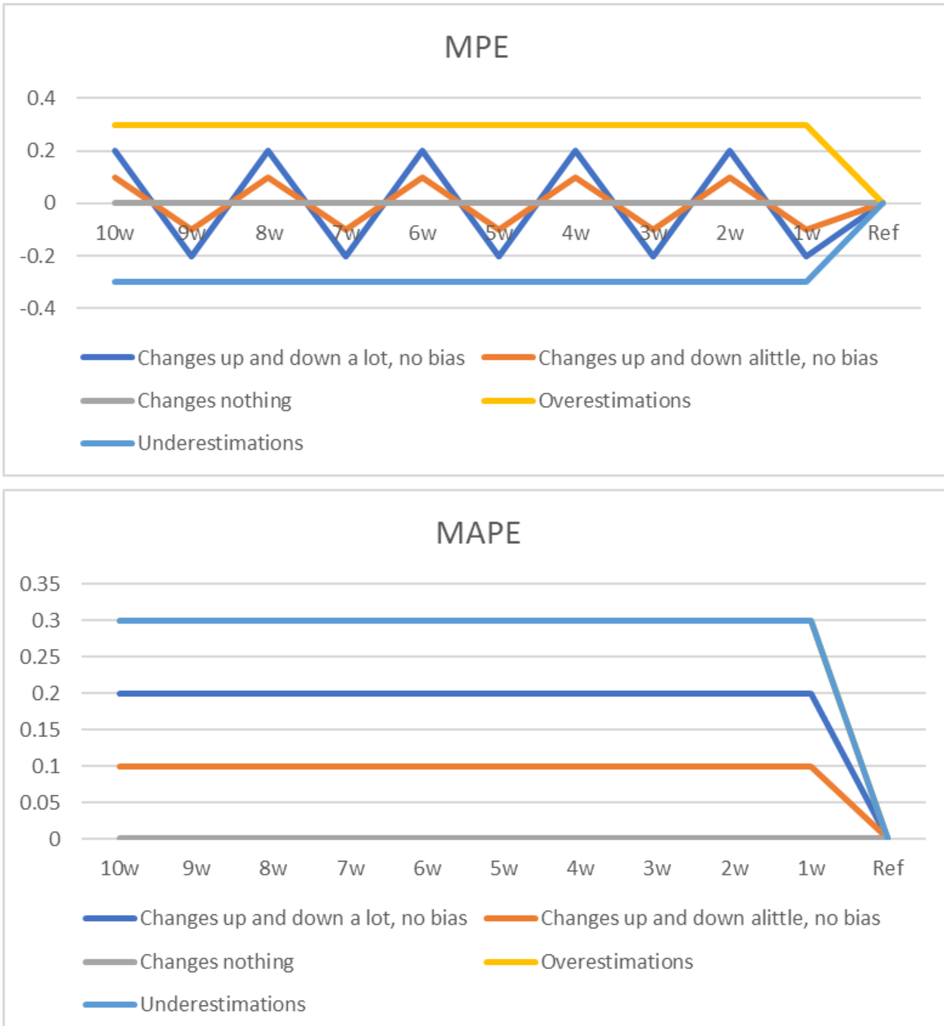

FIGURE 40, FIVE ITEMS PLOTTED AS MPE AND MAPE

On Figure 40, it visualizes that the unbiased item, but with very poor forecast accuracy, could for the untrained eye look biased in the MAPE profile. It is also important to notice that in the MPE profiles, positive and negative bias are represented differently, which will decrease one step of the analyzing process. If you look at the MAPE profile and see a MAPE on 20%, you must further go to a bias graph to show whether it is negative or positively biased. On the other hand, if you have multiple delivery schedules which is consistently bad in both directions, the MPE measurement might cancel out these errors and the graph will look perfect while it is not. MAPE will show these errors, and it might also be more easily interpretable, because it only has positive numbers, and the closer to the x-axis the better forecasts.

Another problem that arises with both MAPE and MPE is when the reference quantity is zero, it creates undefined values in the data set. Also, the case when volumes are very low, both MAPE and MPE might take on extreme values, which might be irrelevant for the business. Another question could be, why not use both measurements, and then the discussion about how many KPIs to look at is important to cover. When tracking many KPIs at the same time, they become PIs (performance indicators) and not KPIs (key performance indicators), because the definition of KPI is that it is a few key performance indicators which is the most important for the business. However, for analyzing the processes deeply to get an understanding, performance indicators are important and both MAPE and MPE could be useful to combine, if you want to separate absolute errors with positive and negative errors or vice versa.

6.6 What is a relevant MAPE-profile to look at?

Related to RQ5, if measures are supposed to be used in decision making, they need to be relevant. In the results section, different MAPE profiles is presented for customers, item numbers, item group. Which one is relevant? It depends on how you plan. The case company is divided into planning teams based on business area. The production planners plan their assigned production lines and all items within the line. However, within the teams, there are customer planners that handles specific important customers as well. This means that the production planning is based on production line, and customers on large OEMs plus smaller customers. However, sometime these OEMs share production lines and item groups. Then the question is should you look at the item group mape profile or the customer mape profile? Maybe both? Looking at item number level might be unnecessary if the production line capacity is the bottleneck. In some cases, the material needed for an item number is unique, which brings up the importance of looking at the item number mape profile for material supply causes.

It is also important to consider that the lower volume the data set contains, the more irrelevant the mape profile gets. This is an issue with item number mape profiles. If you include many years of data to increase the volume of data, this could help bring a larger sample size to the measurement. Using many years of data could be an issue as well, due to that the planner that caused the variations in the delivery schedules might not even work there. The planning processes might have improved during the last few years, which should show an improvement of accuracy, and old data might be irrelevant. New agreements might have been set in place for freeze times or similar processes for forecasting, that increases forecast accuracy which makes old data irrelevant. This is an advantage looking at a higher level of mape profiles.

6.6.1 Volume weighted mape profiles

What is noticed is that if you look at all the different items within an item group and draw a mape profile, to then plot an average profile for the item group, you include changes within the item group as well. In our case company, changes within an item group is something that is very easy to handle and is not of importance. Therefore, the item group is summarized and treated as an object in the mape-profile in what is called a volume weighted mape-profile. When this is done, changes within the item group does not increase the measurement. High volume items also affect the measurement more than low volume items, which is relevant if it is the production capacity limits that is critical which it is in this case. However, if the bill of material is different in the items within the item group, then it might neglect variations that is an issue. This is something that should be evaluated in every planning situation that you act in and in the long run by a computer. Something interesting is to compare the item group mape profile with the volume weighted to see how much large or small items differ, or if changes occur within the item group.

6.7 Predicting a dangerous scenario

The model of predicting a dangerous scenario combines historical MAPE-profiles with historical bias to estimate how delivery schedules will be revised as it is moving closer towards the demand date.

Related to RQ5 where the goal is to find measures to support decision-making in daily operations, by forecasting a change in the delivery schedule before it occurs. It is important to discuss issues with forecasting because forecasting is never 100% accurate. The results suggested a method for anticipating future dangerous scenarios. There are some areas concerning the framework that needs to be discussed. The first one being the reliability of assuming that what have happened in the past will happen again. This is something that usually works in physical models but not in economic models. Economic model is modeling very complex systems with a lot of people involved, a lot of psychology and unknown variables. This creates a somewhat chaotic system and the reliability of forecasts should be questioned. The back testing showed some promising results. Often the results where within 20% of actual. When the results where way off, the direction of the change had been wrongly assumed. However, the size of expected change without direction can still be of value to the production planning process if the limits are known.

6.7.1 Risk of overfitting when estimating an estimate

Overfitting is the phenomena of having a lot of noise as real data in the model which might create a faulty model that does not describe the actual system you try to describe and predict. When using a model to estimate future demand based on another forecast of future demand, the risk of overfitting occurs. Historical demand and forecast errors are used as comparison to adjust for forecast errors, but this leads to the problem of potential overfitting. The more historical data you use and the more you try to find correlations, the larger is the risk of overfitting.

6.7.2 Acting on a forecast

Lastly, how should a planner act when given a warning that commitments need to be done in order to fulfill future demand? If you get a probability of 90% that an existing order will be removed, how should you know how to act? In theory service levels are used to weigh order fulfillment against inventory levels, and with a 90% probability of an outcome, actions might have been taken to not produce the order until the day it actually occurs (the 10% of the cases) and then produce it with a delay. However, at this case company, the company representatives pinpoint the importance of a 100% service level. Not delivering to a customer and paying the invoice for stopping their production line is not an option. This is an interesting situation, because in theory, 100% service level leads to costs going towards infinite.

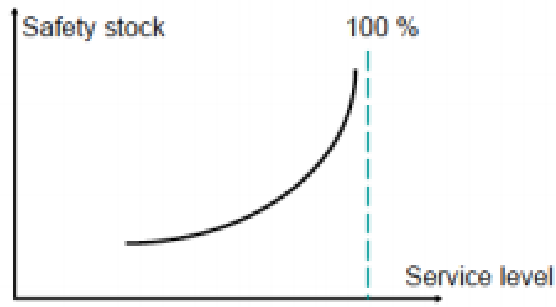

FIGURE 41, THE RELATIONSHIP BETWEEN CAPITAL TIED UP AND SERVICE LEVEL (JONSSON & MATTSSON, 2009)

The costs at the case company is not infinite which implies that the service level is not 100%. Even if the service level is not 100% but close to, it should come with very high costs, as the chart in Figure 41 shows an exponential graph towards 100% service level. Even if information about accuracy in delivery schedules might be hard to act on, and you would need to know with 100% certainty that an order is going to be withdrawn to not act on the order, then the information could be used in a discussion with the customer. It is also useful in future pricing, if it is possible to relate different customers to different inventory holding costs, the pricing of the products should differ as well. Higher inaccuracy should over time lead to higher price which would give the customer an incentive to improve their forecast accuracy.

6.8 S&OE within the case company

The case company have a process for dealing with what they call "short term S&OP". This is a meeting that occurs weekly to plan production as well as report previous week and how the production met expectations. What problems have occurred and what plan do they have to solve it. Bower states that many companies already have a like S&OE process and that they have had for a long time. (Bower, 2018) But what does it consist of without the data? It has been emails, phone calls, spreadsheets and people conversating with each other. This is the type of processes that is hard to capture in an IT-infrastructure and define as a clear process.

As many definitions of S&OE is quite similar to the process at the case company, it could be argued that the case company already have a S&OE process, and that the findings from the report could be used to support this process.

6.9 Recommendation of process

The results and analysis is concluded in a process of seven steps to be able to capture delivery schedule changes in a new way and work with forecasts of delivery schedules.

6.9.1 Define your relevant planning object

Define what level your supply chain planners plan at and what your planning horizons are. Cluster the items after how you plan and what affects the planning. Define your decision points that is important within the organization and what influence it has, and who decides what. What meetings is scheduled related to sales and operations planning and is there any informal decision points? Define the purpose of meetings and who is affected by the decisions that its results in. Planning objects is covered in 6.2.

6.9.2 Map up the internal supply chain

Make a visualization of your internal supply chain including all important planning objects, which components is included in products bill of materials and where do they come from? Map up all production lines that share capacity in prior or following production lines to show interdependencies. An example of a mapped production flow is presented in Figure 29.

6.9.3 Set limitations of the supply chain

Write down your service level target to get an image of what inventory costs that is expected, define your inventory policies to compare against actual scenario to use in the model. Define the limitations in the production capacity, both shift levels that would need a decision to be implemented and the absolute maximum capacity. Set limitations in forms of material supply, what are the agreed level of capacity and how does the capacity situation look like at the suppliers? Details about limitations could be studied in 5.2.3.

6.9.4 Set costs, what are the costs of the limitations?

When the limitations of the production environment are set the task is to define the costs, what are the cost of capacity, both overcapacity, different shift levels and under capacity? What is the shortage cost and what is the costs of express deliveries? Define the costs of inventory of each planning object. If uncertainty is to be linked to cost the inventory related to each object is of importance to define. Define the costs related to the logistics department and the planners working related to delivery schedules. Further details about costs is covered in 5.3 and 6.3.

6.9.5 Measure delivery schedule accuracy

Measure forecast accuracy of the planning objects, customers, individual items as well as systematic variation, or in other terms bias. Construct MAPE-graphs of forecast accuracy 10-20 weeks before demand date depending on how much data is available. Measuring forecast accuracy in systematic variation could be done with the FAI-application. Discussion around how and what to measure is described in detail in 6.5 and 6.6.

6.9.6 Prioritize changes within delivery schedules after cost and probability

With the information and analysis given from earlier parts of the process, it is now possible to sort and prioritize changes in delivery schedules after the most dangerous change and it is possible to focus on the right things. A change that is not affecting production capacity or material capacity should go unnoticed and a change that need a decision should be prioritized.

6.9.7 Forecast future potential issues and prioritize after criticality and probability

Apart from sorting and prioritizing changes, with forecasting it is possible to detect potentially dangerous items or planning objects before they occur. With historical data of MAPE-profiles and biases it is possible to estimate a probability of a future delivery schedule change to alert the planners.

A tool working with prioritization could be a simple matrix multiplication tool, which lets the user fill in perceived cost of a parameter and multiply it with the probability of its occurrence. This could be plotted into tables that would handle and sort the products, product groups or whatever is chosen relevant. After prioritization has been done, the problem could be handled and the cost of solving the issues could be measured, by updating the matrix with the actual cost as Figure 42 shows. The next time the results might be more accurate, and you get a process of plan, do, check and act. Repeating this process repeatedly could be done with machines to generate better and better forecasts about future dangerous scenarios.

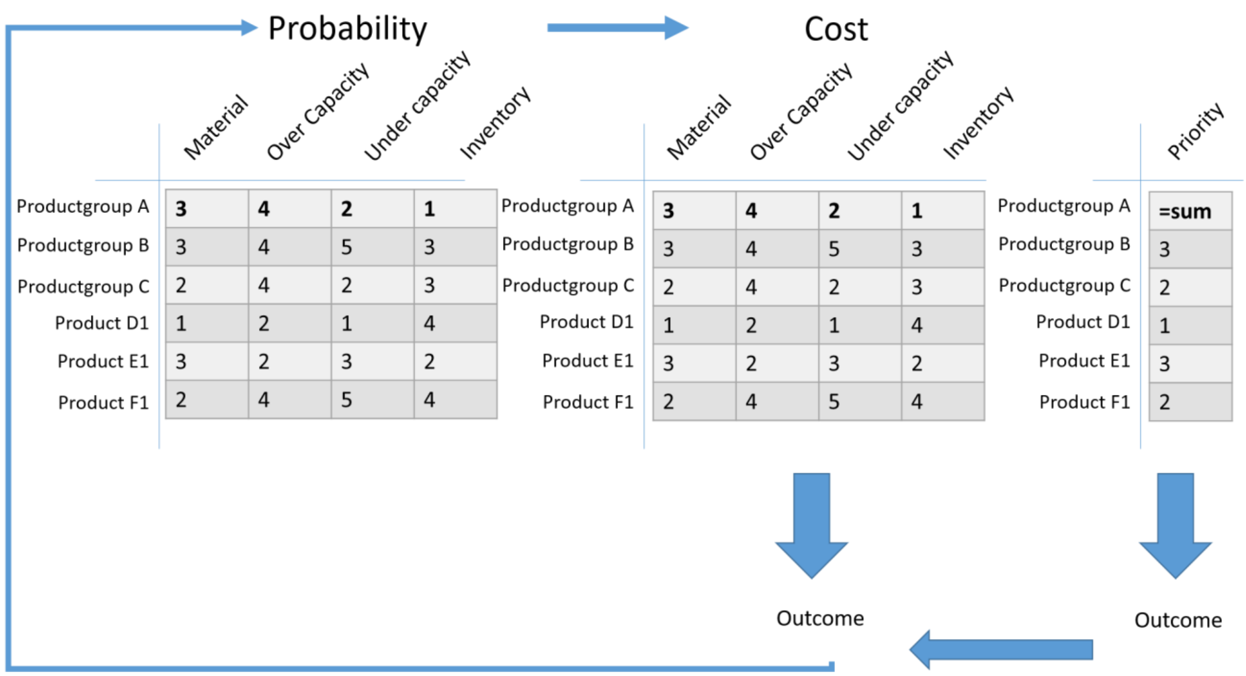

FIGURE 42, A MODEL FOR PREDICTING AND PRIORITIZING DANGEROUS SCENARIOS BY MATRIX MULTIPLICATION

7 Conclusions

This section consists of the research questions and their answers summarized shortly, followed by three sections which also covers general answers of research questions, that is applicable to more than one research question. These sections are called generalization, contribution and further studies. The generalization chapter describes how it is applicable on other companies within the industry and what parts that is applicable on other industries and sectors. The part called contribution is summarizing what this report contributes to in terms of science and research within the field supply chain management. Lastly, the part called further studies brings ideas about follow up research question to this study, as well as how you could dig deeper into the subject and narrow down the research even more and dig into details to cover all parts of the topic.

7.1.1 Research Question 1

How do delivery schedules vary from customers to the case company within the automotive industry from 0 to 8 weeks prior to delivery and how do different clusters of demand relate to/affect production capacity and material supply planning?

In terms of forecast accuracy and biases, it is closely related to the customer, and the customers that is perceived bad according to the planners also show worse FAI scores and larger Biases. The most common bias is overestimations of delivery schedules which then gets revised down on the demand date. This could occur due to that the customers want to secure capacity and create a "buffer" at the supplier in case of a rise in volume. However, the cause is not determined in the report, as more data is needed to validate this hypothesis. The effects on the other side, is shown in the report. Related to production capacity, forecast accuracy is of certain importance when volumes of item groups lie close to shift levels. It is also of importance when volumes of item groups are rising or falling to manage possible shift changes accordingly. Regarding material supply, forecast accuracy is important when supplier lead times are long and when your reach the upper limit of supplier capacity.

7.1.2 Research Question 2

How do variations in delivery schedules from 0 to 8 weeks prior to delivery affect the supply chain planning processes (material and customer/production planning) at the case company's plant in Sweden?

The customer/production planners and the material planners at the case company spend a large part of their working time handling effects and issues related to variations in delivery schedules. This is valuable time that could be spend doing something more important or working with future strategical decisions to improve the supply chain of the company. Variations also create higher inventory levels than necessary to keep safety stock to be able to solve a 100% service level to customers. Due to agreements, suppliers not being able to deliver to OEM receive very high penalty fees and that is why 100% service level is important.

7.1.3 Research Question 3

How do variations in delivery schedules 0 to 8 weeks prior to delivery affect the production process at the case company's plant in Sweden?

Determining how variations affect the production process is shown to vary very much on the context. For example, a large variation can have a small impact in an environment where material and production capacity are available and a small variation can have a large impact if having long lead times to suppliers and no safety stock of raw material. It is important to consider the production capacity within the current work shift. The closer the shift level you get, the larger impact is received from a variation in delivery schedules. Overestimations and plans moved forward in time is assumed the worst variations due to the social stress. 22% of the workforce is temporary employees which have an estimated cost of 25% more than a regular employee.

Variations that lead to change in shift levels also harm the overall equipment effectiveness because of the learning curve of new staff.

7.1.4 Research Question 4 and Research Question 5

How could measures or visualization be used in demand planning, production planning and material supply to improve planning performance? How could we improve the support *for decision-making in daily operations within production planning and customer order planning of the case company?*

With a model that can collect data from the ERP system and compare to new orders to see whether a change in delivery schedule will be an issue, it could help the supply planners with an overview over the production system. If could help with understanding of the situation when a changed order is received. It could also help prioritize and sort between changes to allocate the most important resources to the most important issue. With the use of the tools FAI, WTS and MAPE-profiles of the FAI values, the decision-making process could be improved as more support is added, and these tools could increase the knowledge and understanding of the situation. However, whether you act on the information or not is up to the case companies' internal policies around tied up capital and service levels.

The study has contributed with a list of recommendations for companies within the automotive industry, to improve their sales and operations execution process. The recommendations include practical examples and tools for improving processes and efficiency.

7.2 Generalization

The report covers a Swedish supplier in the automotive industry and gives a view of the supply chain planning issues and effects at the company. The tools used in this report, the FAI application that calculates FAI and WTS is applicable in any company that uses delivery schedules. Further, forecast quality measurements like forecast accuracy and forecast bias is applicable in all industries. There is always a need to evaluate the forecast processes to improve and fine tune parameters.

MAPE-profiles as a measurement for delivery schedules and a tool to see when forecasts and delivery schedules is good, in terms of weeks before demand date. It could be important to study to be able to locate customers, item groups or another planning object that causes disturbances and waste in the supply chain. This is something that could be used in pricing as well, as the customer causing highest cost should pay the price accordingly when the supply chain actors is as integrated as they are in the automotive industry.

Discussion about shift changes and OEE is also generally applicable on a broader spectrum, as every company must deal with learning curves as new staff is employed. If companies are using temporary staff, there is always a risk with them being exchanged and the educational process must be done all over again. This is of course time consuming and could affect quality as the general experience level are lower with new employees.

Empirical results that show how much of the planner's time is put down into handling variations in delivery schedules is also something that could be generalized in the industry. With similar customers and similar planning processes that causes MRP nervousness other companies within the automotive industry might also suffer from the issues that takes time to handle, and measurements of the time spent could be generalized. This to rise awareness of issues that is caused by uncertainties in a supply chain that looks like the automotive industry.

7.3 Contribution

The study contributes to the future of sharing schedule information in automotive industry supply chains using advanced data analytics through the research project of FFI. The contributes with the foundation for future research in building machine learning models to predict delivery schedule variations. The study contributes with scenarios and parameters to consider when building a model for similar production environments in the automotive industry.

The contribution of this thesis is to come up with suggestions of how to improve companies S&OE process, consultancy firms defines a good SO&E process as a one where warnings about current and future problems is released as soon as possible. They also state that centralization of information feed is important to avoid people's individual spreadsheets and email quick fixes. The conceptual model and deviation system suggested in the report is a way to handle this and provide the planning department with a better overview of each other's processes. With a model like this connected to the ERP system, companies could avoid silo-thinking and suboptimal solutions to move towards company total cost beneficial solution.

The report provides data and results about that customers in the automotive industry tend to overestimate the quantities in their delivery schedules, rather than underestimate. It is also providing results about that not all customers have the same forecast inaccuracy and that implies that it is room for improvement at the automotive supply chains regarding forecast accuracy and delivery schedule stability.

Constantly changing delivery schedules is creating issues and comes with a cost, one contribution from the report is enlighten where the costs end up at, and what part of the company's expenses that increase due to delivery schedule changes. This creates waste and is not sustainable economic nor environmental. The report also shows the social sustainability part of uncertainty within the supply chain. It affects people and might cause stress, to not know what will happen tomorrow.

7.4 Limitations

Due to lack of time and resources available, the models and measurements was not connected to a real ERP-system. This is something that is desirable to get closer to real implementation of the models and to be able to measure what difference it could make. Further, interviews with the finance department and more observations with the supply planners was planned the for but because of circumstances out of our control, these were not possible to conduct at the time. Observations at the productions floor was also something that was done but not at the same extent as thought from the beginning.

7.5 Further Studies

Further studies could perform a pilot test of the models and measurement methods with an actual supply planner. This to evaluate the possible improvements in a real scenario. Evaluation how to build the conceptual model in an ERP system is desirable, what are the constraints of building applications within an ERP system? Studies about change management is also applicable, with a purpose to evaluate how willing people are to change their working behaviors and daily tasks within supply chain planning. Further, testing with autonomous decision-making or decision-making support with machine learning could be evaluated and the business value around it. Further research about visualization in S&OE processes is also interesting.

A deeper dive down into the social aspects of uncertainty in the supply chain is something for future work. It is a large topic and relevant as mental health questions is rising this decade. What is causing stress? How is it possible to reduce stress? How is uncertainty in supply chain affecting employees at companies? It is according to the production managers of the case company their hardest task to handle, when they have rescheduled temporary staff downwards.

With a larger dataset in terms of time horizon and quantities, analyses could be done of forecast accuracies and patterns in time with seasonal effects considered or controlled for. This is work that could conclude if customers planning processes are improving or getting worse. Could the work be applied on phase in and phase out products and research what happens with delivery schedules and forecasts?

The report shows that a lot of time is taken from supply planners handling variations in delivery schedules, and further studies could evaluate what this time means. What exactly are the tasks that is done and how are they divided? How does different companies within the industry differ? How does the situation look like in other industries where delivery schedules are not in use?

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9 Appendix

9.1 Mathematical definitions

9.1.1 FAI (Forecast accuracy index)

FAI shows weighted average deviation from reference demand for several chosen time lags in the delivery schedule. (Odette International Ltd, 2012)

if: $d_0 \neq 0$

$$\text{FAI} := \sum_{i=0}^{n} a_i \, max \left\{0; 1 - \frac{|\Delta_i|}{d_0}\right\}$$

if: $d_0 = 0$

$$\text{FAI} := \sum_{i=0}^{n} a_i \; where \; I_n = \{i|\Delta_i = 0; i = 1, \ldots, n\}$$

$$for \; I = 0{:}\; FAI := 0$$

9.1.2 WTS (Weighted tracking signal)

WTS shows bias (over or underestimations) from historical delivery schedules relative reference demand. (Odette International Ltd, 2012)

If: $\sum_{i=1}^{n} a_i \, |\Delta_i| \neq 0$

$$WTS := \frac{\sum_{i=-1}^{n} a_i \, \Delta_i}{\sum_{i=1}^{n} a_i \, |\Delta_i|}$$

If: $\sum_{i=1}^{n} a_i \, |\Delta_i| = 0$

$$WTS := 0$$

9.2 Equations

9.3 Figures

9.4 Tables